3 Milly's Cave: Evidence for Human Occupation of the Inland Pilbara during the Last Glacial Maximum

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The Last Glacial Maximum (LGM) peaked in Australia around 18,000 BP. At this time, many previously-occupied archaeological sites in the northwest quarter of the Australian continent show signs of abandonment or reduced occupation. Previously-reported evidence from the inland Pilbara on LGM activity is ambiguous and has been interpreted to mean both abandonment and continuous occupation. Excavations at Milly's Cave have revealed the first unambiguous evidence for human occupation in the inland Pilbara during the LGM. Stone artefact data from Milly's Cave indicate that the occupants exploited a smaller territorial area during the LGM compared with later periods, but did not substantially alter their land-use system. Population size probably changed very little but social networks and aggregation activities were reduced during the LGM.

Introduction

Archaeological sites in the Kimberley, northwest coast and central Australian ranges show abandonment or reduced intensity of occupation during the Last Glacial Maximum (LGM) (Morse 1988; O'Connor 1999; Thorley 1998). This has been interpreted as an increase in mobility and a retraction to refugia in response to hyper-arid glacial conditions (O'Connor *et al.* 1993, 1999; Veth 1993a, 1995). Previously-published evidence from the Pilbara is ambiguous and has been interpreted both for and against abandonment during this period (Brown 1987; Veth 1993a). In this paper I discuss the ambiguity of the current evidence then present new evidence from a site where the cultural sequence spans the LGM. I suggest that the new evidence indicates that the local environment influenced settlement patterns during the LGM.

Environmental Context

There are some environmental differences between the inland Pilbara, interior, northwest coast and Kimberley that are important for understanding human responses to the LGM (Figure 1). The inland Pilbara is dominated by the Hamersley Plateau, which consists of ranges and gorges that capture the rainfall runoff from the plateau (Figure 2). On the northeastern side of the plateau is a high-relief scarp with long, deep gorges that drain the plateau into the Fortescue River. On the other sides of the plateau are more diffuse drainage patterns of round hills and tributaries of the Ashburton River such as Turee Creek. The landscape is mountain and piedmont desert and although there is a large number of permanent water sources, particularly in the deep gorges along the northeastern scarp, the flora and fauna of the inland Pilbara are characteristic of the arid zone (Brown 1987:8-11).

The interior includes the Great Sandy Desert, the Gibson Desert, the Great Victoria Desert and the central Australian ranges. The named deserts are sandridge lowlands and hummock grasslands without coordinated drainage (Smith 1988). The central Australian ranges are well-watered in places, forming a perpendicular watershed to the local river systems. As in the Pilbara, arid zone fauna and flora live in the interior.

The Kimberley is an ecologically richer and more diverse area than the inland Pilbara and interior because of its strongly seasonal and tropical climate. The Kimberley coastline and islands provide access to marine and estuarine resources not available to the occupants of the inland Pilbara and interior. The northwest coast shares the arid climate of the inland Pilbara and interior but is similar to the Kimberley in its higher ecological richness and diversity because of the wide variety of habitats related to the proximity of the sea, estuaries, rocky shores and reefs.

What were People doing in the Northwest Quarter of Australia during the Last Glacial Maximum?

Around 18,000–21,000 BP there was an increase in aridity and surface winds and a reduction in sea levels, surface temperatures and the availability of surface water in Western Australia and throughout the world (Wyrwoll 1979:129). This aridity resulted from a severe episode of increased glaciation caused by orbitally-induced changes in solar radiation (Sturman and Tapper 1996). The aridity peaked at the Last Glacial Maximum (Oxygen Isotope Stage Two), which occurred at 18,000 BP in Australia (Barrows *et al.* 2002).

Kimberley and Northwest Coast

Data from relict longitudinal dune fields in the Kimberley indicate that conditions in the Kimberley during the LGM were arid, with reduced precipitation and increased evaporation (Jennings 1975). Phytolith evidence from Carpenter's Gap 1 in the inland southwest Kimberley

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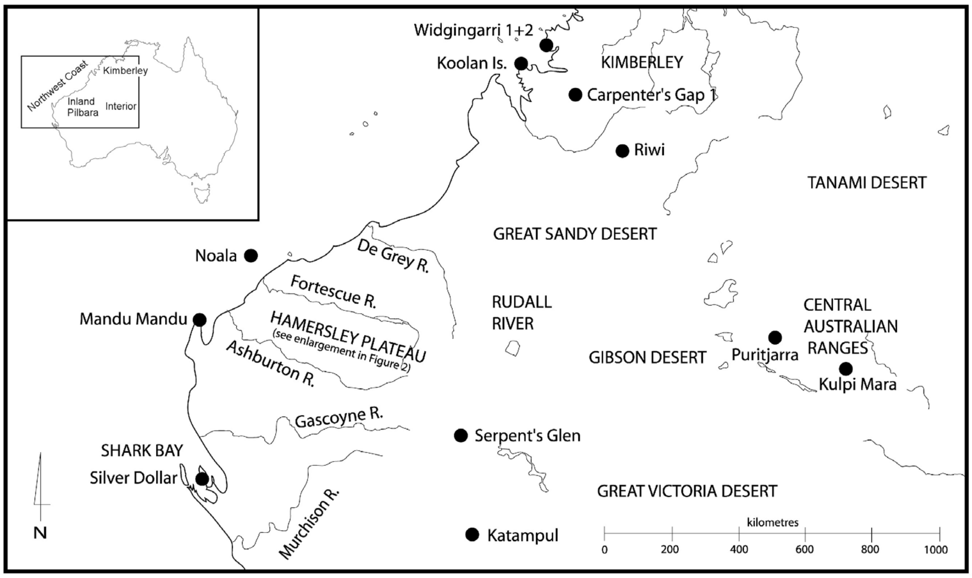

Figure 1. Map showing archaeological sites mentioned in the text.

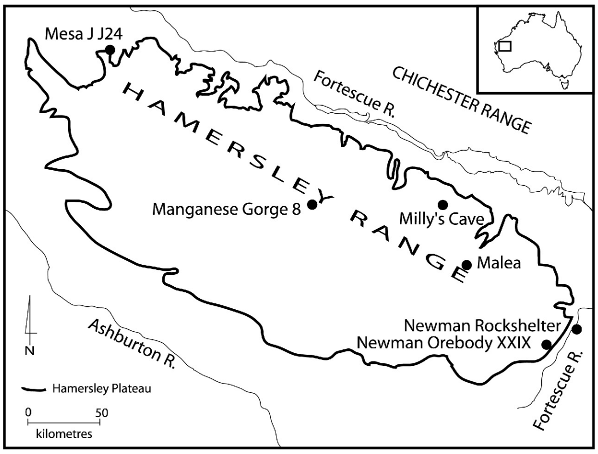

Figure 2. Map of the Hamersley Plateau showing sites mentioned in the text.

indicates that the representation of grassland species of the Kimberley changed very little over the LGM, although a decline in the abundance of palm and Ulmaceae phytoliths suggests that the LGM was a period of significantly reduced water availability (Wallis 2001). In the inland Kimberley, 90km east of Fitzroy Crossing, excavation at Riwi Rockshelter revealed a period of Pleistocene occupation from about 40,000 BP to about 30,000 BP (Balme 2000). Between dates of 29,550 ± 290 BP (Wk-7896) and 5,290 ± 60 BP (Wk-7605) there is a stratigraphic and cultural hiatus. Balme (2000) suggests that the absence of a lag deposit at the stratigraphic unconformity makes erosion an unlikely explanation for the hiatus and proposes that occupation at Riwi was at a much reduced intensity between 30,000–5,000 BP than before or after that period.

O'Connor's (1999) interpretation of the archaeological sequence from the Widgingarri 1 and 2 rockshelters and Koolan Island rockshelter suggests an hiatus in sedimentation and cultural discard between 18,500 BP and 10,000 BP. During the glacial maximum Koolan Island was part of an inland promontory and may have been abandoned because of the increased distance to the coast. However, the Widgingarri shelters are currently about 2km from the coast and were occupied even when much further from the coast several thousand years before the glacial maximum (O'Connor 1999:21-93). On the basis of contrary evidence, O'Connor suggests that the abandonment of Koolan Island rockshelter may be a result of the relocation of the local population in response to the dry conditions of the glacial maximum rather than the retreating coastline.

Changes in the rates of accumulation of biogenic and terrigenous marine sediments indicate that the northwest coast experienced similar environmental conditions to the arid zone, although the winds were probably not as strong and stable ocean circulation patterns may have reduced the severity of the shift to glacial conditions (Veeh *et al.* 2000). At Noala Cave on the Montebello Islands, 125km offshore between Onslow and Roebourne, two squares were excavated 2m apart. In square two, faunal remains and stone artefacts were recovered in association with a date of 27,220 ± 640 BP (Wk-2905) (Veth 1993b). Square one is 2m south of square two and cultural discard began in square one shortly before 10,030 ± 200 BP (Wk-2913) and ceased after 8,730 ± 80 (Wk-2912) (Veth 1993b). Although there are cultural remains in the five excavation units between the 10,000 BP date and bedrock at Noala Cave square one, dates from these units are not yet published (Veth 1993b). From the evidence currently available for Noala Cave square two, it is not possible to conclude abandonment or occupation between 20,000 BP and 10,000 BP, but the combination of evidence from squares one and two suggests abandonment after 27,000 BP.

At Mandu Mandu Creek Rockshelter on the northwest coast, the discard of artefact and faunal remains peaked between 22,100 ± 500 BP (Wk-1575) and 20,040 ± 440 BP (SUA-2614), but sedimentation and cultural discard ceased after 20,000 BP until 5,490 ± 80 BP (Wk-1511), when the site was reoccupied (Morse 1988). Further south on the coast, a similar pattern is found at Silver Dollar, where sedimentation continued but cultural discard ceased between around 20,000 BP and 7,000 BP (Bowdler 1990).

Interior

Glacial conditions in the interior may have been less extreme than the northwest coast and Kimberley. Recent research into LGM climate at central Australian lakes indicates that while precipitation rates were lower, evaporation rates were also low and floods from monsoonal storms in the northernmost region of Australia enhanced the flow of water into central Australia, resulting in increased water levels in the lakes (Kotwicki and Allan 1998; Nanson *et al.* 1998; Nott and Price 1994). On current data, the LGM climate of the interior included markedly suppressed temperatures, substantially depressed evaporation, high water levels at major lakes such as Lake Eyre and Lake Blanche, but probably a less extreme reduction in surface water throughout than has been previously suggested (e.g. Veth 1995). Phytolith data from the Puritjarra archaeological site in the interior indicate a tree-shrub presence continued throughout the LGM, suggesting that the paucity of vegetation and overall dryness of the LGM have been overestimated (Bowdery 1998:122-123).

In the central Australian ranges, rates of sedimentation and artefact discard were very low at Kulpi Mara between 24,000 BP and 12,000 BP (Thorley 1998) as well as at Puritjarra between 22,000 BP and 12,000 BP (Smith 1987:611, 1989:97-98). At Katampul Shelter, in the northeastern goldfields region to the southeast of the Pilbara, a date of 21,170 ± 190 BP (Wk-3241) was obtained near bedrock. The date is associated with less than 1% (n=22) of the total number of recovered stone artefacts. These artefacts may not be in their original depositional context because of the sandy sediments (Cooper 1994; O'Connor and Veth 1996). The 21,100 BP date is 6cm below a date of 4,500 ± 140 BP (Wk-2688) (O'Connor and Veth 1996).

Still to the east but nearer to the Pilbara than the central Australian ranges is Serpent's Glen Rockshelter in the Carnarvon Ranges, occupied before 23,550 ± 140 BP (ANSTO-0ZB582) (O'Connor *et al.* 1998). The Pleistocene occupation at Serpent's Glen was very brief. It is represented by 2% (n=32) of the total number of recovered stone artefacts, and followed by cultural and depositional hiatus from 23,500 BP until after 4,710 ± 180 BP (ANU-10025) (O'Connor *et al.* 1998).

Pilbara

Published environmental data from the inland Pilbara do not extend to the LGM, but Jones and Bowler (1980) assume conditions to have been similar to the interior, namely cooler with less precipitation, based on present physiographic and climatic conditions. The severity of the decline in the availability of surface water in the inland Pilbara was probably reduced by the aquifer-fed pools protected from evaporation by the deep gorges in the Hamersley Ranges and the northeastern scarp of the Hamersley Plateau (Department of Conservation and Land Management 1999).

The evidence for human occupation during peak glacial aridity at the two most frequently discussed inland Pilbara Pleistocene sites, Newman Orebody XXIX Rockshelter and Newman Rockshelter, is currently ambiguous. Brown (1987:23) and Smith (1988:305) argue for uninterrupted occupation from 20,700 BP to the present but Hiscock (1988) and Veth (1989) argue for LGM abandonment. The two opposing views result from different interpretations about the relationship between Newman Orebody XXIX Rockshelter and Newman Rockshelter and the Hamersley Plateau as an oasis or area of refuge for humans from the arid glacial conditions. Hiscock (1988:260-261) proposes a model of fluctuating occupation of the arid zone where sites not located at oases, such as the Hamersley Range gorges, were abandoned between 18,000 BP and 14,000 BP. Veth (1993a) used a biogeographical model of arid-zone refugia and also proposed that the Hamersley Range was a refuge for humans during the LGM. Hiscock (1988:263-264) and Veth (1993a:109) interpret the sequences from Newman Rockshelter and Newman Orebody XXIX Rockshelter as two sites outside the Hamersley refugium that were abandoned along with the rest of the arid zone.

Smith (1988:301) and Brown (1987:33), on the other hand, argue that the Newman sites were intermittently used over a long period with no break in occupation. Brown (1987:55) considers the rockshelters as optimal locations for habitation owing to their proximity to the Fortescue River, but he does not specifically discuss the impact of the LGM on occupation of the sites. Similarly, Smith (1988:296-297, 1989) writes that the Newman sites are near the Fortescue River and floodplains, suggesting that the sites may have been like Puritjarra with a sparse sequence of artefacts at a site representing an area to which people withdrew during LGM aridity. The difference between the opposing interpretations of LGM occupation at the Newman sites is that Smith and Brown view the Newman sites as within a refuge while Veth and Hiscock view them as on the periphery of a refuge.

The question of LGM occupation cannot be answered by Newman Orebody XXIX Rockshelter, although Newman Rockshelter does suggest abandonment. Newman Orebody XXIX Rockshelter does not have sufficient chronological resolution to resolve the ambiguity in human occupation during the period 20,000 BP to 10,000 BP. The 20,740 ± 345 BP (SUA-1041) date represents the lower 30cm of deposit at a depth of 70–100cm below surface, while charcoal from 10cm above is dated to 9,870 ± 80 BP (SUA-2553) (Brown 1987:22-25; Maynard 1980:4-7).

Hiscock (1988:263) and Veth (1993a) interpret the depths of these dates as evidence that rates of sedimentation slowed between 20,700 BP and 9,800 BP compared with before and after. However, as it is not possible to determine the rate of sedimentation before 20,700 BP, the only interpretation available is simply that sedimentation rates increased after 9,800 BP.

Without a range of dates between the base of the excavation and the 9,800 BP date at Newman Orebody XXIX Rockshelter, it is impossible to determine the rate of sedimentation and cultural discard and the sequence of occupational intensity between 20,000 BP and 10,000 BP. In addition, 64% (n=161) of the total number of recovered stone artefacts occurs above the 9,800 BP date, and only 13% (n=33) is associated with the 20,700 BP date (Brown 1987:25). With such a small number of artefacts and a small proportion of the material discarded during the Pleistocene it is difficult to sustain general conclusions about early patterns of behaviour at this site.

Chronological resolution at Newman Rockshelter is also low, with the crucial 20,000 BP to 10,000 BP period bracketed by dates of 26,300 ± 500 BP (SUA-1510) in spit 16 and 6,270 ± 210 BP (WAIT-121) in spit 10 (Brown 1987:27). Only 15% (n=41) of the total number of recovered stone artefacts was deposited prior to 26,300 BP and 68% (n=179) of the assemblage after 6,200 BP (Brown 1987:31). Between the two dates is 17% (n=46) of the assemblage, with five artefacts in spit 14, nine artefacts in spit 13 and no artefacts in spit 12 (Brown 1987:31). Hiscock (1988:264) and Veth (1989:242) regard the relatively small numbers of artefacts in spits 12–14 as evidence for a cultural hiatus. As no spit depths or sediment data are given, it is difficult to assess rates of sedimentation and artefact discard at Newman Rockshelter. However, the relatively small number of artefacts discarded between 26,300 BP and 6,200 BP does suggest lower occupational intensity than during the period after 6,200 BP.

Chronological resolution for the LGM is also a problem when trying to interpret the evidence at Mesa J J24 (Figure 2). The LGM period is bracketed by dates of 23,500 BP (Wk-2514) at 53–58cm below the surface and 3,900 BP (Wk-2634) at 22.5–27.5cm below the surface (Hughes and Quartermaine 1992:91). Between these two dates are 98 artefacts (43% of the total number) and after 3,900 BP there are 58 artefacts (25% of the total number) (Hughes and Quartermaine 1992:91). The relatively small number of artefacts discarded in the 19,600 years between the two dates suggests that, like Newman Orebody XXIX, it is difficult to argue convincingly for continuous occupation or abandonment during the LGM at Mesa J J24. A conservative explanation of the evidence from J24 is that before 23,500 BP and after 3,900 BP human occupation events were more frequent than between 23,500 BP and 3,900 BP, suggesting of a possible reduction of use during the LGM.

At Malea rockshelter stone artefacts are associated with dates of 20,950 ± 330 BP (see Figure 2) (laboratory numbers are not provided by the excavators) from about 100cm below the surface and 15,670 BP from about 75–80cm below the surface (McDonald Hales and Associates 1997). Although exact numbers of artefacts are not given, a graph provided by McDonald Hales and Associates (1997:21) shows that artefact discard is uniformly low from the time of first occupation until 2,900 BP, when there is a large increase. The low proportion of artefacts discarded between 20,900 BP and 15,600 BP suggest that intermittent and brief visits to Malea continued throughout the LGM. McDonald Hales and Associates (1997:19) state that 'the frequency of rock fragments generally increased with depth, particularly between spits 16 and 18, at a depth of 73 to 97 centimetres'. The depth where rock fragments are most abundant is the same depth bracketed by the 20,900 BP and 15,600 BP dates, representing the phase of LGM occupation. The implications of the concentration of rock fragments at the time of the LGM are not clear because no qualitative or quantitative details of the rock fragments are provided by McDonald Hales and Associates (1997), but it could mean that there was a period of zero or reduced net sedimentation (cf. O'Connor *et al.* 1999) during the LGM. If sedimentation rates were reduced during the LGM at Malea then the numbers of artefacts per spit during the LGM are artificially amplified compared to spits representing other periods, suggesting that visits to Malea were actually less frequent during the LGM compared to the rest of the time that the site was occupied.

Veth (1995:736) quotes dates of 17,900 ± 230 BP (Wk-2476) and 8,990 ± 100 BP (Wk-2477) for Manganese Gorge 8 (Figure 2), near Marandoo, but the dates are out of sequence as the 17,900 ± 230 BP date is located two spits closer to the surface than the 8,990 ± 100 BP date. Veth (1995) provides no other details for Manganese Gorge 8 and with the data currently available I do not believe the site contains any evidence relevant to the question of LGM occupation in the inland Pilbara.

Evidence for LGM occupation from the inland Pilbara Pleistocene sites is ambiguous and chronological resolution is low, but the general trend seems to indicate a pattern of abandonment or reduced use. The evidence from Newman Orebody XXIX Rockshelter, Newman Rockshelter, Mesa J J24 and Malea, all excavated as part of salvage projects, does not provide a convincing argument for human occupation between 20,000 BP and 10,000 BP in the inland Pilbara.

Milly's Cave

Milly's Cave, excavated by Lynda Strawbridge in 1990–1991, provides evidence for the critical time period and helps resolve the question of LGM occupation for the inland Pilbara. Milly's Cave contains a sequence of artefacts from 19,000 BP to recent times. I analysed stone artefact discard rates, technology and raw materials to identify changes in the intensity of occupation and the function of the site which may have occurred during the LGM.

Milly's Cave is a rockshelter in the Marra Mamba ironstone formation. The rockshelter is located in the side of a small gully that forms a tributary to Iowa Creek. In the gully near Milly's Cave there is a small spring that provides a constant supply of potable water. The site is in a drainage line that is part of the system along the northern scarp of the Hamersley Plateau that drains the plateau into the Fortescue River. The shelter is 6.1m wide and 4m high at the dripline and 5.5m from the dripline to the back (Figure 3). Strawbridge excavated two 1m x 1m squares to depths of 70cm (square 4A, excavated to bedrock) and 25cm (square 5A). Thirteen units were excavated in depths of 1–6cm. The mass of excavated material from each unit was recorded and sieved through 6mm and 3mm sieves. Analysis of particle size distribution, colour, pH and conductivity of sediments at Milly's Cave indicates that there is no change in the source and method of deposition from the onset of sedimentation at the rockshelter until recent times, except for a period of roof and wall collapse at around 700 BP (Figure 4). The date for the roof fall was determined on charcoal in a bulk sample, but three other dates were obtained from *in situ* charcoal concentrations (Table 1).

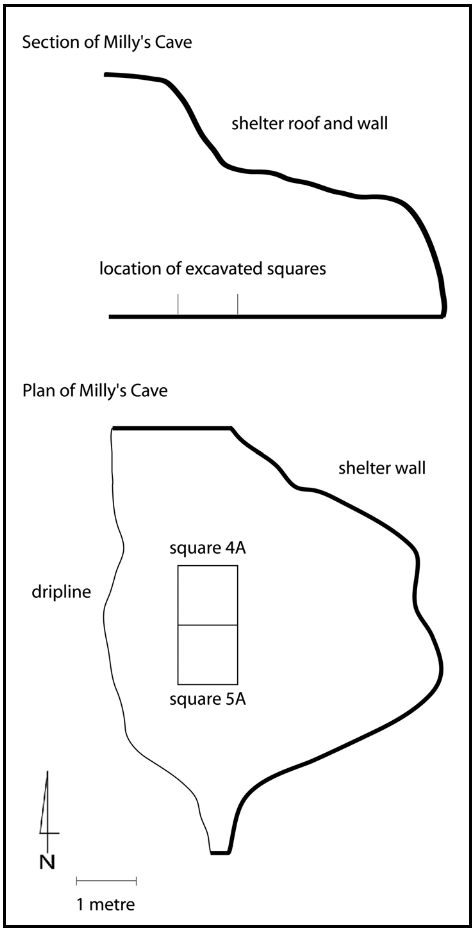

Figure 3. Plan and schematic cross-section of Milly's Cave.

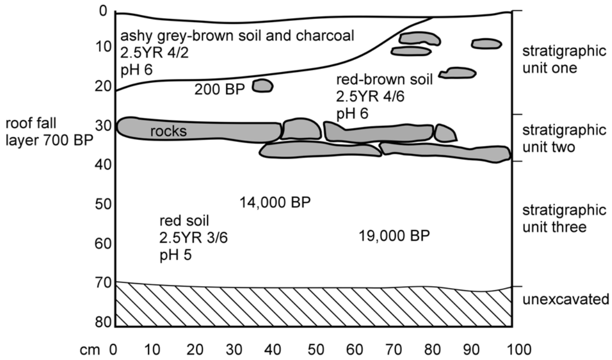

Figure 4. South section of Milly's Cave square 4A.

Table 1. Radiocarbon dates from Milly's Cave.

Date (years BP)	Lab. Code	Sample	Depth (cm)
c.200	Wk-2187	charcoal	20
719 ± 57	Wk-10351	charcoal	27-36
14150 ± 320	Wk-2583	charcoal	48-50
18750 ± 460	Wk-2188	charcoal	55-57

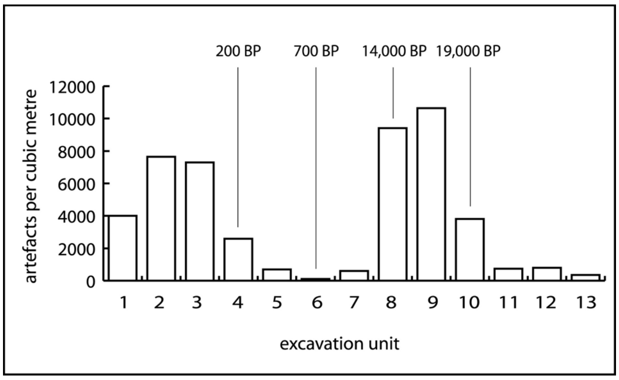

Figure 5. Milly's Cave square 4A: Artefact discard per excavation unit.

Occupational Intensity at Milly's Cave

The numbers of stone artefacts discarded at Milly's Cave show a bimodal distribution, with a main mode between 14,150 BP and 18,750 BP and a subsidiary mode commencing around 200 BP (Table 2). Figure 5 shows this bimodal distribution after the number of artefacts per excavation unit has been standardised to a measure of number of artefacts per cubic metre of excavated sediment (i.e. density; figures for sediment mass are not available). The data suggest that artefact discard at Milly's Cave was highest during and after the LGM, between 18,750 BP and 14,150 BP.

Table 2. Milly's Cave square 4A: Age of levels and distribution of artefacts.

Excavation Unit	Depth Below Surface (cm)	Stratigraphic Unit (SU)	Estimated Age (years BP)	Number of Artefacts	Artefact Density (artefacts m^{-3})
1	0.02	1	0	110	5550
2	0.04	1		152	7600
3	0.07	1		219	7300
4	0.09	1	200	52	2600
5	0.11	1		14	700
6	0.31	2	700	22	110
7	0.46	2		91	607
8	0.50	3	14000	375	9375
9	0.52	3		266	10640
10	0.55	3	19000	95	3800
11	0.62	3		52	743
12	0.65	3		24	800
13	0.72	3		25	357

To determine the cause of the increase in artefact discard during the LGM, I analysed stone artefacts to determine if there were changes in artefact technology or use of the site during this period. I divided the sequence into three analytical units based on natural stratigraphy to create large sample sizes to compare artefacts from the LGM with those from later periods. Figure 4 shows that the stratigraphic units were determined by the roof fall layer, with stratigraphic unit one the unit above the roof fall, unit two the roof fall layer itself and unit three the unit below the roof fall. Table 3 shows the results of the technological analysis of complete flakes, with the significance of difference in variables in each stratigraphic unit measured by chi-square tests on untransformed values. Platform and termination variables and frequencies of overhang removal remain constant over time (Table 3). This suggests an assemblage with long-term technological conservatism. The percentage of flakes with more than one dorsal flake scar and the proportion of flakes with facetted platforms and less than 50% dorsal cortex suggest that the early stages of decortification and the final stages of core exhaustion are not highly represented at Milly's Cave. This indicates that flakes produced at Milly's Cave consistently come from the middle stages of a reduction system throughout the history of its occupation and that the site represents one aspect of an open system of artefact transfer and reduction involving open sites and other rockshelters.

Raw Materials at Milly's Cave

I identified types of raw materials used in artefact manufacture at Milly's Cave to determine if there were changes in the use of exotic and local raw materials over the LGM. The diversity of stone available in the Pilbara makes identifying local and exotic stone difficult (Brown 1987:5-6; Veth 1984). At Milly's Cave I was able to identify two types of chert that could be distinguished as local and exotic. Local chert forms in the banded Marra Mamba ironstone formation, which consists of thin layers of chert and ironstone and is immediately available from the rockshelter walls and roof and the surrounding formation. Local chert (known as bif-origin chert) occurs when the banded ironstone formation becomes highly silicified, resulting in a rock mechanically similar to other forms of chert, but visually distinctive because of its thin, dark layering. Exotic chert is distinctive because it is not banded and comes in a variety of colours not found in bif-origin chert. Table 4 shows that during the LGM occupation period there were significantly higher numbers of artefacts (χ^2=27.97, df=1, p(H_0)=1.22x10^{-7}) made from locally-available bif-origin chert compared with the late Holocene occupation period. The focus on locally-available raw materials to the exclusion of exotic raw materials during the LGM is a reflection of the reduced scale of people's territorial range compared with that in the Holocene.

Table 3. Milly's Cave square 4A: Technological data. Significance assessed by χ^2 tests on untransformed values, $p(H_0)$= probability of the null hypothesis. Value must be less than 0.05 to be statistically significant.

Technological Variable	Measure	Stratigraphic Unit		
		1	2	3
complete flakes (n)		25	9	86
termination	ratio feather to non-feather	4:1	3.5:1	75:11
	χ^2	1:2 0.019 2:3 0.465		
	$p(H_0)$	1:2 0.887 2:3 0.495		
	significant change in termination?	no no		
platform	%flat	60	33.3	57.5
	%facetted	40	44.4	27.5
	%cortical	0	22.2	14.9
	χ^2	1:2 1.888 2:3 1.921		
	$p(H_0)$	1:2 0.169 2:3 0.165		
	significant change in platform surface?	no no		
	significant change in overhang removal?	no no		
reduction level	%flakes with >1 dorsal flake scar	24	44.4	19.5
	χ^2	1:2 1.332 2:3 2.960		
	$p(H_0)$	1:2 0.248 2:3 0.085		
	significant change in scar numbers?	no no		
	%flakes with <10% cortex	25	55.5	34.4
	%flakes with 10-50% cortex	40	44.4	49.4
	%flakes with >50% cortex	0	0	0
	χ^2	1:2 1.044 2:3 1.563		
	$p(H_0)$	1:2 0.306 2:3 0.211		
	significant change in % dorsal cortex?	no no		

Table 4. Milly's Cave square 4A: Chert and bif-origin chert artefacts.

	SU1	SU2	SU3
total number of artefacts	547	113	837
number of chert artefacts	115	12	477
% of total that are chert artefacts	21	10.6	56.9
number bif-origin chert artefacts	5	0	131
% of total chert artefacts that are bif-origin chert artefacts	4.3	0	27.4

Table 5. Milly's Cave square 4A: Mass of complete flakes of different raw materials in stratigraphic unit three. Significance assessed by t-tests on values transformed to their base-10 logarithm to approximate a normal distribution, $p(H_0)$= probability of the null hypothesis. Value must be less than 0.05 to be statistically significant.

		Chert	Bif-Origin Chert (boc)	Bif	Other
quantity	n	40	15	26	5
	%	47.1	17.6	29.4	5.9
mass (g)	mean	0.70	0.98	0.80	0.59
	max	5.89	3.82	3.71	1.58
	min	0.01	0.01	0.01	0.01
	range	5.88	3.81	3.70	1.57
	sd	1.33	1.40	1.01	0.63
t		chert:boc 0.121 chert:other -0.575	boc:bif 0.177 boc:other -0.530	bif:chert 0.096 bif:other -0.454	
$p(H_0)$		chert:boc 0.904 chert:other 0.568	boc:bif 0.860 boc:other 0.601	bif:chert 0.923 bif:other 0.654	
significant difference in means?		no	no	no	no

Table 5 shows that there is no significant difference in the masses of flakes of different raw materials used during the LGM occupation. This suggests that while local cherts were more frequently exploited, all raw materials were reduced to a similar size. The significance of differences in mass between the three stratigraphic units was measured using t-tests on values transformed to their base-10 logarithms to approximate a normal distribution. If the risk of acquiring exotic raw materials increased as they decreased in abundance in the assemblage, then artefacts made from exotic raw materials should be smaller because of attempts to conserve the material through more extensive reduction. Artefacts made from exotic raw materials were not smaller than local raw material during the LGM, indicating that there was no change in the availability or demand of raw materials. This suggests that distance from source was the only variable of raw material procurement that significantly changed during the LGM for the occupants of Milly's Cave. The similar flaking qualities of local and exotic cherts may have made risk irrelevant in the procurement of raw materials throughout the history of occupation at Milly's Cave.

Mobility

Assessments of population mobility were made by measuring artefact curation and assemblage diversity (Shott 1986, 1989, 1996). Ethnographic evidence from various hunter-gatherer groups shows that highly mobile groups generally discard a small number of multi-purpose stone tool types and less mobile groups generally have larger, more diverse stone assemblages (Shott 1986, 1989). I measured assemblage diversity as the number of types of artefacts, including backed artefacts, grinding pieces, artefacts with secondary working and unretouched flakes. The level of artefact curation, defined as the difference between the potential utility the tool starts with versus the amount left at discard (i.e. degree of reduction), increases with mobility (Shott 1989, 1996) but is also influenced by raw material availability (Bamforth 1986). I measured curation as the proportion of the artefacts in the assemblage with secondary working.

Tables 6 and 7 show that there are no major changes in the level of artefact curation and technology of manufacture at Milly's Cave throughout the history of its occupation. Flake length, width and mass do not differ significantly in consecutive units (Table 6), but flakes in unit three are significantly smaller than those in unit one (t-test on mass values transformed to base-10 logarithm, $t=2.40$, $df=108$, $p(H_0)=0.018$). Although the difference in flake mass between unit three and unit one is statistically significant, the difference probably does not indicate a substantive trend. These data could be interpreted to indicate an increased degree of tool maintenance or artefact reduction compared with later units (Sullivan and Rozen 1985:762) but the number of artefacts with secondary working (retouch or use-wear) does not change significantly over time (Table 8). The presence of a few unusually large flakes in unit one, as suggested by the high standard deviation values, is the probable cause of the statistically significant result.

Table 6. Milly's Cave square 4A: Metric data for complete flakes. Significance assessed by t-tests on values transformed to their base-10 logarithm to approximate a normal distribution, $p(H_0)$= probability of the null hypothesis. Value must be less than 0.05 to be statistically significant.

Variable	Measure	Stratigraphic Unit		
		1	2	3
complete flakes	(n)	25	9	86
mass	total	52.4	7.4	65.3
(g)	mean	2.1	0.8	0.8
	range	19.71	4.08	5.88
	max	19.73	4.11	5.89
	min	0.02	0.03	0.01
	sd	4.2	1.3	1.2
t		1:2 0.968 2:3 0.517		
$p(H_0)$		1:2 0.340 2:3 0.605		
significantly different?		no no		
length	mean	17.5	14.9	11
(mm)	range	47.3	26.1	27.6
	max	51.7	29.9	30.5
	min	4.4	3.8	2.9
	sd	11.6	7.7	6.6
t		1:2 0.389 2:3 1.606		
$p(H_0)$		1:2 0.699 2:3 0.111		
significantly different?		no no		

Variable	Measure	Stratigraphic Unit		
		1	2	3
width	mean	15.6	11.3	11.2
(mm)	range	36.8	22.5	26.7
	max	41.2	26	29.5
	min	4.4	3.5	2.8
	sd	9.7	7.4	6.7
t		1:2 1.343 2:3 -0.029		
$p(H_0)$		1:2 0.188 2:3 0.976		
significantly different?		no no		
thickness	mean	3.3	2.8	2.6
(mm)	range	7.4	6.2	6.9
	max	7.8	7.2	7.5
	min	0.4	1	0.6
	sd	2	1.9	1.7
t		1:2 0.371 2:3 0.587		
$p(H_0)$		1:2 0.712 2:3 0.558		
significantly different?		no no		

Assemblage diversity is also unchanged throughout. There are only two types, unretouched flakes and retouched flakes, and they are present throughout the entire sequence. This suggests that Milly's Cave was a location with a constant function in a high-mobility land-use system (Andrefsky 1998:206; Shott 1989).

Discussion

The pattern of reduced territorial area during the LGM observed at Milly's Cave is similar to that observed at Colless Creek Cave and Louis Creek Cave, northwest Queensland, where artefacts made from stone more than 3km from the shelters are absent in the assemblages discarded between 18,000 and 14,000 BP (Hiscock 1988:225-226, 241, 245-248). Hiscock (1988:245-248) suggests that people focussed more on the local gorge environment during the LGM because it was less risky than exploiting the plains. Fern Cave, in southeast Cape York Peninsula, has permanent springs within 2km of the site, and like the Lawn Hill sites, a pattern of intensified use and increased use of local raw materials during the LGM (Lamb 1996). Lamb (1996) and David and Chant (1995:402) interpret Fern Cave as evidence of a narrowing of resource catchments to a small but well-watered area. Like the inhabitants of Fern Cave, people at Milly's Cave during the LGM had access to a local spring. Like the inhabitants of the Lawn Hill sites, people at Milly's Cave were able to take advantage of the local geography that concentrated resources made scarce elsewhere by the increased aridity. At Milly's Cave the LGM occupants were able to focus on the nearby steep northeast scarp that drained the plateau into the Fortescue, where water and other resources were more concentrated than the marginal Pilbara lowlands. The LGM occupants of Colless Creek Cave, Louis Creek Cave, Fern Cave and Milly's Cave adapted in a like manner to extreme glacial aridity through the exploitation of local resources, without significantly changing the role of these sites in their land-use system.

Table 7. Milly's Cave square 4A: Debitage types. Significance assessed by χ^2 tests on untransformed values, $p(H_0)$= probability of the null hypothesis. Value must be less than 0.05 to be statistically significant.

Debitage Type	Stratigraphic Unit					
	1		2		3	
	n	%	n	%	n	%
number of artefacts	547	100	113	100	837	100
complete flakes	25	4.6	9	8	86	10.3
broken flakes (longitudinal)	3	0.5	0	0	1	0.1
broken flakes (transverse)	6	1.1	1	0.9	9	1.1
flake fragment	142	27.4	26	23	284	33.8
angular piece	367	67.1	77	68.1	457	54.6
χ^2	1:2 0.809			2:3 3.786		
$p(H_0)$	1:2 0.847			2:3 0.285		
significantly different assemblages?	no			no		

Table 8. Milly's Cave square 4A: Artefacts with secondary working. Significance assessed by χ^2 tests on untransformed values, $p(H_0)$= probability of the null hypothesis. Value must be less than 0.05 to be statistically significant.

	Stratigraphic Unit		
	1	2	3
number of artefacts with secondary working	17	2	20
% of artefacts in SU with secondary working	3.1	1.8	2.4
χ^2	1:2 0.600	3:2 0.169	
$p(H_0)$	1:2 0.439	3:2 0.681	
significant difference?	no	no	

With the evidence on mobility and territorial area from Milly's Cave it is possible to make some social and demographic observations regarding LGM populations of the inland Pilbara. Nothing in the stone artefact assemblage indicates that Milly's Cave was utilised by different-sized groups of people during the history of its occupation. The increased intensity of site use during the LGM combined with the absence of any change over time in artefact diversity and reduction intensity (Table 3) probably resulted from more frequent visits rather than more people, longer stays or changes in the function of the site in the land-use system of its occupants. The peak in occupation magnitude during the LGM at Milly's Cave generally supports Veth's (1993a:109) prediction that the Hamersley Plateau was a refuge, but I do not believe that the evidence from Milly's Cave shows it to be a site of refuge for a regional population. The response to the LGM at Milly's Cave is the opposite of ethnographic observations that suggest that hunter-gatherer adaptations to aridity involve highly mobile groups with extensive social networks. On the basis of ethnographic analogy (e.g. Gould 1980; Yengoyan 1976), the expected occupation signal at Milly's Cave during the LGM would be one of a seasonal aggregation site where people gathered around abundant and dependant resource supplies. There are no indicators, such as an increase in artefact diversity or an increase in exotic raw materials, that Milly's Cave became an aggregation locale during the LGM. The social implications of the LGM pattern at Milly's Cave are a major reduction in the areal extent of exchange networks and probably less frequent, if any, population aggregation events compared with the late Holocene. Further evidence for reduction in exchange networks is found on the northwest coast, where ochre from the Hamersley Plateau occurs throughout the occupation sequence except between 20,000 BP and 10,000 BP (Morse 1988). The LGM interruption of exchange networks is also evident in the Kimberley, with finds of edge-ground axes, baler shell, mud clam, pearl shell and *Dentalium* sp. shell beads suggesting exchange over 300km in pre-LGM times (Balme 2000; O'Connor 1999).

As for demography, it could be speculated that the LGM was a punctuation event which saw a major contraction in population size (e.g. Morse 1988, O'Connor 1999). Yet there is currently no direct evidence, such as genetic data, that significant changes in population sizes occurred during the LGM (Adcock *et al.* 2001). Palaeodemographic reconstructions based on cultural discard are difficult because of numerous known and unknown variables that obscure the relationship between the numbers of people at a site and the formation of the archaeological record (Dortch and Smith 2001). A more parsimonious explanation is that stable, low-density populations maintained their land-use system in a reduced territorial area. The success of the LGM adaptation at Milly's Cave was probably owed to hunter-gatherer systems that already possessed a degree of cultural and technological latitude or pliancy that could accommodate the stresses imposed by arid glacial conditions. This conclusion is similar to recent suggestions that European hunter-gatherers were much less affected by the LGM than previously suspected (Montet-White 1994; West 1997; Williams 1998).

Conclusion

Milly's Cave provides the first unequivocal evidence for human occupation of the inland Pilbara during the LGM. While sites in surrounding regions are abandoned or show a reduction in occupational intensity during the LGM, human activity at Milly's Cave intensified during this period. Milly's Cave was an attractive location for human occupation during the LGM because of the local freshwater spring and the advantageous concentration of resources provided by the high relief northeast scarp of the Hamersley Plateau.

Evidence from Milly's Cave supports some previous explanations of human activity during the LGM and contradicts others. It has been suggested that the widespread abandonment or reduction in occupation intensity of sites in the Kimberley, northwest coast and interior is a result of reduced population sizes and distribution and increased residential mobility in response to the intense aridity (O'Connor *et al.* 1993; O'Connor *et al.* 1999; Veth 1995). The suggestion of reduced population sizes is not supported as no demographic changes are required to explain the sequence at Milly's Cave. Increased residential mobility is also not supported as the stone artefact assemblage shows no significant indicators of reduced assemblage diversity and increased reduction levels compared to later periods. Evidence from Milly's Cave suggests a reduced territorial area during the LGM, supporting interpretations of reduced population distribution. Suggestions of reduced social networks and aggregation activity are supported by evidence from Milly's Cave. Previous arguments of LGM demography and mobility typically rely on the absence of evidence because most Pleistocene sites are abandoned or show reduced activity. This means that evidence from sites such as Milly's Cave, where activity intensifies over the LGM, plays a crucial role in testing and shaping our interpretations of the unique cultural adaptations of late Pleistocene humans.

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