KEYWORDS: ***Rockshelter – Rock art – Geomorphology – Jawoyn – Arnhem Land – Australia***

ROCKSHELTER DEVELOPMENT ON THE ARNHEM LAND PLATEAU (AUSTRALIA) AND ITS IMPLICATIONS FOR ROCK ART RESEARCH

R. G. Gunn, L. C. Douglas and R. L. Whear

Abstract. While the range of factors affecting pigment preservation in rockshelters has been the subject of study, the degree to which the physical form (shape) of individual rockshelters affects the preservation of the rock art within remains largely unexplored. The Arnhem Land Plateau is well-known for its wealth of pigment rock art, some of which is reported to be amongst the longest-lasting (oldest) in Australia. To test whether the geomorphic form of a shelter influences pigment preservation, a qualitative and quantitative study of rockshelters within the quartzitic sandstones of the Arnhem Land Plateau was undertaken. The study concluded that the geomorphic form of a rockshelter plays only a minor role in the preservation of rock art and, by implication, the initial choice for rock art placement or its subsequent survival.

Introduction

The interaction between pigment rock art and the underlying rock support has been well-studied and is considered the major factor in rock art preservation, particularly in relation to the manner in which water penetrates the rock matrix beneath the pigment and moistures support for the growth of micro-organisms (e.g. Clarke 1976, 1978; Hughes 1978; Clarke et al. 1991; Bolle 1995; Thorn 1996; Lastennet et al. 2011; Orial et al. 2011). Dragovich (1981) and Thorn (2008) found that rockshelters mollify diurnal fluctuations in internal air temperature, rock temperature and air humidity compared to exterior readings. Thorn (1996, 2005) has also shown the deleterious effects of incident solar light on pigment preservation. No published study, however, has examined the influence of shelter form on rock art preservation or site selection.

The Arnhem Land Plateau and its rocky outliers have one of the highest concentrations of pigment rock art in Australia (Mountford 1956; Edwards 1979). The region, along with the Kimberley and Pilbara, is also reported to contain one of the longest records of rock art anywhere in the world (Chaloupka 1993; Mulvaney 2015; Walsh 2000). Recent rock art surveys in the Jawoyn Lands of the Arnhem Land Plateau noted a range of variations in the forms (shapes) of rock art shelters (Gunn and Whear 2007; Gunn and Douglas 2010; Gunn 2016). Although working closely with Jawoyn elders, no information was proffered by them regarding the selection of shelters based on their form. This paper then investigates the geomorphology of the Arnhem Land Plateau sandstones concerning rockshelter development and use by Aboriginal people, and the implications shelter form has for the survival of shelter rock art.

The Arnhem Land Plateau, in northern Australia (Fig. 1), is characterised by quartz sandstone that is relatively undeformed, although interspersed with minor interbedded volcanic units (Ferenczi and Sweet 2005: 2). The plateau rises some 300 m above the surrounding plain with occasional peaks to 500 m. With a steep escarpment along its north-western margin, the plateau slopes gently to the south-east. The sandstone consists of sharply dissected and horizontally-bedded Proterozoic quartz sandstone units of the Katherine River Group and Kurrundie Sandstone (Ferenczi and Sweet 2005: 2; Nott 2003) — the orthoquartzites of Hughes and Watchman (1983). Being cemented by silica, the Arnhem Plateau sandstones are very stable, and silicification has casehardened and stabilised most of the exposed rock surfaces (Needham 1992). For the past 250 thousand years, the plateau margin has been eroding at a rate of 20–200 mm per thousand years, with that mostly confined to the weaknesses of the structural lines rather than the flat-lying surfaces (Nott and Roberts 1996: 884). This weathering has not been constant through time but has largely occurred during climatic periods of greatly enhanced erosion, with the most recent erosional events essentially limited to the mid-Cretaceous, 100 million years ago (Nott and Roberts 1996: 887). Hence, the majority of rock features within the plateau, including the rockshelters, were

Figure 1. *Location of the Arnhem Land Plateau and the Jawoyn Lands.*

mostly formed and stabilised more than a million years ago during the late Tertiary (Galloway 1976: 54; see also Sullivan and Hughes 1983; Twidale and Campbell 2005: 169), and well precedes human occupation of the region. Minor rockfalls within these shelters, such as lamina disintegration or blocks falling from the shelter lip, continues today; however, these very rarely destroy or alter the overall form of the shelter.

Approximately one-third of the land surface of the Arnhem Land Plateau consists of essentially bare bedrock (Christian and Aldrick 1977: 16). These rock expanses decrease in size and frequency to the south and east. Between these outcrops, extensive and largely stabilised sand sheets have developed that now support extensive savannah woodlands.

All of the rock art shelters recorded on the plateau are within the quartz sandstones of the Kombolgie Formation. Of the 95 rockshelter complexes recorded to date in the Jawoyn Lands of the plateau, 55 (58%) occur within the Marlgowa Sandstone unit of the Kombolgie Formation (Table 1). The Marlgowa Sandstone unit is a fine- to very coarse-grained and pebbly quartz sandstone, in which medium-grained sandstone dominates (Sweet et al. 1999). The unit is one of the middle sandstones of the Kombolgie Subgroup; its formation dates to some 410 million years ago (Carson et al. 1999; Sweet, Brakel and Carson 1999; Ferenczi and Sweet 2005: 6, 43), with the stratigraphically lower layers being deposited around 1700 million years ago (Russell-Smith et al. 1995: 109). The other quartz sandstones of the plateau are similar but with either lightly scattered pebbles or conglomerate layers. Low-angle cross-bedding is common. The upper layers of the Kombolgie Formation sandstones have thinner bedding and abundant ripples on the flat-bedded surfaces consistent with deposition under a low-energy wave-dominated regime. In contrast, the lower layers of the Kombolgie Formation are thicker and were formed from braided fluviatile sands deposited by sheet-flooding over sandy flood plains (Ferenczi and Sweet 2005: 6).

The plateau sandstone is crisscrossed by numerous fault and joint lines (Fig. 2). These have been subjected to severe solutional weathering as both subsurface and surface processes, producing deep gorges along the major drainage lines and a maze of seasonal tributaries along the shallower ones (Young et al. 2009: 142–143, 190–193); this gives an orthogonal or rectangular drainage pattern (Twidale and Campbell 2005: 192). Between these erosion lines, the bedrock has weathered into remnant flat-topped block outcrops, essentially rectangular or triangular. While these individual blocks vary in area, few exceed a maximum length of one kilometre, ranging from pavements 1.0 × 0.5 km in area to rock-stack or block clusters less than 300 m in diameter (Fig. 3). Consequently, the cliff lines available for

Geological Group	Geological Subgroup	Geological Unit	Description	No. of locations	%
Katherine River	Kombolgie	Marlgowa Sandstone	quartz sandstone	55	*58*
		Gumarrirnbang Sandstone	qz sandstone	16	*17*
		Mamadawerre Sandstone	qz sandstone	13	*14*
		Gundi Sandstone	sandstone	6	*6*
		Cottee Formation	arenite	4	*4*
Mt Rigg	-	Bone Creek	qz sandstone	1	*1*
Total				95	*100*

Table 1. *Lithologies of recorded rock art shelter locations on the Arnhem Land Plateau.*

Figure 2. *The regular pattern of fault and joint lines that criss-cross the Arnhem Land Plateau highlighting the limited extent of the individual bedrock blocks and ridgelines. Photograph RGG.*

rockshelter development also rarely exceed 500 m in length, are isolated and separated from each other by substantial rock joint fissures or sand plains. For this reason, rockshelters on the plateau tend to naturally fall into discrete clusters limited by the spatial extent of the rock outcrop or cliff line (see below).

Cliff retreat within and around the plateau is due to erosion of the underlying sediments and subsequent collapse of the cliff faces (Galloway 1976: 60; Young and Young 1988: 14–20). These collapses are primarily due to inherent stresses on the overlying rock, or other forces such as earthquakes or exceptionally heavy rainfall (Mills 1981; Harp and Jibson 2002; Twidale and Bourne 2011). Fresh cliffs, rockfall blocks or blocks, and remnant rock stacks result from these collapses (Fig. 4). Minor differences in the composition of the various sandstone layers have further facilitated differential weathering rates, resulting in the sculpting of the remnant rock caps, stacks, blocks and outcrops. The caps are the remnant surfaces of an older landform, mostly around 6 m high with broad flat-tops due to the flat-lying nature of the sandstone beds. Cliff retreat is prominent mostly around the plateau margins, but it is within the sculptured retreating layers on top of the plateau that rockshelters are most commonly found (Fig. 4).

While rockshelters on the plateau have resulted from a variety of weathering processes and possess a range of forms (see below), they are most commonly associated with progressive 'layer retreat' around the margins of rock outcrops (Figs 5A–B). This can be from all sides of a block or focused on one corner of a block or gully line. In time, such erosion can result in the formation of remnant rock stack groups or

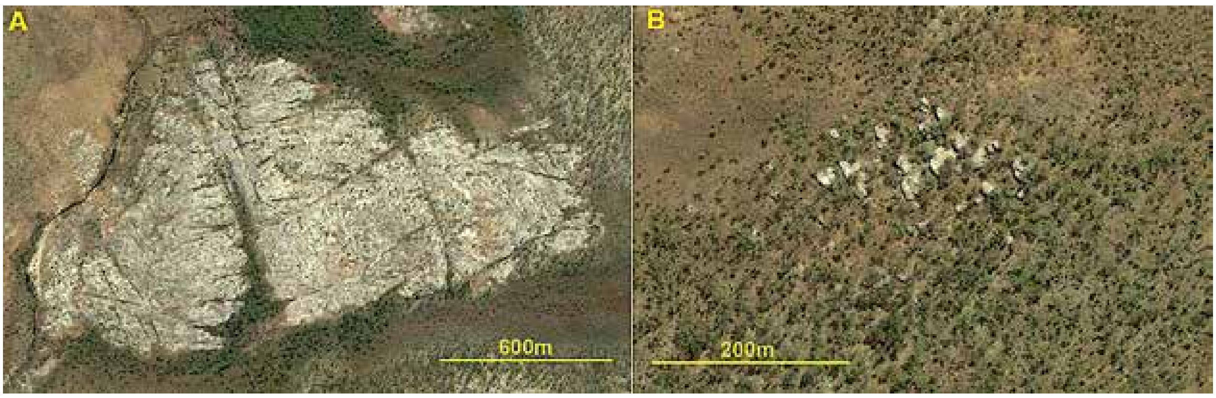

Figure 3. *Plateau rock major outcrop forms. A: broad pavements; B: small stack cluster. Photographs Google Earth: Image © 2017 Digital Globe.*

Figure 4. *Plateau sandstone erosion. B, C: cliff collapse and resultant scree blocks; F: fault line gully; J: joint line fractures; L: layer retreat; P: cap; S: stacks. Photograph RGG.*

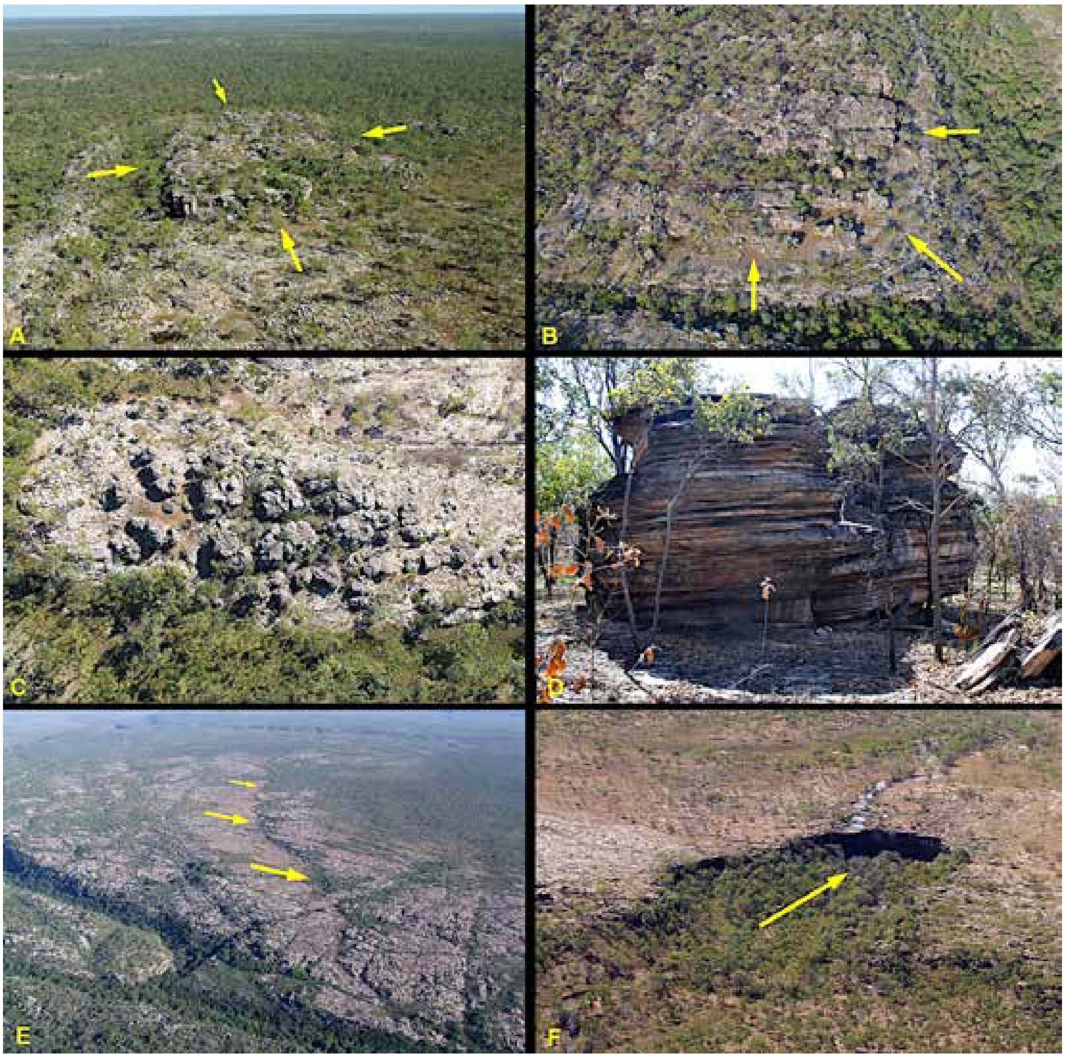

Figure 5. *Variations of retreating layer erosion in which rockshelters occur. A: block; B: corner; C: stack (group); D: stack (single); E: linear; F: embayment (horseshoe). Photographs RGG.*

isolated rock stacks (Figs 5C–D), which are a common feature of the Arnhem Land Plateau landscape. Elsewhere, shelters develop as linear arrangements along the low (<5 m) exposed face of the gently dipping bedding planes (Fig. 5E), or within cliff-line embayments that tend to be within active creek-lines (Fig. 5F) (Young et al. 2009). Embayments are localised ovoid erosion features (amphitheatre or horseshoe canyons commonly associated with waterfalls) formed by groundwater sapping beneath the sandstone, rather than being cut back by surface water erosion (Young et al. 2009: 83–87). Shelters formed in such embayments tend to be damp, as they are exit points for subsurface moisture. Only two large embayments have been recorded from Jawoyn Lands of the plateau, both having rock art shelters; unlike other shelter forms, both embayments complexes are still actively eroding. While this may suggest that they present a more biased rock art sample due to taphonomic processes, the evidence indicates that 'art' from most if not all recognised 'art' periods occurs within embayment rockshelters. Hence, while individual shelters at the apex of the embayment may be deteriorating more rapidly than shelters in other erosion landscapes, overall this does not bias the general 'art'-survival pattern on the Arnhem Land Plateau.

These erosion forms are found widely dispersed across the study area rather than clustering in localised areas (Fig. 6), suggesting that the erosion forms are not the result of landscape-scale erosion processes, but are due to local variations within the bedrock.

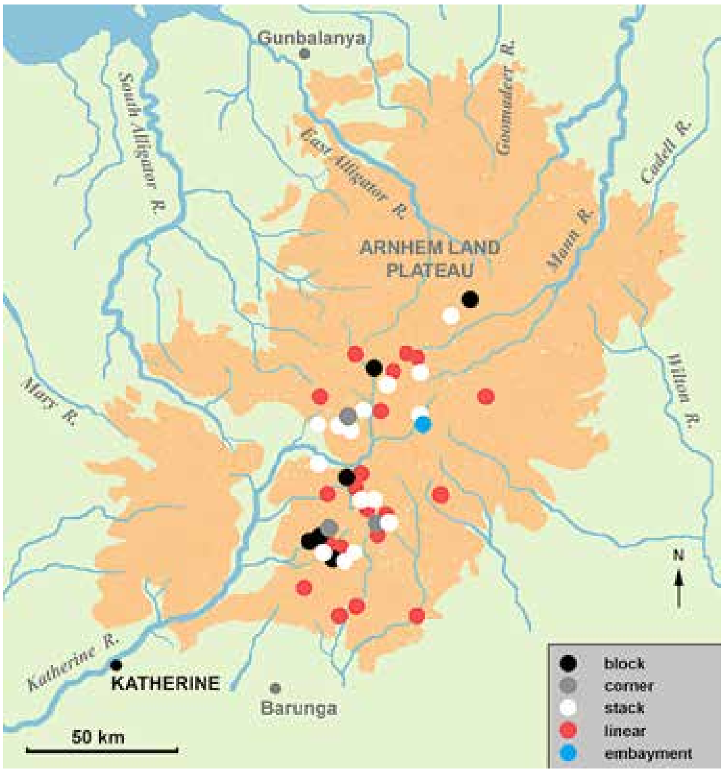

Figure 6. *Distribution of site complexes by principal erosion form.*

Rockshelter development

The various near-horizontal sandstone units within the Kombolgie Formation are composed of bedding planes of varying degrees of cementation and, as a result, these units weather at different rates. Rockshelters on and around the Arnhem Land Plateau have largely developed through erosion of more susceptible, often less-well cemented ('softer') sandstone layers from beneath more resistant layers. Development occurs through the movement of internal moisture dissolving the sandstone matrix (primarily silica) that eventuates in the rock returning to sand and forming the surrounding sand plains. The strongly-layered, narrow beds of the Arnhem Land Plateau sandstones prevent the development of niche caverns common elsewhere in Australia (Fig. 7; cf. Hughes 1978; Dragovich 1981; Thompson 1991; Viles 2005). Rockshelters on the plateau tend to develop horizontally following the planes of the strata, with the sandstone breaking down into fine particles, slabs or blocks, depending on the thickness of the bedding plane (cf. Mills 1981). Shelter initiation on the Arnhem Land Plateau appears to have been a subterranean process: a concentration of sub-surface moisture is captured in a layer sandwiched between two better-cemented layers, dissolving the matrix of the intermediary layer and initiating a cavern (Twidale 1980: 80, 83; Bremer 2010). The cavern retreat is halted by a lessening of the intensive subterranean weathering following the down-wearing of the surrounding etch plain. At some later period, the rocks are exposed as an overhang, and the cavern is then subject to either stabilising or further enlarging processes with continuous seepage along the base of the bedding plane. On the broad scale, shelter development occurred during the Tertiary when the climate was significantly wetter than during the subsequent Quaternary period (Smith 1978; Jones and Johnson 1985: 174; Young et al. 2009:

Figure 7. *Typical niche shelter in loosely cemented sandstone with near-spherical interior. Note the upward and backward parabolic retreat. Photograph RGG.*

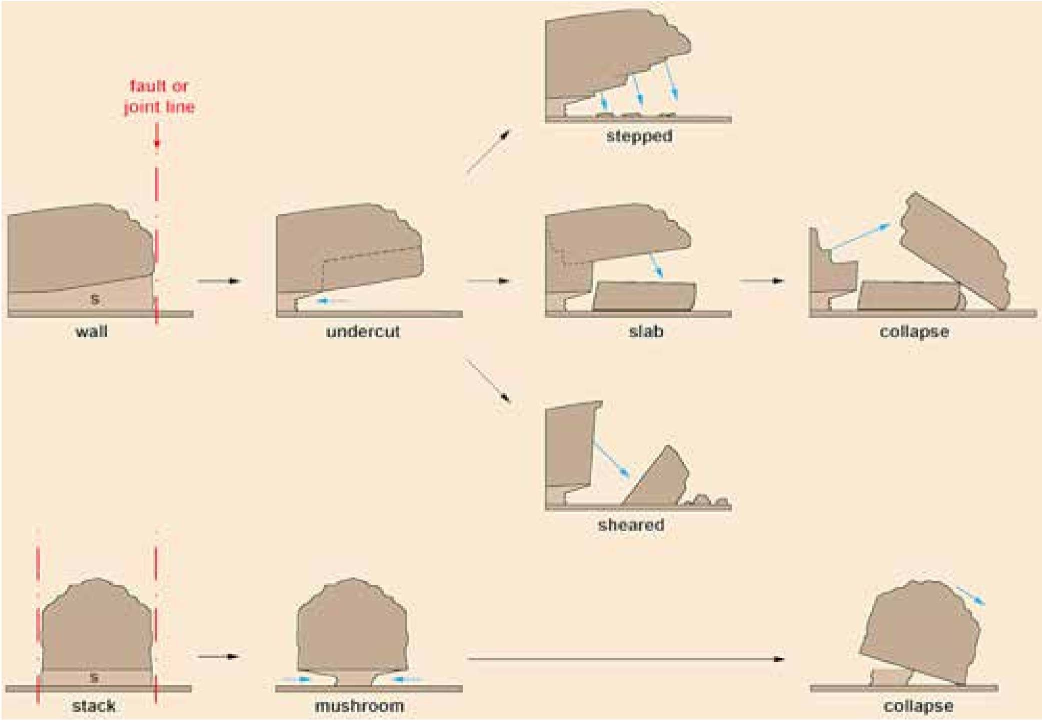

***Figure 8.** Model of the progressive development of shelter forms.*

99–100, 220–223). It is generally accepted that scarp processes, which include the initial development of shelters that undercut cliff faces, are intimately connected to periods of climate oscillations, although episodic events of exceptionally heavy rainfall during dry phases may replicate these conditions (Oberlander 1989: 68; Nott and Roberts 1996). Progression of the scarp has produced rockfall (blocks) which, over time at the geological scale, break down through erosion or are buried by the build-up of the surrounding soil; hence, their presence or absence is seen as an indicator of the stability of the overbearing cliff line (Matmon et al. 2005: 805). The undercutting of the wall-foot usually caused these collapses, triggered by tectonic activity, lightning or extreme rainfall events (Matmon et al. 2005: 805). Although of low frequency, even at a geological time scale, such collapses are the primary cause of landscape evolution (Stock and Uhrhammer 2010: 941). The lack of such tectonic activity over the past 120 million years (Nott 1995), and hence the notion of the plateau's general stability, is supported by the rarity of scree blocks seen below the escarpments in Jawoyn Lands.

After a time, the precipitation of mobile silica from within the rock forms a protective skin on and within the newer rock surface, which inhibits further shelter growth (Watchman 1991, 1992) until it is fractured or broken by earth movements, internal water pressure or other physical processes (e.g. gravity, human agency, fire). In such cases, the shelter will continue to enlarge until the rate of growth is again matched by the rate of deposition, at which point the new surface will again become protected and growth curtailed (Mabbutt 1977: 34–36). Consequently, most rockshelters on the Arnhem Land Plateau have formed as a result of progressive erosion of a more susceptible horizontal rock layer underlying a more stable layer (Fig. 8), with the resultant form determined by the amount of post-exposure erosion.

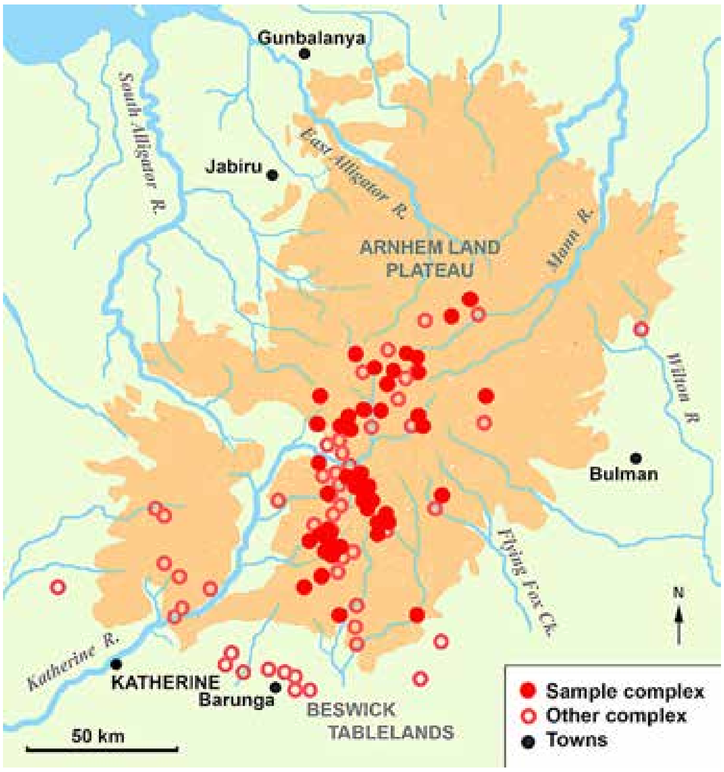

***Figure 9.** Distribution of site complexes sampled for shelter forms.*

The Jawoyn Rock Art Project and rockshelter classification

From 2005 to 2012, the Jawoyn Association supervised a rock art recording project across the Jawoyn Lands (Gunn and Whear 2007; Gunn 2016). These surveys were targeted on rock outcrops that form a feature of the Arnhem Land Plateau (Gunn et al. 2017) with a general aim to provide a roughly north-south transect. The project recorded 95 archaeological site complexes in the central and southern areas of the Arnhem Land Plateau and another 32 elsewhere within Jawoyn Lands (Fig. 9). All rock art shelters within a complex were recorded: very few shelters did not contain rock art. To quantify the relation of the erosion processes to its rock art, 45 site complexes (47%) were selected from the study area (Table 2). These 45 site complexes include 720 rockshelters with some 27 138 individual motifs recorded in the field. The site complexes analysed were selected to show the frequency of shelter forms and also to identify any north-south variations across the study area. While further rock outcrops with rock art are known within the study area and to the west of the study area, very few rock outcrops to the east of this area have been seen during aerial reconnaissance. Consequently, it is expected that the survey area is representative of the full suite of rock art site complexes within the Jawoyn Lands of the Arnhem Land Plateau.

Shelter form	Rock art surfaces
Undercut	Large but low horizontal ceiling
Stepped	Small but long and narrow horizontal faces
Slab	Large horizontal ceiling
Sheared	Medium-sized, flat vertical wall
Collapse	Various; but rarely large
Wall	Large vertical wall
Pillar	Horizontal ceiling and small vertical sides of pillars
Mushroom	Horizontal ceiling, irregular wall
Block	Various; but not large
Window	Horizontal ceiling, vertical walls
Cave	Various; including large ceilings

Table 2. *Summary of potential rock art surfaces for each shelter form.*

From our field observations of all site complexes recorded, 12 distinct classes of shelter form can be identified. These we term: undercut, stepped, mushroom, slab, sheared, blocks, pillars, wall, cliff, cave, window and collapse (Table 3, Figs 10 to 20). While many shelter alcoves will have developed through a mix of different erosional processes, most have a dominant shelter form that can typify the shelter for classification. The archaeological potential or limitations of the different shelter forms for human occupation and the production and preservation of rock art varies considerably. For example, a shelter with a horizontal ceiling over 1.5 m above its floor provides a greater area for occupation (standing room) and also provides greater protection

Shelter Form	Description	Fig. Nos	References
Under-cut	Tend to be long (>10 m wide) and relatively low (<2 m high), with a smooth, horizontal ceiling and irregularly textured rear walls. This development is initially a process of subterranean moisture attack, identifiable by substantial rounding of corners and edges. Following soil erosion, this weakened layer is exposed above ground where it becomes an outlet for internal moisture. This moisture continues the breakdown of the rock, increasing the depth and height of the undercut cavern.	10	Twidale and Campbell 2005: 66
Stepped	As the depth of a shelter increases, gravity draws on the ceiling, causing a *stepped* ceiling to form and producing a series of narrow hanging wall panels. The formation process is much the same as that of undercutting cliff erosion, albeit on a smaller scale. Depending on the size of the lamellar fragments falling from the ceiling, the stepping can be either thin (c. <2 cm) or thick (>5 cm). Thin stepping fragments are readily trampled into the sand, while thick fragments remain as broken debris on the floor or, in larger falls, as large slabs (see slab form below).	11	Oberlander 1989; Matmon et al. 2005; Yang and Yan 2009; Stock and Uhrhammer 2010
Mush-room	Where the erosion is continuous around a block or stack, the typical mushroom or pedestalled rock is produced, with the overhang surrounding a central core or stem. In Arnhem Land, these are not seen to be wind 'sand-blasted' features as they are invariably adjacent to similar-height escarpments or outcrops.	12	

Table 3. *Arnhem Land shelter forms (part 1).*

Slab	Where the layers are thick, a characteristic *slab* shelter is developed, with a horizontal ceiling, a near-vertical, smooth and coherent rear wall, and a rock slab-covered floor. The height and depth of the resultant shelter will largely be a function of the thickness and coherence of the collapsing sandstone layer.	13	
Sheared	Where the layers are very thick or massive, the ceiling collapse (due to inherent stresses, structural flaws or fabric imperfections) may shear through the outcrop, usually along a joint line, to produce a new, and usually a smooth vertical, rock face. These *sheared* forms can be either an inclined uncapped face, offering little in protection for any 'artwork' or, where an overhanging cap survives, a capped face, that affords a measure of protection to any rock art placed on the face below.	14A 14B	Young et al. 2009: 51*ff*
Block	*Blocks* are large rock slabs (or floaters) that have slid or tumbled down the talus following cliff failure; given a favourable inclination when they come to rest, they can create a protected rockshelter on their underside.	4, 15	Stock and Uhrhammer 2010: 944
Pillars	Pillar shelters are an unusual form derived from sandstone-karst formations (see Wray 1997b for a comprehensive discussion on sandstone karsts and their formation). As with conventional shelters, *pillar* shelters are initiated in a subterranean context but are a product of parallel subterranean solution tubes dissolving, expanding and partially merging (phantomisation), creating caverns with remnant pillar formations. These caverns are then exposed through soil erosion. The largest and most dramatic of the known Arnhem Land examples is the shelter of Nawarla Gabarnmang in the north of the Jawoyn Lands.	16	Jennings 1983; Wray 1997a, 1997b; Aubrecht et al. 2008; Delannoy et al. 2013, 2017
Wall	Near-vertical faces that developed around the margins of rock outcrops, mostly following joint or fault lines. These walls are comparatively stable and usually highly silicified, and tend to front onto a flat area of soil and vegetation. They were formed by water erosion as subterranean features rather than by the process of cliff retreat described above. Unlike most other shelter forms, these are well suited for the production and viewing of large-scale 'artworks'.	17	
Cliff	A particular and distinctive form of the wall form mostly found within a fault- or joint-formed gorge, most commonly along major waterways. Other cliff faces occur around the perimeter of the plateau where they can reach heights of 60 m. While the bedrock is inherently stable, in Arnhem Land cliff faces are prone to the deleterious effects of seasonal flooding events, whose pressure can attack both the base and top of the cliffs.	18	Young et al. 2009: 192–193
Cave	*Caves* develop through the enlarging of a single solution tube within sandstone karst-formations (described above), similar to the more common limestone tunnel caves. Unlike the latter, which can extend for kilometres underground, the sandstone caves so far recorded are of limited depth (<10 m). Caves are defined here as being deeper than twice their width.	19A	Young et al. 2009: 167–170
Window	*Windows* develop by the breaching of a narrow sandstone wall. The window formation is not a true arch, but rather an opening through a rock wall, usually with a broad mass on one side and a smaller pillar mass on the other. No true arch shelters have been located in the Jawoyn Lands of the plateau.	19B	Young et al. 2009: 100*ff*
Collapse	Collapsed rocks, rock-stacks and slabs are, like blocks, the result of prolonged erosion and/or past tectonic activity, with shelters made below randomly protected faces. Unlike blocks, however, these fallen rocks have not otherwise moved away from the location of their collapse.	20	

Table 3. *Arnhem Land shelter forms (part 2).*

for any ceiling pigment art than one with a sloping rear wall. *Window, cave, cliff* and *sheared* forms generally provide very poor environments for pigment preservation due to moisture passage through the rock induced by evaporation-accelerated capillary movement (window), moisture retention in enclosed environments

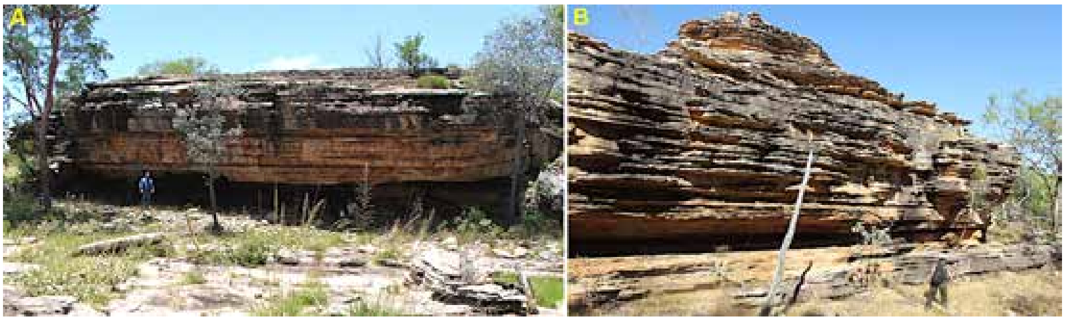

Figure 10. *Shelter forms: undercut. Photographs RGG.*

Figure 11. *Shelter forms: stepped. Photographs RGG.*

Figure 12. *Shelter forms: mushroom. Photographs RGG.*

Figure 13. *Shelter forms: slab. Photographs RGG.*

(cave), or prolonged exposure to tropical rain and/or solar impact (cliff and sheared, depending on shelter orientation and overhang depth) (e.g. Coye 2011).

Shelter geomorphology and rock art

The various rockshelter forms described above have particular qualities relevant to the production and preservation of rock art, particularly concerning the

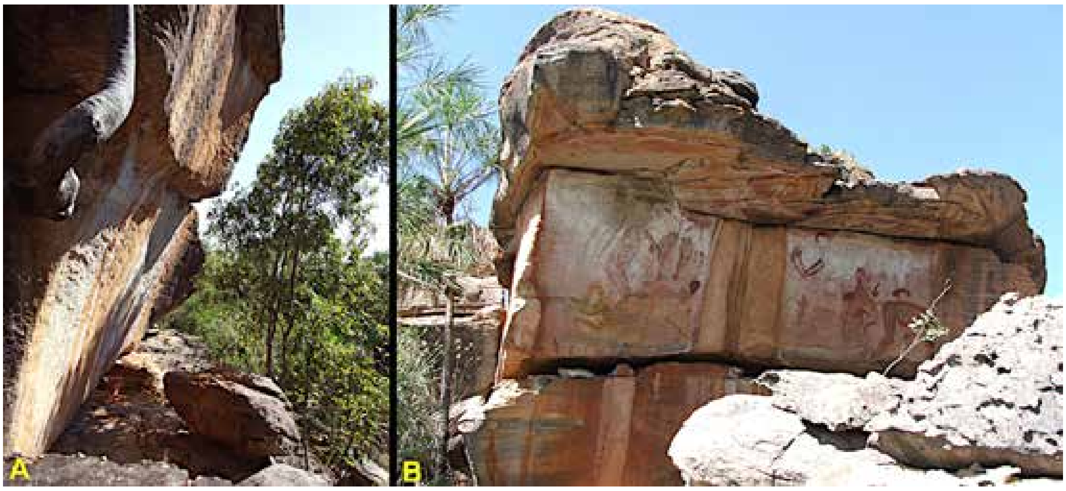

Figure 14. *Shelter forms: sheared. A: uncapped; B: capped. Photographs RGG.*

Figure 15. *Shelter forms: blocks. Photographs RGG.*

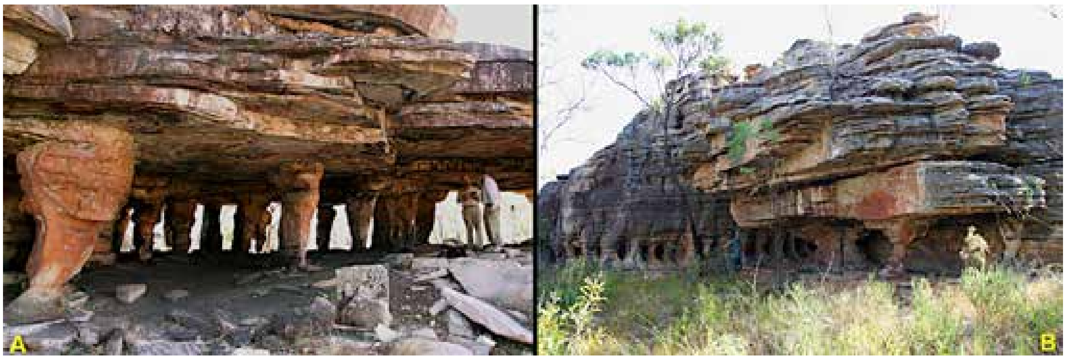

Figure 16. *Shelter forms: pillars. Photographs RGG and LCD.*

Figure 17. *Shelter forms: wall. Photographs RGG and LCD.*

Figure 18. *Shelter forms: cliff. Photographs RGG.*

Figure 19. *Shelter forms: A: cave; B: window. Photographs RGG and LCD.*

Figure 20. *Shelter form: collapse. Photograph LCD.*

availability and potential size of surfaces suitable for rock art production (Table 3).

Of the five landscape erosion forms identified above, *linear* and *stacks* are by far the most common (36% each), with the other three erosion forms together accounting for just 28% (Table 4). The percentage of both rockshelters and rock art motifs largely parallels that of the occurrence of erosion forms in the study area (Table 5). Hence, it appears that the form of landscape erosion (linear, stack etc.) was not a significant factor in either

Erosion form	**Shelter form** Undercut	Stepped	Slab	Sheared	Collapse	Wall	Pillar	Mushroom	Block	Window	Cave	Total	%
Linear	66	59	54	24	17	19	1	6	11		1	258	36
Stack	62	61	57	44	14	10		6	1	3		258	36
Block	23	28	17	8	9	3	24	2				114	16
Corner	27	24	15	3	13	2						84	12
Embayment	1		4			1						6	<1
Total	179	172	147	79	53	35	25	14	12	3	1	720	100

Table 4. *Erosion form numbers by shelter form.*

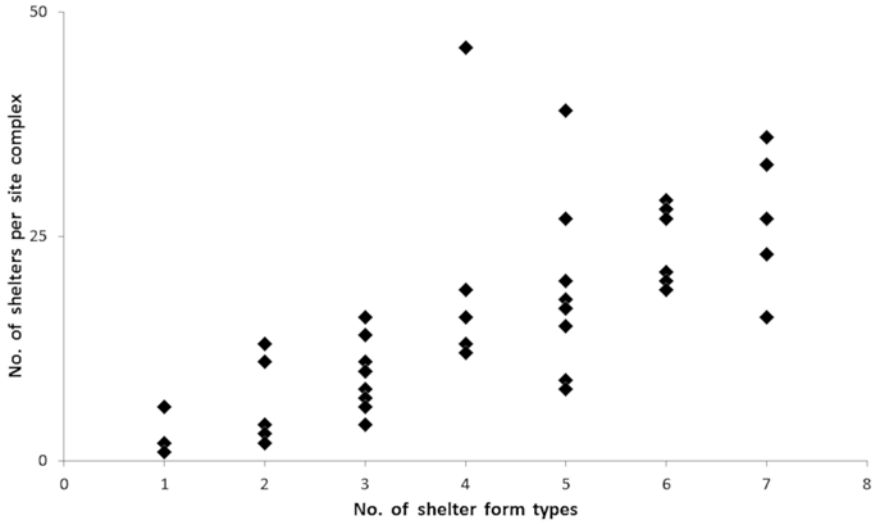

***Figure 21.** Number of shelter form types per site complex.*

Erosion form	% of erosion form	% of shelters	% of motifs
Linear	42	*36*	*36*
Stack	36	*36*	*31*
Block	13	*16*	*17*
Corner	7	*12*	*14*
Embayment	2	*<1*	*<1*
(n)	45	720	27 138

***Table 5.** Frequency of erosion forms.*

Shelter form	% of shelters	% of complexes
Undercut	*25*	*96*
Stepped	*24*	*62*
Slab	*20*	*76*
Sheared	*11*	*58*
Collapse	*7*	*44*
Wall	*5*	*40*
Pillar	*4*	*7*
Mushroom	*2*	*22*
Block	*2*	*7*
Window	*<1*	*4*
Cave	*<1*	*2*
Cliff*	-	-
(n)	720	45

*Although a small number of examples of cliff forms have been recorded within the study area, none occurred within the site sample used here.

***Table 6.** Shelter form frequencies.*

the survival of rock art here or for the selection of shelters for art production.

It was observed during the surveys that while a small number of small rock outcrops on the Arnhem Land Plateau contain shelters without rock art, the greater majority of outcrops do, and within these, almost all shelters contain galleries, panels, or at least traces of rock art. Outcrops with rock art also contain a range of other archaeological site types, some of which are open sites (such as lithic scatters, standing stones or scarred trees not within rockshelters), and hence are termed archaeological site complexes (cf. Vinnicombe 1984; Gunn 1997; Gunn et al. 2017). In general, the greater number of shelters per complex the greater variety of shelter forms present (Fig. 21), suggesting that the pattern of shelter forms present may be part of the broader retreat erosion process; a pattern that may reflect the variation in the concentration of water movement within the bedrock block. It also suggests that shelter form diversity per site complex is related to the quantity of rock art present. At this stage, however, it is seen that the number of rock art shelters per site complex is simply related to the number of shelters present, rather than their particular form (Gunn et al. 2017). Of the 720 'art' shelters sampled (Table 5), *undercut, stepped* and *slab* shelter forms are the most common both in overall numbers and in the number of complexes at which they are represented, with one or other occurring in over 60% of site complexes. *Collapse* and *wall* are also widely represented although fewer in number. The number of *pillar* shelters in Table 3 is considered an over-representation, as only three complexes with *pillar* shelters have been located in the survey area and all three fall within this sample; while others may exist, given the extent of the survey coverage, their overall numbers are likely to be very low.

Comparison of the range of shelter forms within each class of erosion form (Table 6) suggests that each erosion form contains a wide variety of shelter forms. All six of the widely distributed shelter forms (*undercut, stepped, slab, sheared, collapse* and *wall*) occur within all but the *embayment* erosion form class, which has only three of these six (*undercut, slab* and *wall*). Within most site complexes, however, one shelter form will be dominant. Hence, it appears that the processes of landscape erosion form and shelter form are not closely linked. The geomorphological reason for the location and variety of particular shelter form types within a site complex has yet to be addressed.

The length of the largest shelters within each of the shelter form classes varies considerably (12 m to 60 m). The smallest lengths and median values are similar for all types: overall range 1 m to 60 m; median 7 m (Fig. 22). From this sample there are only ten shelters with lengths over 25 m (1%), indicating that large shelters (>25m in length) are exceptional. This then suggests that shelter form is not a major factor in determining shelter length. The similarity in shelter lengths within all shelter form types suggests, therefore, that shelter size is a characteristic of the sandstone rather than of the particular shelter form.

The range of motif numbers within individual shelters varies considerably in each of the eleven shelter form types in this sample (from 1 to 1300; median 16) (Table 7). Excluding the exceptional site of Nawarla Gabarnmang with its 1300 motifs, the range drops from 1 to 619 motifs. Looking at the form of the shelters with the highest motif numbers from each site complex (Table 8) suggests that rock art production was more frequent in shelters with *undercut, stepped* or *slab* forms. These shelter forms are also the most common from the site sample (Table 7), and consequently, the pattern in Table 8 is likely to be largely a reflection of shelter form numbers and availability. The median number of motifs within *block, window* and *cave* forms is comparatively low, implying that these forms were either not conducive to rock art production or, at least, not conducive to pigment preservation, although again, these form types are only poorly represented in the site sample.

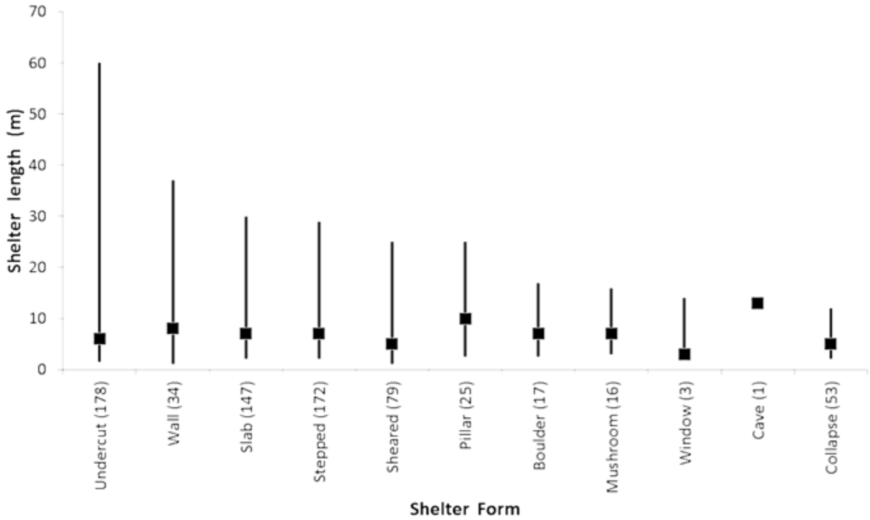

Figure 22. *Rockshelter lengths by form (maximum, minimum and mean). *Measurements for two shelters unavailable.*

Shelter form	Motif Nos			No. of shelters
	Minimum	Maximum	Median	
Pillar	1	1300	16	25
Stepped	1	619	16	172
Undercut	1	380	15	179
Slab	1	318	15	148
Wall	1	325	13	34
Block	1	174	7	12
Mushroom	2	137	36	14
Sheared	1	153	6	79
Collapse	1	102	9	53
Window	3	72	50	3
Cave	29	29	29	1

Table 7. *Range of shelter motif numbers by shelter form.*

The greater number of these major art production shelters are the largest or second-largest shelters within their respective site complexes (76%). Most of these shelters are ten metres or longer. The exceptional shelters tend to be at conspicuous locations, such as having ready access to, or being on, open rock pavements.

With regard to the timing of shelter development, Watchman (2004) found oxalate crusts over petroglyphs in a rockshelter within Kakadu National Park to be >8000 years old, suggesting to him that the 'processes leading to crust formation [within Kakadu] probably started in the late-Pleistocene or early Holocene when climatic conditions changed from cool and dry to warm and wet' (Watchman 1991; see also Jones et al. 2017, and Kershaw 1986 and discussion of climate below).

Periods of high rainfall occurred during the late Pleistocene (c. 22 000–18 000 BP) and the early- to mid- Holocene (c.12 000–5000 BP) (Nott and Price 1994; Reeves et al. 2013: 10). These wetter phases resulted in severe episodic erosion of the surface soils on the plateau (Nott and Roberts 1996), creating peak levels of moisture penetrating and weakening joint lines and bedding planes (cf. Twidale and Campbell 2005). These conditions would likely have caused an increased frequency of cliff failure and block collapse from the sandstone outcrops. Excavations of rockshelters on the plateau and its perimeter to the north, however, indicate that these shelters have remained relatively stable for at least 65 000 years (cf. Roberts et al. 1993; Roberts et al. 1994; Geneste et al. 2010; Clarkson et al. 2017). The Warton Sandstone in the Kimberley region of Western Australia, which houses much of the Kimberley's rock art, is similar to the stable quartzose sandstone of the Kombolgie Sandstone. Optically stimulated luminescence (OSL) dating of wasp nests on the Warton Sandstone indicates that rockshelter surfaces have been stable for more than 30 000 years (Yoshida et al. 2003). Hence, the major periods of cliff failure and block collapse most likely occurred during the early Pleistocene (up to c. 1.5 Ma) when, for prolonged periods, rainfall was up to 2.5 times that of the present day and temperatures 1–3°C higher (cf. Nanson et al. 1992; Sniderman et al. 2009); a time well before human occupation of the region. However, as some areas of the Arnhem Land escarpment are continuing to retreat today (Russell-Smith et al. 1995: 148), minor local examples of cliff failure have probably continued periodically throughout the Pleistocene and Holocene

Shelter form	No. of site complexes	%
Undercut	14	*31*
Stepped	12	*27*
Slab	9	*20*
Mushroom	3	*7*
Pillar	2	*4*
Sheared	2	*4*
Block	2	*4*
Wall	1	*2*
Total	45	

Table 8. *Highest motif numbers per site complex by shelter form.*

periods. Hence, while a small number of rockshelters may have been created during the Holocene period, and others collapsed since their use by Aboriginal people, the *vast majority* of rockshelters would have been created before the arrival of Aboriginal people into Australia at least 65 000 years ago, and have survived to the present day.

This is not to say that all of the rock art produced over the millennia of human occupation on the Arnhem Land Plateau still survives in its rockshelters. The deleterious effects of human, animal and natural agencies, especially water-wash on relatively recent rock art, have been well documented (Edwards 1979; Gillespie 1983). On account of the stability of the plateau sandstones, however, in rockshelters where environmental conditions are optimal, the rock art from the plateau's earliest pigment 'art' periods may continue to survive. The deterioration of pigment and individual motifs by shelter form is not taken up here as preservational factors can influence different sections within the one shelter. Overall, however, the present results indicate that shelter form is not a significant factor in rock art preservation.

Conclusion

Despite clear visual and geomorphic differences in the form of rockshelters in the Jawoyn Lands of the Arnhem Land Plateau, the results of this study found no clear link between shelter form and the quantity of rock art contained. This suggests that the preservation of rock art, and also the selection of shelters for the production of rock art, was not related to the form of the shelter.

Linear and *stack* erosion forms are the most commonly encountered in the study area, and shelters formed by the undercutting of a bedrock outcrop and the resultant ceiling collapse (*undercut, stepped* and *slab*) are the most common shelter forms, in number and site complex representation. In any site complex, if present, rockshelters of these shelter forms will be the major rock art shelters; being amongst the largest and containing the highest number of motifs within the complex.

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