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Investigating the Anthropic Construction of Rock Art Sites Through Archaeomorphology: the Case of Borologa, Kimberley, Australia

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Abstract
Archaeologists usually see, and understand, rock shelters as taphonomically active, but pre-existing, physical structures onto which people undertake a variety of actions including rock art. Our aim in this paper is not only to document the changes undergone by rock shelters but also to identify traces of anthropic actions that have intentionally led to these changes. Recent research in northern Australia provides empirical evidence that for thousands of years, Aboriginal peoples altered the physical shape of rock shelters by removing masses of rock to create alcoves, restructure internal spaces and create stone-worked furniture. Through archaeomorphological research, this paper presents evidence from Borologa in Australia's Kimberley region, where hard quartzite monoliths were shaped and engaged as architectural designs by Aboriginal people prior to painting many surfaces, making us rethink what have traditionally been distinguished as *natural* versus *cultural* dimensions of archaeological landscapes and rock art sites.

Keywords Archaeomorphology · Kimberley · Landscape architecture · Rock art · 3D modelling

Introduction

Like stone artefacts and other items of material culture, rock art offers insights into past cultural practices and their patterns and trends. Rock art has two great advantages over

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most other types of artefacts. First, its malleability and symbolism offer enhanced possibilities for an archaeology of cognition. Second, its fixity on rock allows for an archaeology of place, for a phenomenological archaeology of how people are connected in places. Yet despite being anchored on rock, by itself, the rock art only offers a partial avenue of enquiry into relations between people and the locations in which the art was undertaken. For rock art to be adequately informed on cultures of emplacement, we also need to venture beyond the art onto the place itself. Place is the where "on which the concrete things of a given landscape repose: where 'things' may be humanly constructed" (Casey 2001, p. 418). For such a place-based (in Casey's term "placial") archaeology to occur, and as previously argued by a number of researchers across the world (*e.g.*, Bradley 1997; Chippindale and Nash 2004; Gjerde 2010; Meirion Jones *et al.* 2011), we need to go beyond a myopic focus on the art, sundered from its surroundings, and look both more closely and more broadly at its physical settings. Here, we present an *archaeology of the materiality of place* by investigating in new ways how rock surfaces, sites and landscapes were socially engaged and, in doing so, how they were actively constructed at nested spatial scales. Our aim is to find out how, by engaging with their materiality, anthropic actions intentionally led to physical changes to sites.

Archaeomorphology: a Question of Method

At three large rock shelter and rock art sites in Australia (Nawarla Gabarnmang: *e.g.*, David *et al.* 2017; Delannoy *et al.* 2017), Spain (La Garma: Arias and Ontañón 2012) and France (Chauvet Cave: Delannoy *et al.* 2012, 2018), a closely integrated archaeological and geomorphological examination of the rock walls, ceilings, present floors and buried deposits found conclusive signs that people had profoundly altered each site's rock matrix more than 10,000 years ago. This signalled that the sites had not only been occupied or otherwise used, but that each site's material layout could be investigated as Pleistocene architecture engineered by both planning and cultural engagement. These findings alerted us of the need to study whole sites and landscapes as expressions of cultural design and social practice that could, in turn, shed more light on the meaningfulness of the rock art and smaller and usually more portable artefacts that they contain and that we are more accustomed to study.

In the case of Nawarla Gabarnmang, La Garma and Chauvet Cave, people were shown to have undertaken entirely unexpected activities. The physical structure of each site had been transformed. For example, pre-existing subterranean chambers and corridors were marked with piles of rock, sometimes to create underground pathways that demarcated appropriate means of passage, such as the placement of a stone step deep in a cavern at Chauvet Cave (*e.g.*, Delannoy *et al.* 2018). At Nawarla Gabarnmang, rock pillars and ceiling surfaces were manually removed, opening up the usable space and exposing new rock surfaces for painting (David *et al.* 2017; Delannoy *et al.* 2017). Such rock-workings from the deep past are sometimes easy to see, but often they are not, and require focused investigation of the spatial properties of both sites and objects. In such circumstances, archaeology alone does not suffice. Rather, an integrated archaeological-with-geomorphological study ("archaeomorphology") is called for, along with all the tools of enquiry that each discipline can bring (for further applications of archaeomorphology, see Barker *et al.* 2017; Jaillet *et al.* 2018; Monney and Jaillet 2019).

Archaeomorphology investigates human engagements with, and in, place by studying the spatial distribution, characteristics and life history of fixed and movable objects. It asks how one object in one place at a site relates to another in another place at that site or elsewhere across the landscape, and how they got to be where they are. For example, which part of a rock outcrop did a rock now lying on the floor come from, and what factors, including modes of transport, could have caused the rock to be in its current position? To do this, every object and set of objects are examined both archaeologically and geomorphologically, be it by one person with expertise in both fields or several researchers working and communicating in an integrated way on a shared question. Archaeomorphological research, in many ways akin to geoarchaeology, also differs from most approaches to the latter by treating the material world as socially engaged: the aim of archaeomorphology is to determine through combined archaeological and geomorphological methods the nature and effects of social and cultural engagements with the material world.

In addition to the standard archaeological and geomorphological skills it employs, an indispensable tool of archaeomorphology is three-dimensional (3D) laser modelling, which is used to investigate the layout of sites and objects and their changing configurations through time. These 3D models are made using short-range terrestrial laser scanning (TLS), enabling individual rocks to be digitally "picked up", rotated and accurately refitted onto the rock surfaces from which they originated (for technical information on how such 3D models are made using TLS, see Jaillet *et al.* 2018; for an example, see Barker *et al.* 2017). They enable the viewing and study of spatial patterns at scales not normally possible with more conventional means. For example, digital 3D models enable us to look "through" rock pillars and rock walls to compare floor configurations on either side (*e.g.*, David *et al.* 2017) or to ask how the development or removal of speleothems affected patterns of air flow through cave passageways and mineral accretions on their painted walls (*e.g.*, Delannoy *et al.* 2018). Most importantly, archaeomorphology explores how people may be implicated in physical changes to the place.

We here demonstrate the value of archaeomorphology to rock art research by undertaking a detailed study of two areas of Borologa 1, a densely painted rock shelter on a mushroom-shaped monolith in northwestern Australia's Kimberley region. Despite a rich ethnography and ongoing cultural knowledge of the art, much of the earlier rock art of this region is enigmatic, both in terms of its age and how it relates to past Indigenous cosmologies and site use.

Borologa in Its Landscape Setting

The Borologa rock shelters lie in Balanggarra Country, of the Kwini-speaking peoples of the east-central Kimberley region of northwestern Australia. The sites are on the northern bank of the Drysdale River, just at the exit of a deep gorge incised into the hard quartzites of the Warton Sandstone formation (Kimberley Group Lower Proterozoic; Gellalty *et al.* 1965) (Fig. 1). Topographically slightly higher than the

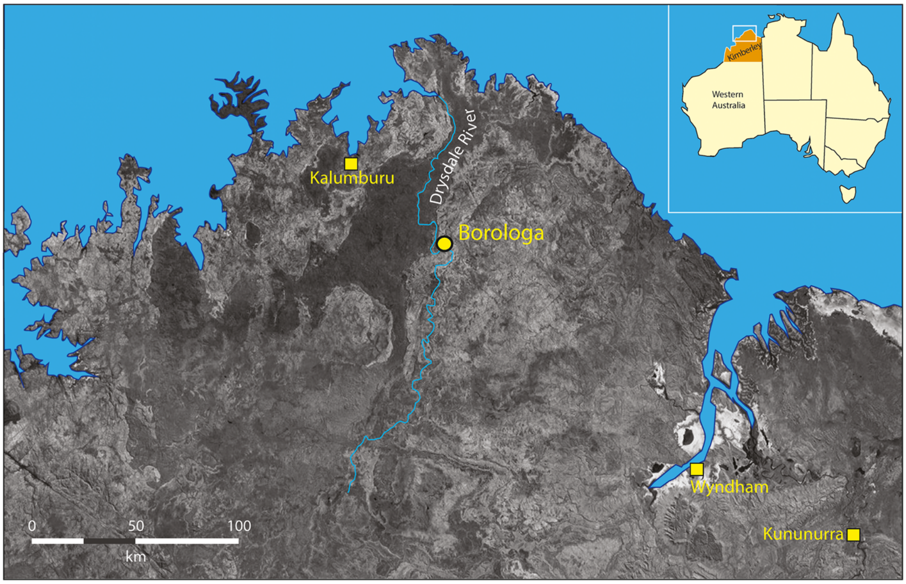


Fig. 1 Location of the Borologa sites, Drysdale River, Kimberley, Australia (artwork by Jean-Jacques Delannoy)

river, the Borologa site complex consists of three large quartzite boulders (Borologa 1–3), each with rock art on its walls under shallow overhangs (Fig. 2). The three shelters are at the base of an uneven, rock-strewn slope that emanates from a rocky escarpment above and that extends to the river below. The shelters are aligned at the base of the slope, slightly above an ancient alluvial terrace. That terrace is clearly evident on both sides of the river, testimony of a significant phase in the valley's geological history (Fig. 3).

Fig. 2 Location of the three Borologa rock shelters in their Drysdale River valley setting (photo: Jean-Jacques Delannoy)

Located behind the terrace, the Borologa rock shelters (geologically “floats”) eroded from the cliffline and came to lie in their current positions sometime after the Drysdale River/*marraran* (Kwini word for “river”) had already incised the valley, destabilised the slope and accumulated the flood deposits of the ancient terrace. The river’s wet season high water levels and dry season low levels are clearly visible below the site (Figs. 2 and 3). The protected position of the three shelters above peak floodwaters is further evident by the presence of accumulated aeolian sands at the mouth of the gorge and in front of Borologa 1, the eastern-most rock shelter. Here, a thick layer of wind-borne deposits has covered the upper levels of the ancient terrace. That aeolian sand layer also lies above the current floodplain, where it remains undisturbed by floodwaters (Fig. 3).

Borologa’s Rock Art

The three Borologa rock shelters are extensively painted (Fig. 4). Previous studies at the sites have been limited to descriptions of their motifs and art styles (*e.g.*, Welch 2015). Six major chronologically sequential rock art styles are currently broadly, but not universally, accepted for the Kimberley (see Veth *et al.* 2018): (1) cupules and other rock markings, which are thought to date from the earliest to recent times (see also Taçon *et al.* 1997); (2) Irregular Infill Animal; (3) Gwion Gwion, consisting of

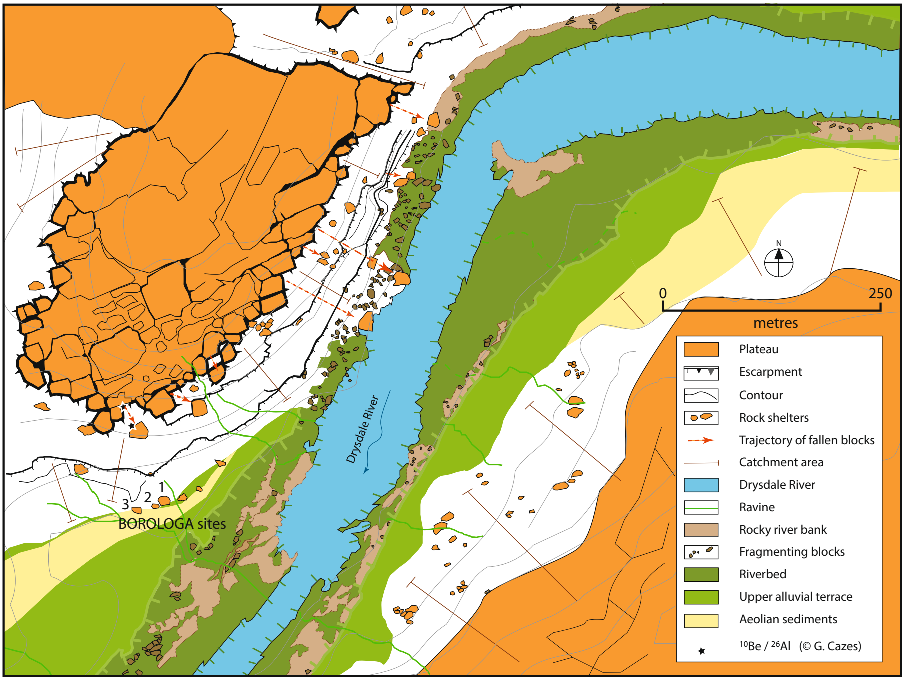


Fig. 3 Landscape features downstream of the Drysdale River gorge, showing the location of the Borologa sites (cartography by Kim Genuite)

generally thin vertical anthropomorphs depicted with elaborate paraphernalia often thought to indicate ritual regalia (also known as “Kiro Kiro”, “Kuion” and “Gwion” figures, which occur in Tassel Gwion Gwion, Sash Gwion Gwion, and Elegant Action Figure variants, the latter depicted with little ritual regalia and often occurring in composed groups); (4) Static Polychrome; (5) Painted Hand; and (6) Wanjina (also “Wandjina”), being large solid-bodied figures usually aligned horizontally, with distinctive crescent headdresses and faces with prominent eyes (Welch 1993, 2016). A further style, Kimberley Stout figures, has recently been proposed and situated sometime between Gwion Gwion and Static Polychrome, but its chronological relationship to Elegant Action Figures remains unknown (Gunn *et al.* 2019). Although some absolute ages have been obtained for elements of the overall sequence (*e.g.*, Finch *et al.* 2019), the validity of the full sequence itself remains speculative, especially as degrees of contemporaneity have not yet been adequately explored (*cf.* David *et al.* 2019; Ross *et al.* 2016).

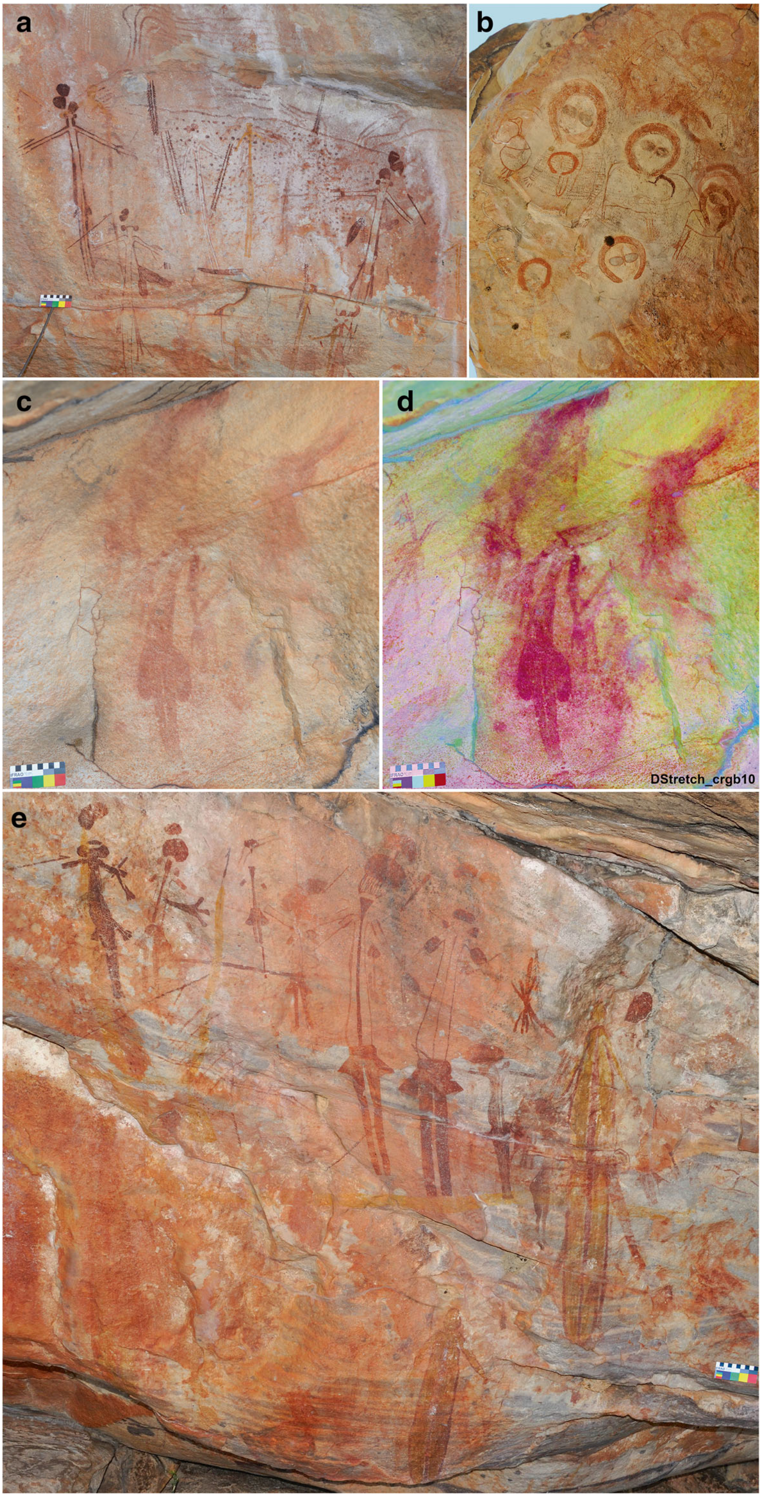
The three adjacent art shelters at Borologa are all on “floating” rocks of differing sizes and quantities of art, much of which is poorly preserved. Borologa 1, the largest and most decorated, has 446 individual motifs on 40 distinct art panels that extend to all sides of the boulder except the northern, weathered side. The distribution of motif styles is as follows:

- Irregular Infill Animal figures are represented on four art panels.
- Tassel Gwion Gwion figures occur on two art panels on each of the eastern and southern sides.
- Elegant Action Figures are on two art panels on the western side.
- Static Polychrome figures are on three panels also on the western side.
- Painted Hand figures occur on two art panels on the eastern side.
- Wanjina figures occur on nine panels on various sides of the boulder, on walls, ceilings and blocks (*e.g.*, Fig. 4b).

Borologa 2 contains three art panels with 12 motifs on its western and southern sides, all of which appear to be Tassel Gwion Gwion (*e.g.*, Fig. 4c, d). Borologa 3 has seven art panels with *c.* 120 motifs on its western side. Static Polychrome figures (Fig. 4e), similar to those at Borologa 1, dominate a repertoire of otherwise largely unclassified images.

At Borologa 1, a major panel (art panel B1) contains numerous superimposed Wanjina paintings on an overhanging ceiling. Archaeological excavations were undertaken under this overhang in 2016 and 2017, with the aim of finding now-buried exfoliated or otherwise collapsed pieces of rock and associated archaeological deposits that could shed light on the art’s antiquity (David *et al.* 2019). Adjacent archaeological excavations were also undertaken in 2016, at the edge of that same overhang. In addition to archaeological evidence such as stone artefacts and occupational horizons,

Fig. 4 Examples of rock art panels from Borologa. **a** Art panel E4 dominated by Static Polychrome figures, Borologa 1. **b** Art panel B1 dominated by Wanjina figures, Borologa 1. **c** Art panel B1 dominated by Tassel Gwion Gwion figures, Borologa 2. **d** Art panel B1 (Borologa 2) after D-stretch enhancement. **e** Art panel G dominated by Static Polychrome figures, Borologa 3 (photos and digital enhancement by Robert Gunn and Leigh Douglas)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individually and together each of these excavations revealed useful details on the history of the site's rock matrix, including the rock surfaces that now bear the paintings (see below).

How the Borologa Sites Attained Their Present Positions and Configurations

The three Borologa sites differ in size and topographic position from many of the other rock shelters on the edge of the plateau. The Borologa boulders, like those further upslope, originated from the collapse of rock escarpments further up the plateau. Some of these boulders are particularly imposing, measuring hundreds of cubic metres, as are sets of adjoining boulders that have calved from clifflines and rolled or slid a few tens of metres downslope.

More modest in size (5–6 m high), the Borologa 1–3 boulders align along the foot of the slope. They all sit on a bedrock surface that appears to have acted as a landing platform, blocking their further downhill movement (Genuite 2019) (Fig. 5). This bedrock surface backs slightly above the ancient alluvial terrace, indicating that it was probably formed during an earlier phase of incision by the Drysdale River.

Even though they are relatively well aligned compared with the tilted blocks further up the slope, there are slight but important differences in the layout of the three Borologa boulders. Borologa 2 and 3 are both strongly tilted downwards towards the thalweg (the line of the lowest elevation of the valley floor of the Drysdale River), following the same direction as the slope on which they sit. This orientation is not as pronounced at Borologa 1, and that difference had important implications for the development of overhangs and human habitability (Fig. 6). Borologa 2 and 3 thus contain low, shallow overhangs (0.8–1.2 m from bedrock to overhang), whereas Borologa 1 developed a much higher (1.8–3.0 m), wider (5 m from overhang to back wall) and longer (7 m length along the overhang parallel to back wall) overhang facing the river. A small overhang facing Borologa 2 also formed at Borologa 1. It is in the voids under these overhangs that Borologa's many extant rock paintings are found.

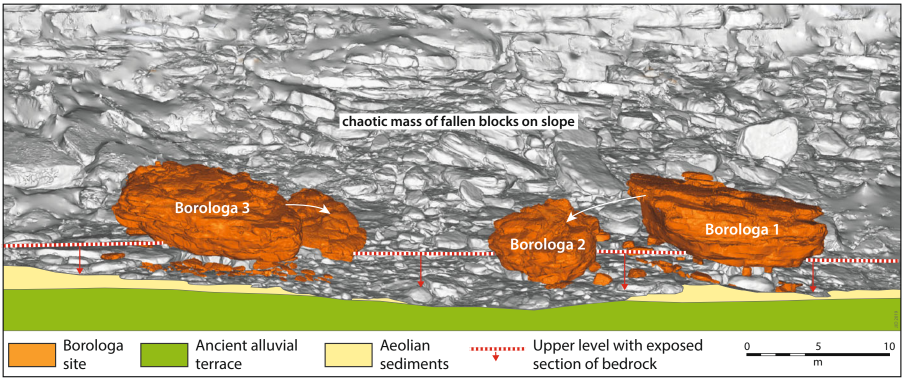

Fig. 5 Geomorphological context of the three Borologa sites (artwork by Jean-Jacques Delannoy and Kim Genuite)

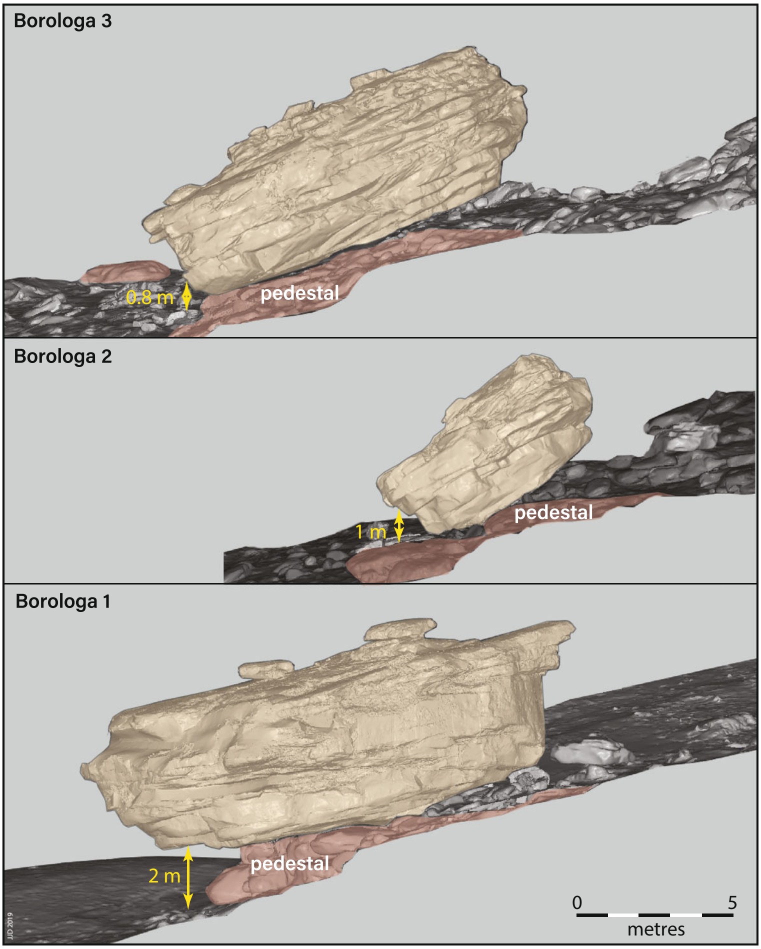

Fig. 6 Comparative topography of the three Borologa boulders (artwork by Jean-Jacques Delannoy)

Fine sediments of alluvial and/or aeolian origins are only present on the downslope periphery of the three rock shelters. Upslope to the side and back are many blocks either tumbled down the slope or detached from the edges of the rock shelters themselves. A large boulder near the eastern edge of Borologa 3 thus came from the latter when an overhang collapsed, in much the same way that Borologa 2 became detached from Borologa 1 and subsequently tilted until it came to abut against the bedrock (Fig. 5). In each case, the boulder became isolated and attained its present position in the landscape sometime before the rock paintings were made on the current walls of Borologa 1 and 2. We know this because in both sites, the art could only have been made after the now-painted rock walls of the outer overhangs came into existence. This tells us that when the first paintings were made, the orientation and landscape setting of the two sites were much like they are now.

Many large blocks can be seen under the outer edges of the overhangs at each of the three Borologa sites, with the exception of the major overhang at Borologa 1. This exception is also the overhang that contains the most densely painted ceiling, art panel

Fig. 7 Southern side of Borologa 1. It is along this edge that the overhanging ceiling of art panel B1 developed. Note the paucity of blocks on the floor under and in front of the overhang, in contrast to the rock debris on the eastern side (photo by Jean-Jacques Delannoy)

B1 with its many Wanjina paintings (Fig. 7). Here, the few small blocks on the sandy floor are incommensurate with the considerable mass vacated under the extensive flat ceiling. Had that cavity already formed when the Borologa 1 boulder landed in its current position at the base of the hill? Or are the collapsed blocks buried beneath in soft sediments? If they are buried in stratified deposits, can we date their collapse? And how does the history of human occupation and of the art articulate with the ceiling's collapse? To answer these questions, archaeological excavations (David *et al.* 2019) and archaeomorphological investigations were undertaken under the edge of the painted ceiling.

Evidence from the Archaeological Excavations

Three pits were excavated[1] in 2016–2017. Contiguous squares C5–C6–D5–D6–D7–DV–DIV were positioned beneath art panel B1, and squares E4, F5 and G5 along the outer edge of the overhang (Fig. 8) (see David *et al.* 2019 for details of excavation methods).

Square F5 proceeded to 1.5 m depth where large blocks of quartzite were reached, inhibiting further excavation (Fig. 9). The blocks are each tens of centimetres long and wide and range from 46 cm (block 2 in Fig. 9) to > 30 cm (block 4) in thickness. Blocks 1 and 2 lie vertically, whereas blocks 4 and 5 appear to be inclined along an old surface sloping down towards the south. This is confirmed by a layer of gravel that is also

[1] Squares C5-C6-D5-D6-DV-DVI-D7 were excavated by Bruno David; squares E4, F5 and G5 were excavated by Peter Veth and Sven Ouzman, as part of the Australian Research Council's *Kimberley Visions* Linkage project.

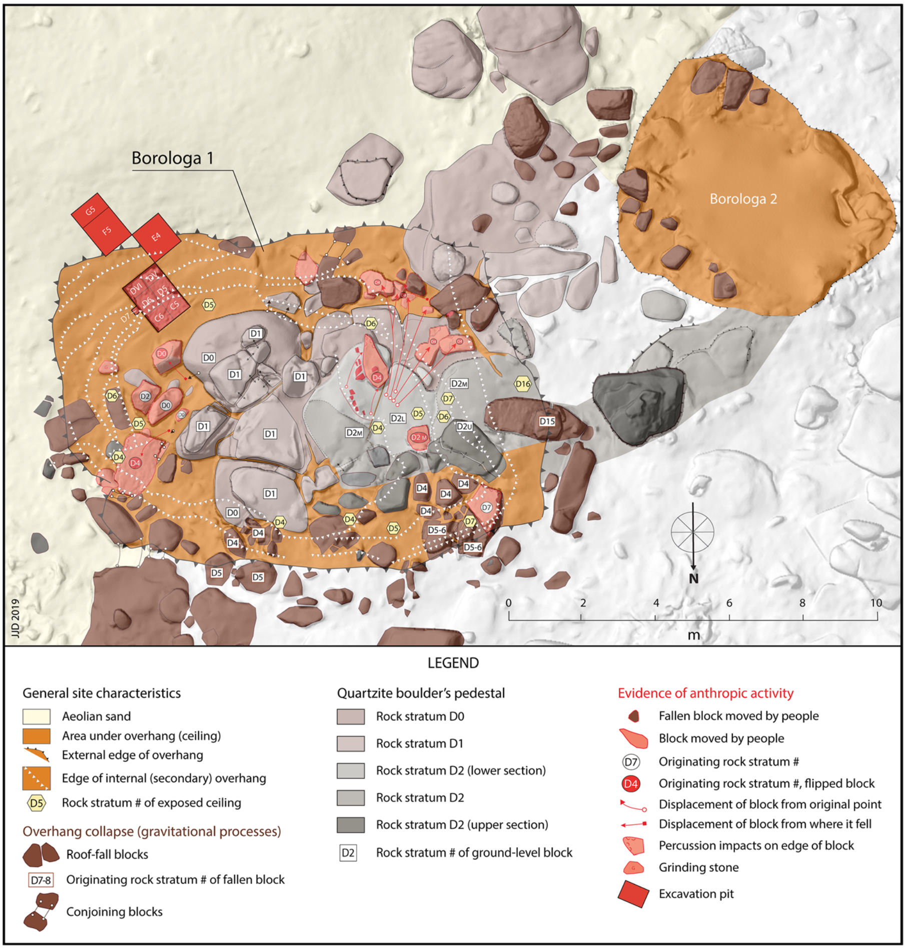

Fig. 8 High-resolution archaeomorphological map of Borologa 1 (artwork by Jean-Jacques Delannoy)

inclined towards the Drysdale River ("6" in Fig. 9). While the gravels each measure a few centimetres long, their size increases with depth ("7" in Fig. 9). Both gravel components in Fig. 9 lie in a layer of coarse sand. Beneath the layer of gravel, blocks 1 and 2 lie in compact sand with rounded ferruginous pisolites and quartzitic nodules with rounded edges.

The middle and upper parts of the sequence consist of horizontal layers of fine aeolian sand that overlie the angled layers. A thin horizontal layer of relatively homogenous gravels with angular edges occurs at *c.* 60–65 cm depth.

The composition and orientation of the sediment layers indicate that

1. Blocks 1 and 2 collapsed from an ancient overhang of Borologa 1. That overhang has retreated northward as a result of the collapse. The vertical positioning of these blocks indicates that the floor level downslope (towards the Drysdale River) was considerably deeper, and possibly steeper, than it currently is.

Fig. 9 Details of the geomorphology of square F5 (artwork and photos by Jean-Jacques Delannoy)

2. The sandy and rocky sediments between and above blocks 1 and 2 show that those sediments had remained exposed to the elements for some time. The rough surfaces and rounded morphologies of the quartzite gravels indicate that they have weathered over a long period, while the presence of ferruginous pisolites ("buckshot gravel") suggests that they lay near the surface for a considerable time for soil development. The rounded upper surface of block 2 resulted from weathering while exposed to the elements.
3. The southern edge of Borologa 1 experienced a second collapse, as indicated by the presence of large blocks (blocks 3, 4 and 5) and other smaller rocks ("6" in Fig. 9) resting in angular discordance on the underlying blocks and sandy matrix rich in pisolites. The angle of both the gravel surfaces and the layer in which they lie indicates a slope of 10–15° dipping towards the south. The angled edges of block 3 and other blocks of similarly moderate size were formed by fragmentation

during the collapse of the old overhang. This contrasts with the rounded edge of the visible parts of block 4, which came from the outer edge of the former overhang that had weathered as a result of exposure to the elements.

4. Following the deposition of a layer of smaller gravels ("7" in Fig. 9) over the collapsed blocks and gravel slope, sedimentation changed significantly. Aeolian sands now become predominant, with 80–100 cm of sand covering the underlying rocky layers in square F5. These sands accumulated as a result of the "Venturi effect" caused by the nearby gorge, being the increased pressure and velocity that resulted when fine particles of sediment were forced by wind through the gorge, redepositing as winds slowed down at the exit of the gorge. Aeolian sands continue to be deposited in this manner today, especially during the dry season when strong winds blow down the valley.

Square F5's stratigraphy thus brings initial answers as to why rockfall is absent beneath and beyond art panel B1's overhang: the rocks are now buried by sand. The Borologa 1 boulder had clearly undergone changes after landing in its current position. The buried layers show that two phases of overhang collapse took place; these events are relatively old, as suggested by their successive coverage by aeolian deposits. But, this is only the start of what we can say, as the stratigraphy in the neighbouring excavation squares, together with the distribution of other rocks to the north of the sand sheet, reveals additional details.

This first set of observations is replicated by the sequence in square E4 and contiguous squares C5–C6–D5–D6–DV–DVI–D7, closer to art panel B1 (Fig. 10). Here, the base of the excavations again reveals blocks collapsed from an old overhang (square E4) and from an ancient ceiling (squares DV–DVI–D5–D6–D7–C5–C6) that correspond with the second phase of collapse evident in square F5. Across all the excavated squares, these rocky layers angle down southward towards the thalweg of the Drysdale River, as previously noted for square F5. Similarly, the gravels visible at the base of square E4, continuing into square F5, begin immediately below the edge of the site's current overhang. The gravels are largely absent from the mass of collapsed blocks that came from the ceiling above squares DV–DVI–D5–D6–D7–C5–C6. This spatial partition of the gravels indicates that they mainly resulted from erosion (gravitational collapse, thermoclastic exfoliation, *etc.*) of the upper surfaces and outer edge of the overhang. This is due especially to the weakening of the edge of the shelter following collapse of the old overhang (process of mechanical readjustment), and not from the formation of the cavity and ceiling that now houses art panel B1. The production of these gravels corresponds with a specific phase in the site's evolution: their near-absence in the overlying aeolian sands indicates a marked slowing down of the boulder's geological breakdown. The onset of pronounced aeolian sedimentation under the overhang and in front of the site also marks a major phase in the environmental and geomorphological history of the broader landscape. Aeolian sand accumulation at the site potentially relates to decreased strength of the Indonesian-Australian summer monsoon in the Late Holocene (Denniston *et al.* 2013), with "very dry conditions" interpreted for the Kimberley from coarsely dated pollen records after *c.* 2750 cal BP (McGowan *et al.* 2012, p. 2) and from oscillations in the wet-dry phases of mound springs after *c.* 2600 cal BP (Field 2010; Field *et al.* 2017).

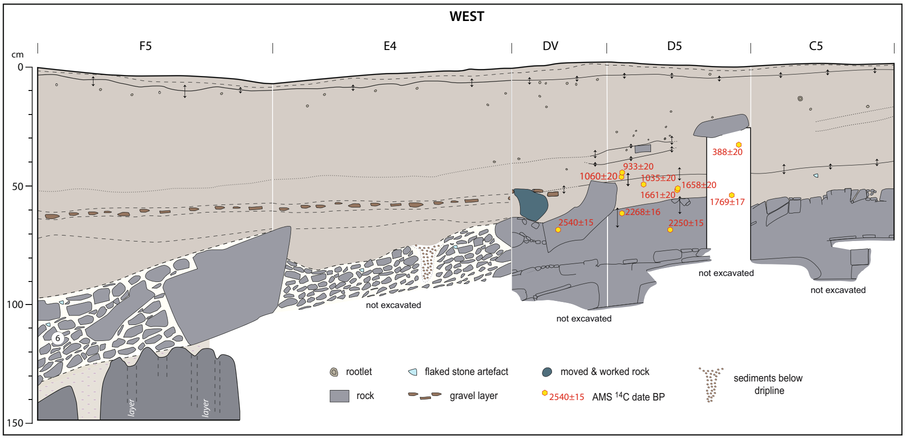

Fig. 10 Stratigraphic drawing of the west wall of squares F5–E4–DV–D5–C5, with back-plotted radiocarbon ages on individual pieces of charcoal (artwork by Jean-Jacques Delannoy, Bruno David and Kara Rasmanis)

Archaeological Evidence from Squares DV–DVI–D5–D6–D7–C5–C6

Further details can be gleaned from the archaeological excavations. Evidence of human activity was found in all the excavations extending down to the base of the excavated soft deposits. Here, the horizontal layer of angular gravels in the aeolian sands of squares E4 and F5 is associated with a period of occupation dated to *c.* 1000 cal BP (David *et al.* 2019). At 60 cm depth, squares D5–D6–DV–DVI also revealed a 60-cm-long × 55-cm-wide × 27-cm-thick, 186 kg quartzite block with flat surfaces which is clearly distinguishable from underlying collapsed blocks in four ways (Fig. 11). First, the block sits horizontally in the aeolian sand layer (stratigraphic unit 4). Except for the thin layer of gravel noted previously for square F5, no rocks other than stone artefacts occur in the aeolian sands above the rockfall layers in any of the excavation pits. Second, there are clear anthropogenic flaking impact scars along its lower edge. Third, it has an extensively ground and red ochre-stained upper surface, on which is also found a small, *cupule*-like hollow. Fourth, it has also been moved from elsewhere by people and horizontally set and stabilised with chock rocks on the flat sandy floor immediately in front of art panel B1, sometime between 2110 and 2370 cal BP (David *et al.* 2019).

The archaeological excavations revealed the presence of camp fires immediately above the collapsed strata of the old overhanging ceiling at the base of squares DV–DVI–D5–D6–D7–C5–C6. Here, charcoal is present, and the surface of the rock is burnt black and strongly reddened for some depth and exhibits heat-cracking. Radiocarbon dating of charcoal on the rock surface at the very base of the sand layer effectively dates both the antiquity of this occupation phase and the commencement of aeolian sand deposition to *c.* 2500–2700 cal BP, with the collapse of the underlying ceiling slabs taking place sometime earlier (David *et al.* 2019). This onset of aeolian sedimentation *c.* 2500–2700 cal BP at Borologa 1 corresponds well with a period of peak aridity beginning *c.* 2600–2750 cal BP across the Kimberley (Field 2010; McGowan *et al.* 2012; see above). This means that the physical setting fronting art panel B1 was slightly different to now, as the floor consisted of large collapsed rock slabs with expansive flat

Fig. 11 Large grinding stone moved, positioned and stabilised horizontally with chock blocks under one corner, squares C6–D6–DVI (photos and artwork by Jean-Jacques Delannoy)

surfaces. Those collapsed slabs came from the ceiling or outer southern side of the overhang. The height from floor to ceiling was then much greater than the height of the alcove of art panel B1 is today. The distance to the ceiling has gradually decreased as aeolian sediments have built up underfoot.

Bayesian modelling of the radiocarbon ages indicates that this part of the site then saw a series of occupational events dated to within 2110–2370 cal BP, 1160–2080 cal BP, 760–1110 cal BP, 500–630 cal BP and 120–480 cal BP (David *et al.* 2019). Each of these occupational phases was separated by a hiatus variably lasting between 110 and 660 years. The past 500–630 years saw much shorter spacing between occupations, within an archaeological timescale at times giving the appearance of near-continuous occupation.

Finding out what the site looked like during its various phases of occupation requires additional information on where the buried and surface blocks came from. This is the subject of the next archaeomorphological analysis.

Archaeomorphological Investigations

The paucity of blocks under the overhangs of the three Borologa boulders leads us to question how the blocks that do occur got there. To do so, the thickness, petrographic characteristics and joints (*e.g.*, frequency and amplitude of ripple marks) of each rock stratum making up the boulders were analysed in the field. In addition, in the laboratory thin sections, mineralogical characterisations and quantifications of major chemical elements were made of rock strata considered of special importance for this study (Appendix Table 2; Fig. 12; Delannoy *et al.*, in preparation).

The Large Excavated Grinding Stone

The bedrock base (rock strata D0–D2) at Borologa 1 is lithologically distinctive from the overlying boulder's rock strata (D4–D25). Although today it is hardly visible, rock stratum D3 belongs with the latter and constitutes its base. In contact with the underlying bedrock, it has been strongly compressed by the weight of the overlying rock mass.

None of the excavation squares reached bedrock, as boulders at the base of the squares prevented further excavation. Given that the bedrock is deeper and thus precedes the layer of aeolian sands and underlying rockfall, at least 2 m of bedrock would have been exposed to the elements prior to the collapse of the outer overhang of art panel B1 (Fig. 12).

Petrographic analyses were also undertaken on the blocks found on the present ground surface and in the excavations, enabling them to be matched with the Borologa 1 boulder's rock strata (Fig. 13). The large blocks at the bottom of square F5 correspond with an old overhang that extended considerably further out along rock strata D13 and D14 than is the case today. Their stratigraphic positioning indicates that the thick rock stratum D13 underwent a first episode of gravitational collapse, with

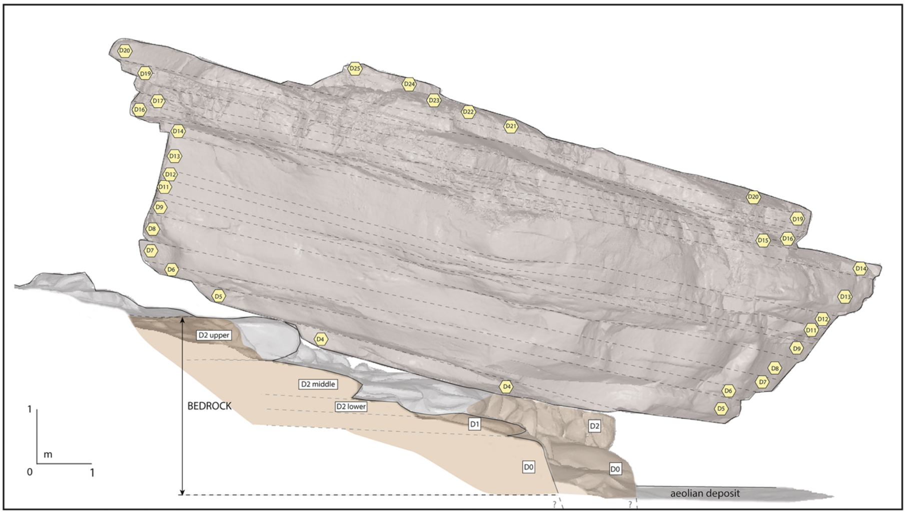

Fig. 12 Side view of the west of Borologa 1, showing the boulder's rock strata (D4–D25) that sit on those of the underlying bedrock (D0–D2U) (artwork by Jean-Jacques Delannoy)

collapsed blocks rolling down a slope that was much steeper than it is today. A second collapse, mainly of rock stratum D14, led to the retreat of the overhang to approximately where it is today. The sloping sediments of the angular gravels in the lower levels of square E4 sit over the blocks at the base of squares F5 and DV–DVI–D5–D6–D7–C5–C6 (Fig. 13). This suggests that the gravels were deposited soon after overhang collapses involving the lower (D5–D6) and upper (D14) rock strata, as well as after the fall of a section of the rock stratum D4 ceiling that once covered part of art panel B1. The gravels seen in the excavations represent a mechanical readjustment of the edge of the overhang, mainly at rock strata D12 to D7. The morphology of Borologa 1's southern overhang, along with its Wanjina art panel B1 ceiling, largely formed after these undated collapses, but before the aeolian sand layer had begun to accumulate (*i.e.*, sometime before *c.* 2500–2700 cal BP).

The large grinding stone revealed in excavation squares D5–D6–DV–DVI (Fig. 11) has the same thickness, highly compacted fine quartz grain matrix and light shade without dark venules as rock stratum D6. But, its isolated position and artificially raised flat orientation on an ancient archaeological floor signal that it does not lie in its original position. Initially, we suspected that it may have originated from rock strata D5 and D6 of the overhang immediately above it. But, these rock strata had collapsed during earlier times, prior to the accumulation of the aeolian sands in which the block now lies. And, those collapsed rock strata D5–D6 stretched uninterrupted across the base of the

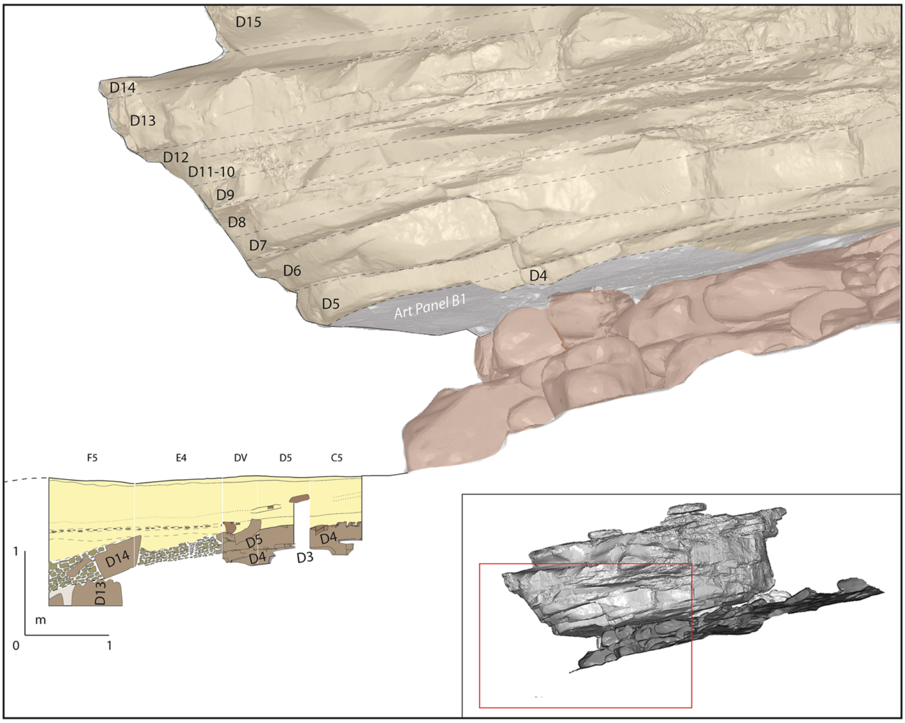

Fig. 13 Stratigraphic drawing of excavation squares F5–E4–DV–D5–C5 under and beyond the extant southern overhang of Borologa 1, showing which rock strata the buried roof-fallen blocks came from (artwork by Jean-Jacques Delannoy)

square DV–DVI–D5–D6–D7–C5–C6 excavation pit, so it could not be duplicated by the isolated block higher up in the sand layer. The stratigraphic sequence in adjacent squares E4 and F5 also showed that here, there are no signs of rock strata D5 and D6 beyond the lower part of the ancient overhang (Fig. 13). Moreover, there is no trace of the reddening (other than surface traces of ochre) on the large grinding stone, which had affected all of the collapsed rock stratum D5–D6 surface below the aeolian sand in squares DVI–D5–D6–D7–C5–C6. We thus looked elsewhere for the origin of the large grinding stone.

Three metres to the west of squares DVI–D5–D6–D7–C5–C6, collapsed blocks from rock stratum D6 can be seen on the floor beneath the remnant overhang (orange blocks in Fig. 14). These blocks are either stuck in a recess at the base of bedrock stratum D0 or found among a rocky extension of this bedrock stratum slightly to the south. The fallen blocks have the same geological characteristics as the large grinding stone found in the excavation. With the aid of the 3D laser model, the individual collapsed blocks on the floor, along with the grinding stone found in the excavation, were digitally extracted, measured and repositioned onto their matching surfaces as unambiguously conjoining refits (Appendix 2). In doing so, the relative chronology of the collapsed blocks could be worked out by their relative positions in the now-reassembled palaeo-overhang. This made it possible to determine that the large grinding stone found in the excavations (block A in Fig. 14) conjoins perfectly with block B as part of a larger set of collapsed blocks that together refit onto the rock stratum D6 scar on the extant overhanging ceiling.

Archaeomorphology conclusively shows that block A had been moved a distance of at least 3 m sometime following its collapse from the boulder and positioned flat with the aid of chock rocks on the ground surface immediately in front of what is now art panel B1. No other collapsed block from rock stratum D6 possesses cupule-like depressions (which could theoretically be found as dissolution marks on rock surfaces),

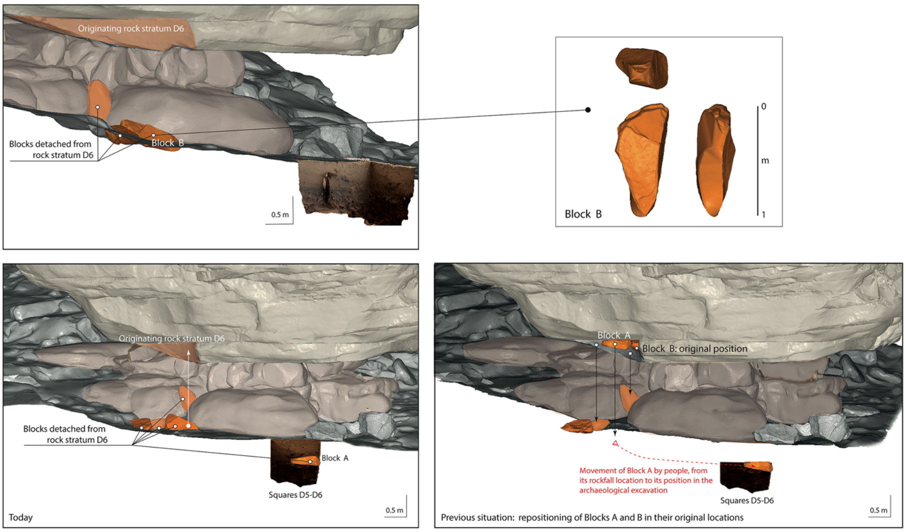

Fig. 14 Repositioning of the large grinding stone buried mainly in square D6 onto its originating rock overhang 3 m away (artwork by Jean-Jacques Delannoy)

further supporting the anthropic nature of the shallow cupule on the ground and ochre-stained surface of block A. No transport agent other than people could have carried and balanced the rock to its position as found in the excavation.

The Blocks on the Eastern Slope of Borologa 1

The blocks lying on the present floor of Borologa 1 were investigated following the same methods. Our aim was again to determine where they came from and how they got to lie in their current positions, so as to better understand both their and the Borologa 1 boulder's formation history.

Geomorphological mapping of the Borologa landscape (Fig. 15) revealed a range of rocks along the Drysdale River's northern bank. As noted, Borologa 1–3 constitute the front of a complex of massive boulders that slipped down the slope towards the ancient thalweg of the Drysdale River. We note that the bedrock surface on which the three boulders came to rest descends towards the Drysdale River in a series of stepped benches. Although alluvial and then aeolian sediments largely conceal this underlying bedrock, a small gully descending down the slope reveals the outcropping bedrock and further confirms that nowhere does the base of the Borologa 1 excavation squares correspond with the level of the bedrock (Figs. 15 and 16).

At Borologa 1, collapsed blocks are found mainly along its northern and northeastern perimeter. We note the presence of many collapsed blocks along the edges of Borologa 2 and 3. There are few such blocks between Borologa 1 and Borologa 2 to the west and along Borologa 1's southern perimeter, where we have argued that the overhang collapse is buried beneath aeolian sands. Between Borologa 1 and Borologa 2, the blocks at ground level mainly derive from fragmentation of the bedrock, which

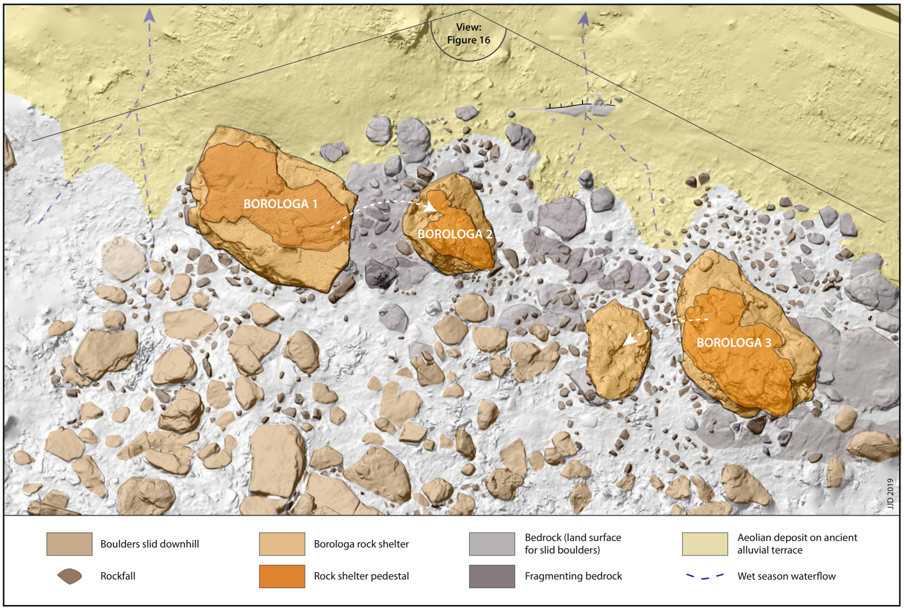

Fig. 15 Geomorphological map of the three Borologa sites (artwork by Kim Genuite and Jean-Jacques Delannoy)

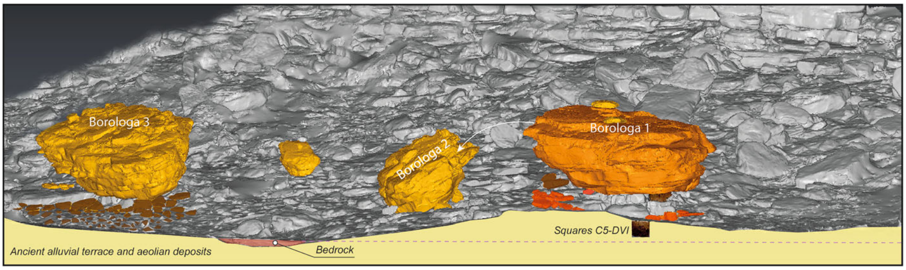

Fig. 16 Geomorphological context of the three Borologa sites in relation to the bedrock on which they landed (artwork by Jean-Jacques Delannoy)

was impacted by the detachment and collapse of Borologa 2 from Borologa 1. Borologa 2 tilted towards the WSW following its separation from Borologa 1, after which blocks largely fell from its western edge.

Blocks located on Borologa 1's bedrock and along its western, southern and eastern perimeters were investigated because of their unusual morphologies and distributions (Fig. 8). Of particular interest was where these blocks had come from and how they came to be in their present locations. In particular, we wanted to know whether they had come from the edges of overhangs, from detached alcove ceilings or from other parts of the landscape. About 20 blocks along the southwestern, southern and south-eastern edges of the overhang attracted our attention. Here, we focus on two sectors: the southeastern and SSW sections of Borologa 1.

Southeastern Sector of Borologa 1

We have already seen that a large grinding stone was moved *c.* 3 m and laid into position by people into the area of excavation squares DV–DVI–D5–D6–D7–C5–C6 sometime between 2110 and 2370 cal BP. Slightly to the northeast of the excavation squares, a quartzite slab 1.7 m long × 1.0 cm wide × 20 cm thick lies horizontally on the slope near the edge of art panel B1 (Fig. 17). Its flat positioning is particularly curious as it lies across the sloping base of a chaotic group of blocks that had originated uphill or from the edge of Borologa 1 (Figs. 8 and 15). The slab is supported and balanced horizontally by small, flaked rocks, creating a tabletop-like surface. The flaked footings and horizontal layout on a sloping ground surface signal an anthropic installation: indeed, the natural fall of an overhanging slab that included this small section, totalling more than 1000 kg, would have shattered the small underlying blocks. The petrography and mineralogy of the slab reveal that it originated from rock stratum D4, a large section of which had fallen from the ceiling of art panel B1. The horizontal slab on the ground is found directly beneath a remnant overhanging section of rock stratum D4, so it could not have fallen from that part of the overhang to its current position. Here, again, high-resolution 3D modelling enabled the slab to be digitally picked up and precisely conjoined onto its parent ceiling rock (Fig. 18). It had covered a part of the ceiling that is now heavily painted, its fall resulting in the creation of the extant rock stratum D5 ceiling surface. Today, the outline of a detachment scar on the ceiling of art panel B1 corresponds with that of the slab that forms the horizontal installation on the ground. The refitting of the slab to its originating position clearly shows that following its fall, it was rotated to its current position and propped up by small blocks flaked to an appropriate height for its stabilisation and horizontal positioning (Fig. 18).

To work out when the slab fell, a visually old and weathered mud wasp nest was sampled for radiocarbon dating from art panel B1's extant ceiling that formed as a result of the slab's collapse (Figs. 19 and 20). The radiocarbon determination (8420 ± 60 BP (OZW423U2)) obtained from the nest revealed an age range between 9303 and 9530 cal BP (95.4% probability on Calib 7.10 using IntCal13 curve selection, with a median of *c.* 9400 cal BP; Reimer *et al.* 2013) (Table 1; for sampling methodology, see Finch *et al.* 2019). The radiocarbon age signals that the slab must have detached sometime before *c.* 9300 cal BP.

Fig. 17 Southeastern edge of Borologa 1 with anthropically moved and flaked blocks (photos by Jean-Jacques Delannoy)

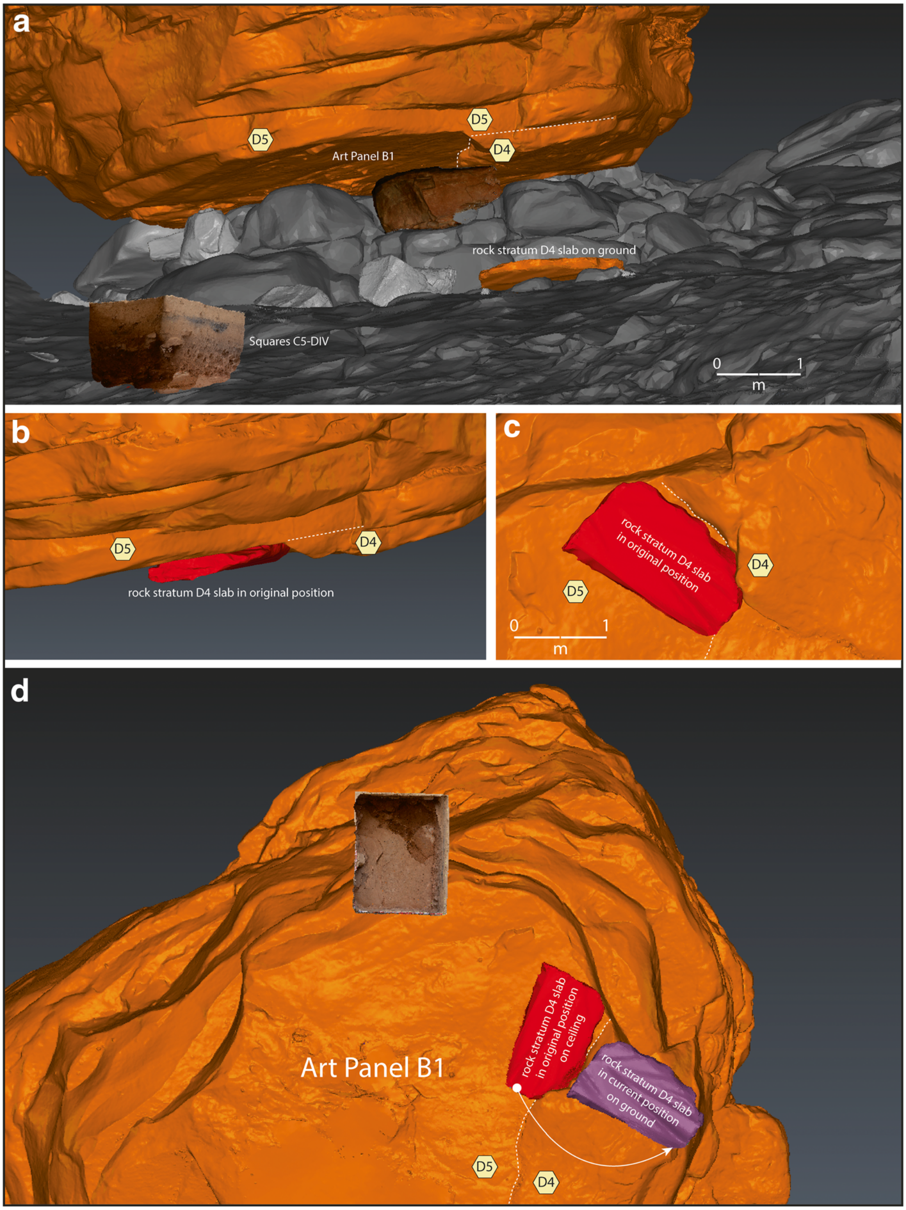

Fig. 18 Repositioned slab beneath the southeastern overhang of Borologa 1. **a** Side view of the boulder, slab and hillslope. **b** Rock stratum D4 slab conjoined in its original position on the ceiling, as it would have laid before it fell. **c** View of the repositioned slab on the ceiling, from ground level. **d** View of rock stratum D4 slab's current position on the ground (purple), projected vertically up to the ceiling. In red is the slab's original attached position prior to falling down. The arrow indicates how people rotated the slab into its current position after it fell from the ceiling (artwork by Jean-Jacques Delannoy)

It is interesting to compare these results with the evidence from the archaeological excavations, where it was shown that *c.* 2500–2700 cal BP aeolian sands began to cover a large collapsed ceiling slab that had also come from the art panel B1 cavity.

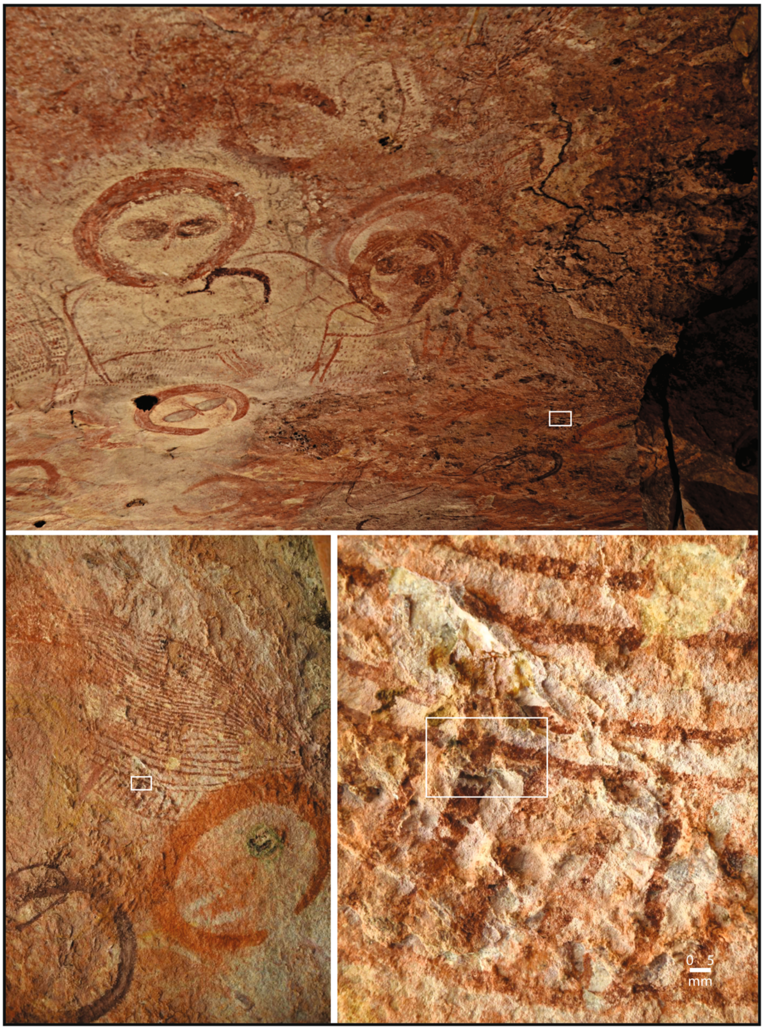

Fig. 19 Sample location of remnant mud wasp nest dated to 8420 ± 60 BP (OZW423U2), superimposed by a painted striped motif on art panel B1. The radiocarbon pretreatment method is detailed in Finch *et al.* (2019) (photos by Damien Finch)

This means that the repositioning of the horizontally installed slab from its landing position took place sometime after the slab fell ≥9300 cal BP but not later than 2500–2700 cal BP.

The area where the slab from rock stratum D4 initially fell is today littered with large blocks originating from the edge of bedrock strata D0–D2. These blocks largely lie on top of Late Holocene aeolian deposits, indicating that they attained their current positions during Late Holocene times. The spatial distribution of these blocks in or over the aeolian sands suggests that after their detachment from the bedrock, they, too, were moved by people, and this must all have happened over the past *c.* 2500–2700 years (Fig. 21). These displacements of blocks by people, like the installed

Fig. 20 The densely painted Wanjina ceiling of art panel B1, Borologa 1, showing where the rock stratum D4 slab currently lying horizontally on the ground originally came from (infilled red), the edge of remnant rock stratum D4 on the ceiling (dotted line) and the radiocarbon-dated mud wasp nest (photo by Robert Gunn; artwork by Jean-Jacques Delannoy)

horizontal slab from rock stratum D4, indicate that the overall site gradually took shape as a result of ongoing human engagements with its material matrix.

Borologa 1's SSW Alcove

Under the overhang that marks the western edge of Borologa 1, there is evidence at ground level of blocks that fell from the ceiling (brown blocks in Fig. 8) as well as of other blocks that do not seem to have come directly from the overlying walls and ceilings. Our attention is drawn to this area by the presence of a 2-m-deep alcove (measured from the inner edge of the outer overhang to its inner extremity) whose internal margins contain a range of motifs on two distinct art panels (Fig. 22). Art panel E9 includes several unidentified Gwion Gwion figures, an Elegant Action Figure overlying a white geometric design, Kimberley Stout figures and an overlying yellow hand stencil. Art panel E10 includes a set of fresh-looking red hand prints and a row of underlying Elegant Action Figures. Together, these motifs represent a broad range of Kimberley rock art styles including Gwion Gwion, which are one of the older, possibly terminal Pleistocene, rock art styles. In contrast, the outer face of the isolated block (art panel E11) bears a Wanjina image overlying several indistinct images also from the more recent periods.

An isolated quartzite block, 1.6 m long × 65 cm wide, sits on the flat surface of the outer edge of the alcove. Its lower edge is raised by small slabs, and it exhibits clear flaking impact scars. A flat piece of rusted iron of a kind typically used to make "shovel-nose" spear points across the region during the early European-contact period of the late 1800s has also been placed under the block, and a quartzite rock on top of it. At the back of the block are a number of small quartzite blocks each measuring

Table 1 Radiocarbon date on mud wasp nest from art panel B1 ceiling surface, southeastern part of Borologa 1

Laboratory code	Carbon mass (μg)	Pretreatment	% modern carbon (pMC %)	^{14}C age (BP)
OZW423U2	46	A-HLS-BA (8 M)	35.04 ± 0.24	8420 ± 60

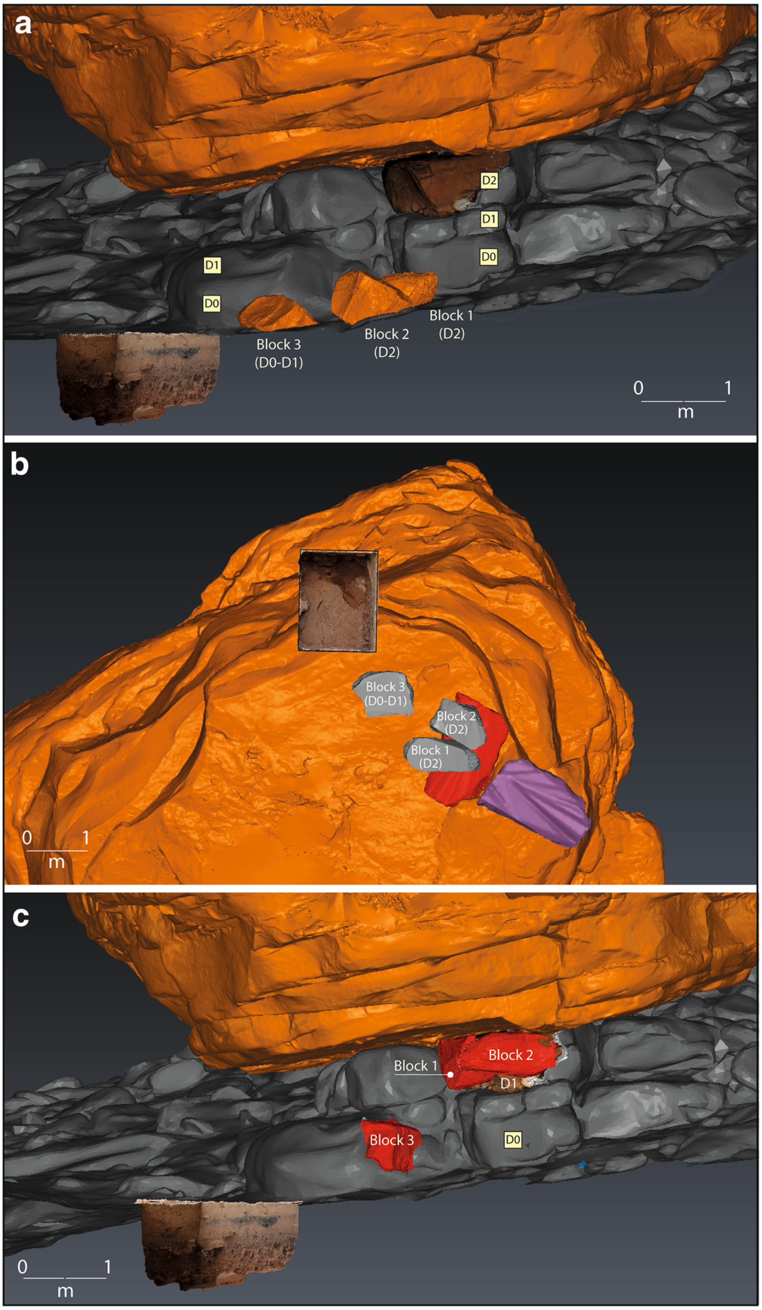

Fig. 21 Repositioning of blocks fallen after the detachment and anthropic removal of rock stratum D4 at the southern end of Borologa 1 (see Figs. 17 and 18). **a** Side view of the studied area. **b** View up from ground level to the ceiling, with blocks 1, 2 and 4 and the rock stratum D4 slab repositioned in their original positions prior to falling. **c** Blocks 1–3 conjoined in their original positions. Note that prior to their collapse, blocks 1–3 were attached to bedrock strata D0–D2 and not to the ceiling, nor did they then obstruct access to the ceiling with the still-attached slab (artwork by Jean-Jacques Delannoy)

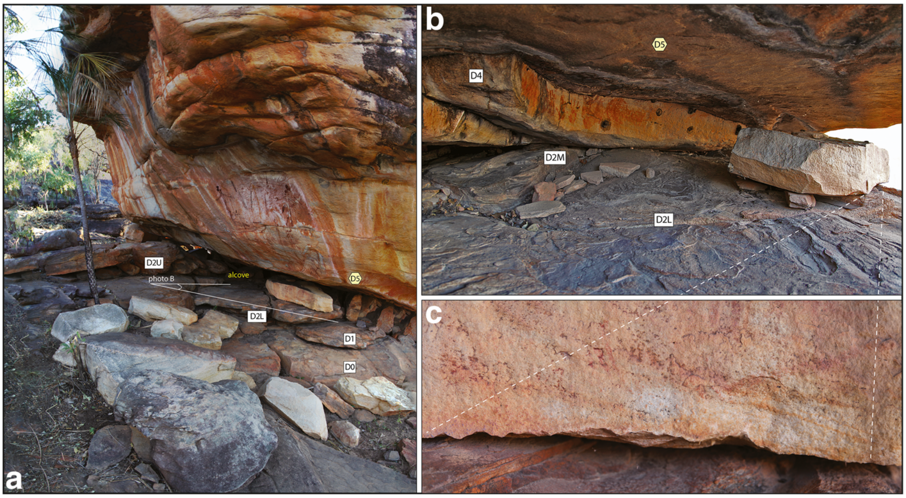

Fig. 22 SSW edge of Borologa 1, showing details of the worked alcove. **a** Alcove with the evacuated blocks on the ground, as they are today (the lighter-coloured blocks). **b** View inside the alcove. **c** Negative flaking scars made along the base of the isolated block before it fell from the ceiling (photos by Jean-Jacques Delannoy)

between 19 and 25 cm long and 10 cm thick. Both the larger block and the small pieces have a distinctive granular texture. A group of 12 rocks, each 2.5–3.0 cm thick and with identical petrographic characteristics, is aligned on the rock floor against the internal edge of the alcove that contains the paintings and hand prints. This area was investigated to determine whether people are implicated in the formation of this alcove.

Petrographic examination of the isolated block (block 1 in Fig. 23) confirms that it came from rock stratum D4. It is in effect by the removal of rock stratum D4 and the middle of rock stratum D2 (D2M) that the alcove was formed. The base of the alcove corresponds with the upper surface of the lower part of rock stratum D2 (D2L), and its ceiling with the base of rock stratum D5 (Fig. 22). The location of the isolated block leads us to ask whether it is in its original position following its fall from the ceiling or not. If not, how did it get there and from where in or outside the alcove? Also, where are the other blocks that should have filled the alcove space but that must have fallen out or been evacuated from rock stratum D4? Finally, why is the rock from stratum D2M missing in this alcove space? Sometimes, we need not just to ask about the presence and movements of rocks but also to consider the rock voids and why they exist.

We again employed high-resolution 3D laser modelling together with geomorphological analysis and came up with the following findings. First, the slightly sinuous upper surface of the isolated block conjoins perfectly onto the corresponding slightly sinuous overhang inside the alcove. One edge of the block also conjoins perfectly with the internal rim of the alcove. We thus conclude that the isolated block was deliberately placed in its current position by people, as it could not have naturally slipped along the flat rock platform on which it lies (Fig. 23). Its current position seems to have resulted from the unfinished clearance of this small cavity by the progressive removal of blocks from the collapsed ceiling. Other blocks from rock stratum D4 are found outside the alcove. They are easily identifiable by their distinctive petrographic characteristics and form a line of blocks positioned on the exposed D1–D0 bedrock (Figs. 8 and 24). Some

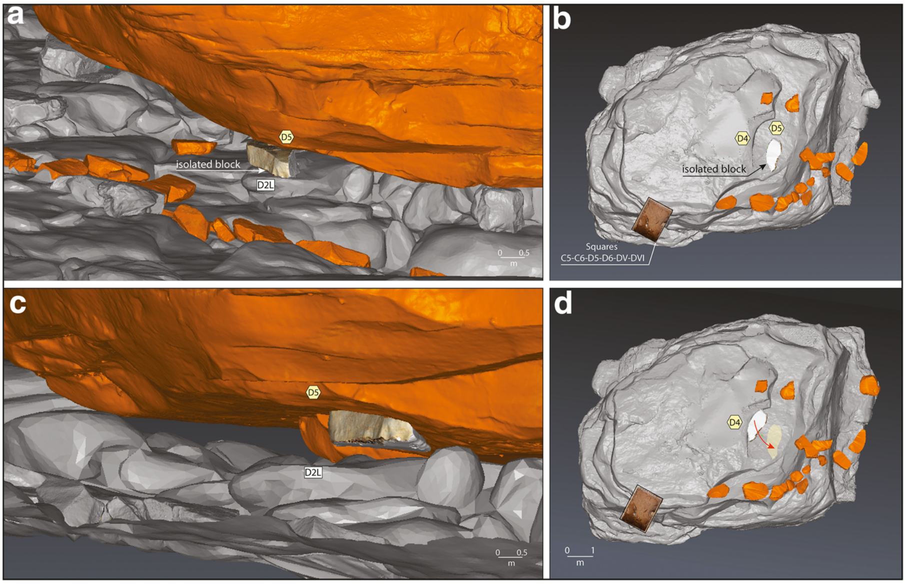

Fig. 23 Repositioned fallen and moved block from the SSW alcove of Borologa 1. **a**, **b** Side view and view up from the ground with the current position of the blocks projected up onto the rock. **c**, **d** Side view and view up from the ground with the remnant block conjoined onto its original position against the ceiling and side wall, prior to its detachment and evacuation from the alcove by people (artwork by Jean-Jacques Delannoy)

of these blocks have been flaked down to reduce their mass, presumably to facilitate their evacuation from the alcove. Like the isolated block, this set of rocks could be conjoined both with the isolated block on the alcove shelf and back onto its originating wall and ceiling (Fig. 23).

In total, over 2.5 tonnes of rock have been evacuated by people from the alcove. While this process of emptying the alcove of fallen blocks is clear, less certain is the cause of the fall of the blocks from the ceiling. Did they fall prior to human involvement, or were they prised apart from the ceiling by people?

It is clear that the evacuation of the blocks was made easier by the removal of the middle layer of rock stratum D2 (stratum D2M). Along the northern edge of the alcove (edge of rock strata D2U–D2M), there are signs of anthropic removal of parts of the bedrock in the form of flaking scars and partly removed blocks (Fig. 25). These lines of evidence confirm that this alcove space was the location of purposeful human action that involved a sequence of steps:

1. Progressive removal of rock stratum D2M
2. As the width of the alcove was cleared, the blocks from rock stratum D4 were removed
3. This *chaîne opératoire* or production sequence was repeated until the alcove space attained its current size

Today's isolated blocks (block 1 in Fig. 25 and the moved block in Fig. 24) in the alcove mark the unfinished anthropic expansion of the alcove space. It was only at the

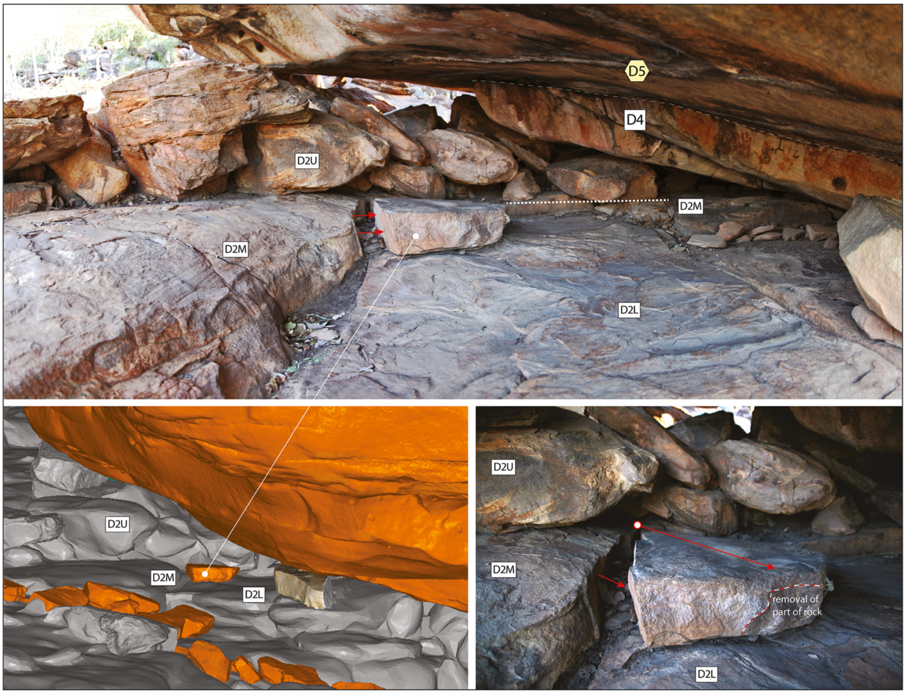

Fig. 24 Conjoining anthropically moved blocks in the northern part of the alcove on the west side of Borologa 1 (photos and artwork by Jean-Jacques Delannoy)

end of this process of evacuation of blocks that the paintings and hand prints on the inner edge of the alcove could have been made, and it is from this inner location that remnant but partly evacuated block 1 originally came.

Discussion

A focused archaeomorphological study of Borologa enabled a hitherto unimagined dimension of the history of rock art-making in this part of northern Australia. While the art creates a highly visual expression of past cultural activity that immediately calls on our attention as researchers, it was by focusing as much on the canvas, on the rock that supports the art, that past human activities relating to the formation of the subsequently painted art panels were revealed. It enabled a differently nuanced and longer-term biography for Borologa.

The narrative generated through a combined archaeological and geomorphological approach also begs a multi-scale viewing that shifts between the minutiae of each rock and a broader landscape perspective, with each spatial scale informing the other scales. Beginning in geological time, Borologa's present environment was established as the Drysdale River incised through the quartzite plateau, destabilising its developing slopes. This caused large masses of rock such as the Borologa boulders to slide down (Genuite 2019). Cosmogenic dates obtained from slid and rolled blocks on the upper parts of the slope (Fig. 3) have dated such movements to *c.* 90,000–130,000 years ago

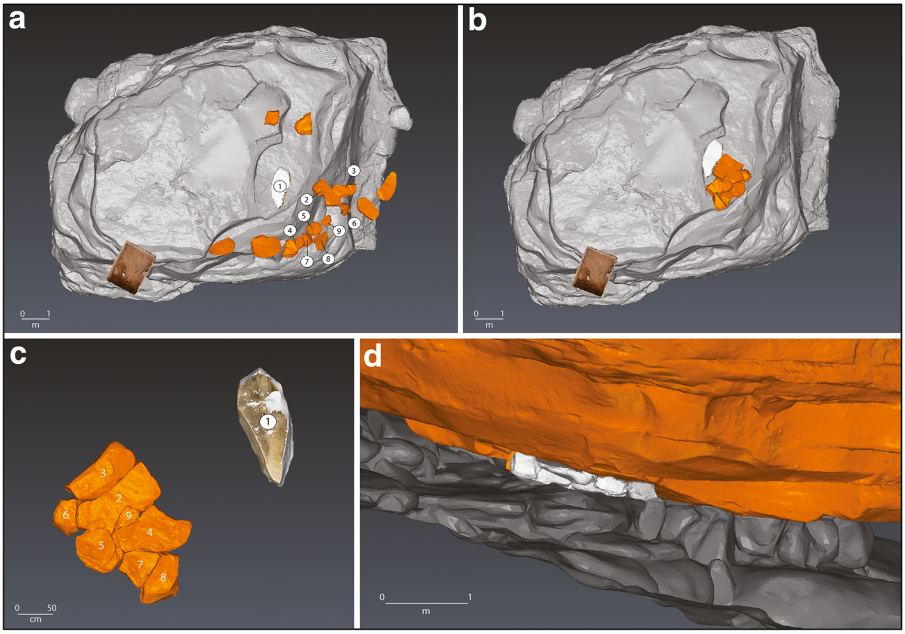

Fig. 25 Repositioned fallen and evacuated blocks from the SSW alcove of Borologa 1. **a** View upwards from the ground with the present position of rock stratum D4 blocks projected upwards onto the alcove's ceiling. **b** View upwards from ground level with the conjoined rock stratum D4 blocks repositioned onto their original alcove surface. **c** The fallen and evacuated blocks digitally conjoined back together with the help of the 3D laser scans finding clearly matching surface sizes and morphologies. **d** Side view of the alcove prior to the fall and evacuation of rock stratum D4 (artwork by Jean-Jacques Delannoy)

(Cazes 2019). Given the lay of the land and location of the source rock outcrops near and at the top of the plateau, the blocks at the bottom of the slope were among the first to have slid or rolled down, with progressively younger blocks found upslope. The three Borologa boulders are thus considerably older than 100,000 years old. Once settled on their landing bedrock base (rock strata D2–D0), mechanical and equilibrium readjustments led to the detachment of Borologa 2 from Borologa 1, and of a large section from Borologa 3.

In the absence of direct ages, it is more difficult to determine the age of the upper alluvial terrace but it too has its genesis in geological time, given that it lies higher than—and thus predates—the current Drysdale River channel.

It is this general landscape setting that people encountered when they first came to Borologa. The three rock shelters experienced many occupational events, as indicated by the archaeological excavations, rock art and evidence of workings of the shelters' rock walls and ceilings. The earliest evidence of people comes in the form of the Irregular Infill Animal, and Gwion Gwion paintings on regional stylistic grounds have long been theorised to be terminal Pleistocene in age (*e.g.*, Lewis 1988). A recent program of radiocarbon dating mud wasp nests lying under (giving maximum ages for the paintings) and over (minimum ages) Gwion Gwion paintings elsewhere in the Kimberley region, "support[s] the proposition that the Gwion motifs in this study were painted between 12-13 ka cal BP", including one painting with dated mud wasp nests both under and over the art, securely bracketing its age within the period *c.* 11,500–

12,600 cal BP (Finch *et al.* 2020). Another painting has a minimum age of *c.* 17,000 cal BP, suggesting that while most of the Gwion Gwion paintings in this region were painted over a relatively short period of time, some Gwion Gwion motifs may be more than 4000 years older (Finch *et al.* 2020).

The most recent activities at Borologa relate to the time of the Wanjina figures and include the inclusion of a metal bar beneath a block at Borologa 1, and date to the end of the nineteenth or beginning of the twentieth century CE. These findings are also consistent with the radiocarbon age obtained on a mud wasp nest at Borologa 1, signalling that a massive slab (parts of which are visible at the base of excavation squares C5–DVI) fell sometime before *c.* 9300 cal BP. They are also consistent with the mineral encrustation of a low-lying rock *c.* 7177–7426 cal BP (6385 ± 62 BP (OZW427U1) on calcium oxalate) at Borologa 3 (Delannoy *et al.*, in preparation; Green et al. 2017)). The timing of the wasp nest and mineral encrustation at the two sites confirm that the physical environment of the Borologa sites has remained similar for at least the past *c.* 9300 years. The changes relating to the deposition of aeolian sediments in front of Borologa 1 are more recent.

The high spatial resolution archaeomorphological study of two key areas of Borologa 1 emphasises that this densely painted site is also an anthropically constructed and mediated architectural space that developed through time as a result of planned and coordinated engagements with the materiality of the rock. These rock-workings often preceded the painting episodes. For example, before the Elegant Action Figures and Kimberley Stout figures (both styles thought to be Late Pleistocene or Early Holocene in age) were painted in the SSW alcove and before the Kimberley Stout figures and Wanjina were painted on the ceiling in the southeastern part of the site, the rock had been hollowed out to create alcoves (Fig. 26). These two areas are not the only ones to have involved stone-working at Borologa. The northwestern margin of Borologa 1 and the entire southern margin of Borologa 3 show significant signs of anthropic transformation (for details, see Delannoy *et al.*, in preparation).

The physical matrix of the SSW, southern and southeastern sections of Borologa 1 was worked by people well before the accumulation of aeolian sands *c.* 2500–2700 cal BP. Collapsed ceilings and edges of shallow overhangs have been found below the aeolian sands but remain undated, and blocks from these rockfalls were moved by people in the past (Figs. 14, 17, 22 and 24). Irrespective of their age, these stone-workings not only led to the creation of new cavities with fresh rock surfaces but also led to the creation of new site furniture (*e.g.*, ochre grinding stone and horizontal slab) as focal locations of social activity; they also changed how walls and ceilings could be accessed at a time well before the deposition of aeolian sands (Figs. 27 and 28). Purposeful installations such as the positioned horizontal rock stratum D4 slab on the floor of the southeastern edge of the site, and the evacuation of blocks from the SSW alcove, enhanced access to rock surfaces in these two locations where the highest extant art panels occur immediately above the horizontal slab and worked alcove.

Beyond these apparent associations between the painted high walls or ceilings and physical modifications through stone-working, it is now also clear that both Borologa 1 and Borologa 3 have undergone substantially more anthropic stone-working than just the two examples presented here (for further details, see Delannoy *et al.*, in preparation). The magnitude of human engagements with the rock revealed here is easily lost if we do not consider the total mass of rock that people worked on. Taking into account

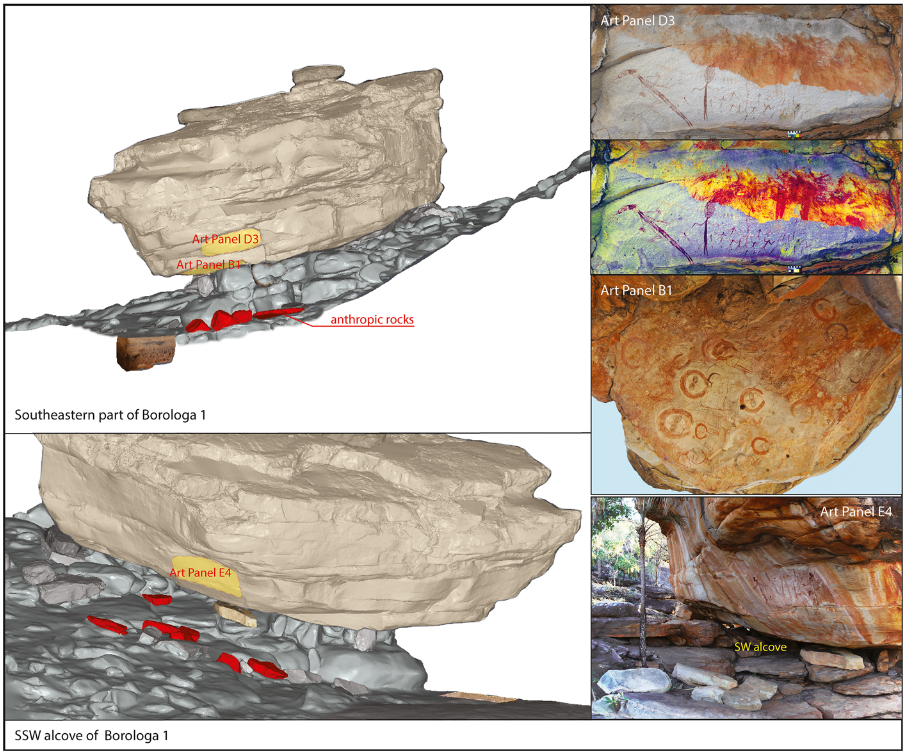

Fig. 26 The SSW and southeastern sections of Borologa 1 discussed in this paper, with some of their art panels and blocks moved by people (artwork and photos by Jean-Jacques Delannoy and Robert Gunn)

only the manually evacuated rock visible at ground level and that found in the archaeological excavations from these two areas, *c.* 3.5 tonnes of rock were manually extracted and, in some cases, further moved to new selected locations by people. More than 2.5 tonnes of currently visible rock were manually removed from the SSW alcove alone, including the 270 kg block moved to, and abandoned at, the edge of the alcove. In total, nearly 4.5 tonnes of rock were moved by people at Borologa 1, 2 and 3 combined (Delannoy *et al.*, in preparation).

Comparing these findings with those of Nawarla Gabarnmang on the Arnhem Land plateau 700 km to the east sheds further valuable light on past social relations across the two regions. Much like the alcove of Borologa 1, where a large block was left only partly evacuated on the rock shelf, so, too, at Nawarla Gabarnmang do we find unfinished stone-workings, with large blocks having been abandoned along their paths out of the site. In both cases, the extraction of large blocks to create cavities and the cessation of unfinished works within these densely painted sites date to Late Pleistocene times. At Nawarla Gabarnmang, the cessation of massive rock-workings dates to *c.* 11,000 cal BP. As at Borologa, this stone-working predates the 1391 extant motifs on 42 ceiling panels and many of the *c.* 500 motifs on the pillars, which are overwhelmingly Late Holocene in age (Castets 2017; Delannoy *et al.* 2017, 2018; Gunn 2018). At Borologa 1, the wasp nest radiocarbon date indicates that the large painted rock surface of the southeastern alcove formed more than *c.* 9300 cal BP: the ceiling could only

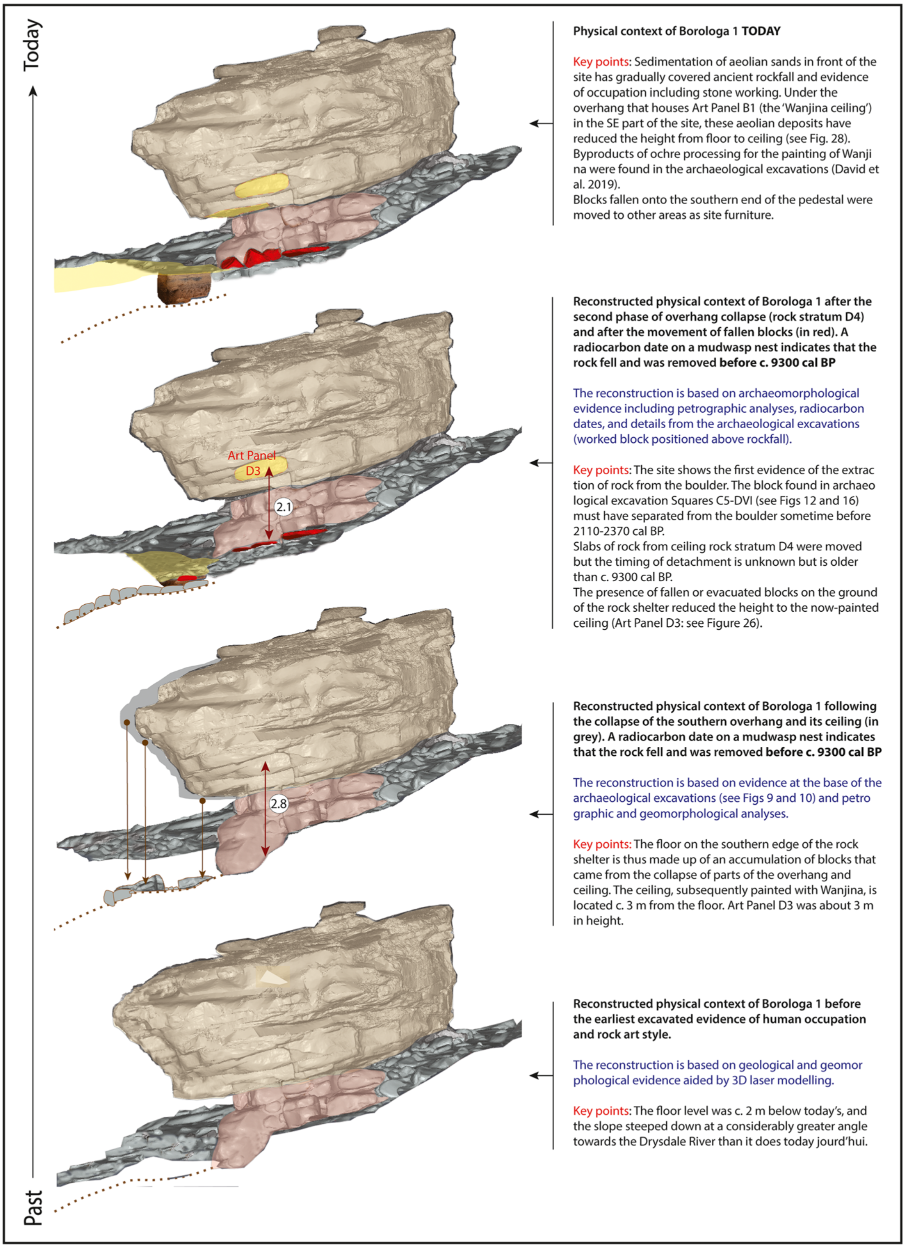

Fig. 27 The southeastern side of Borologa 1's life history through time, as reconstructed from geomorphological, archaeological and archaeomorphological evidence (artwork by Jean-Jacques Delannoy)

have been painted after the evacuation of the rock from its cavity. But, the vast majority of paintings are more recent, as indicated by the presence of the oldest style on top of the wasp nest, absence of the earliest recognisable Kimberley styles (*e.g.*, Irregular Infill Animal and Tassel Gwion Gwion) and the predominance of Late Holocene Wanjina figures. In the SSW alcove, the rock must also have been extracted during

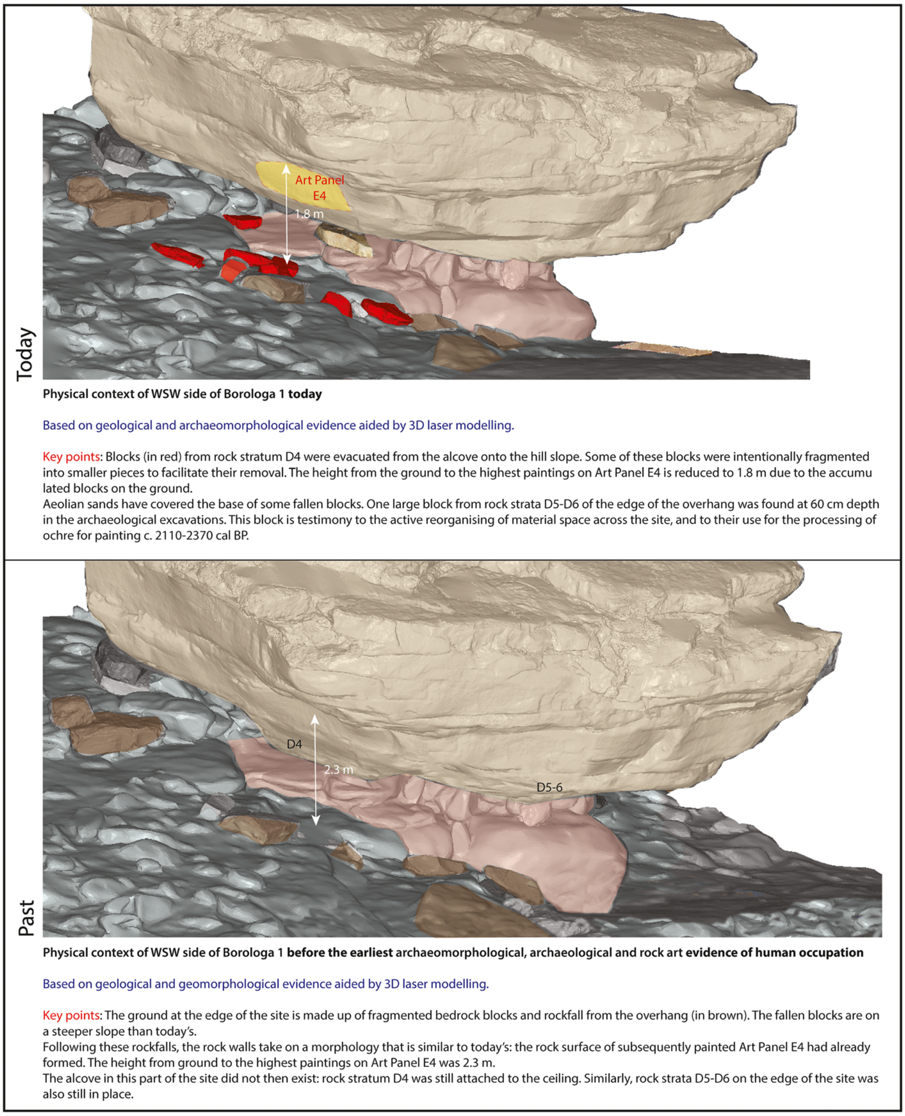

Fig. 28 The SSW side of Borologa 1 through time, as reconstructed from geomorphological, archaeological and archaeomorphological evidence (artwork by Jean-Jacques Delannoy)

Late Pleistocene or Early Holocene times, for both Elegant Action and Kimberley Stout figures were painted in the hollowed-out cavity. Both at Nawarla Gabarnmang and at Borologa, it is the extraction of rock at a massive scale and, with this the creation of new alcoves and rock surfaces, that set the foundation for new artworks. Those two regions were connected during this period by a land bridge that became submerged with post-glacial rising sea levels near the Pleistocene-Holocene boundary. Art styles on either side of this land bridge, from the Kimberley (*e.g.*, Irregular Infill Animal, Gwion Gwion) in the west to Arnhem Land (*e.g.*, Large Naturalistic Animals, Dynamic figures) in the east, were iconographically comparable when the two regions were linked by a land bridge but began to differentiate stylistically with rising seas that eventually separated them in the Early Holocene (Lewis 1988; see also David & Chant 1995). Significantly, a common practice of massive stone-working to hollow-out rock shelters can now be shown also to signal this shared community of culture across this broad landscape during the land bridge phase of the Late Pleistocene.

The Borologa physical and cultural landscape, like landscapes everywhere, is not and has never been fixed. This is not just a statement of geological scale or process but also one of the "anthropo-scene". It would be an archaeological shortcoming to treat rock art sites as made up of *natural* caves or rock shelters onto which *cultural* artworks were passively placed. Rather, as the Borologa case demonstrates, through social engagements, physical landscapes are culturally shaped, and it is a key role of archaeology to try to determine the specific forms of such engagements and landscape constructions. Landscapes are "the arrangement in physical space of artifacts and activity" (Duncan 1976, p. 391). To understand the art let us try to better understand when and how the rock canvas that supports it was created. After all, it is this engagement with the rock that from the onset enabled the art to be put in place.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Appendix 1

Table 2 Basic petrographic description of Borologa 1's rock strata

Rock stratum	Thickness (cm)	Petrographic characteristics
D25		
D24		
D23		
D22		
D21		

Table 2 (continued)

Rock stratum	Thickness (cm)	Petrographic characteristics	
D20	25	Fine grains, homogeneous and highly compact	
D19	25	Medium to coarse grains, homogeneous, weakly compact, sensitive to erosion	
D18	25	Medium to coarse grains, homogeneous	
D17	15	Coarse grains, weakly compact, moderately fused	
D16	35–40	Homogeneous, fine-grained, compact	
D15	10	Coarse-grained, weakly compact, poorly fused	
D14	20	Light-coloured with grey cross-colouring	
D13	115	E: 35 cm D: 25 cm C: 22 cm B: 12 cm A: 20 cm	Homogeneous set of sublayers with fine grains and moderate compaction, characterised by cross-bedded light and grey colours. These layers are separated by 4 micro-joints of clearly distinguishable horizontal strata
D12	25–15	Homogeneous light grey with clearly distinguishable fine bedding; the base is marked by a dark compact layer of variable thickness	
D11	B: 30	2 superposed (grey and light in colour) compact layers, homogeneous in texture and grain density	
	A: 12	Fine grain, homogeneous, grey, compact	
D10	18	Homogeneous with fine bedding	
D9	40	Fine-grained, very homogeneous, grey	
D8	55	This layer subdivided into two sublayers. The upper unit is homogeneous, 40 cm thick and grey in colour. The lower unit (15 cm thick) is equally grey but contains *c.* 3-cm-thick clear veins. These veins occur along stratified micro-joints. The contact with rock stratum D7 is clearly marked by a light-coloured horizontal level	
D7	35–40	Homogeneous set of micro-layers characterised by oblique beds (relative to the adjacent strata immediately above and below) of grey and light colours. The light-coloured beds consist of less compact fine quartz grains that are amenable to exfoliation	
D6	40	Fine-grain, homogeneous, grey with a 0.5-cm-thick light-colour level, 5 cm from the joint beneath, and a 1.5-cm-thick light-coloured bed, 15 cm from the joint above it	
D5	20	Fine-grain, homogenous, compact	
D4	22	Alternating grey (with middle-sized grains) and light-coloured (with fine grains) layers	
D3			
D2	45–60	Rock strata consisting of 3 layers: • Upper layer (28 cm thick): alternating light-coloured and grey beds (medium to fine grains) • Middle layer (12 cm thick): thin, light colour of coarse-grained alternating beds (2–3 cm thick) • Lower layer (20 cm thick): set of homogeneous coarse-grained quartz beds	
D1	18	Grey-green, compact with beds of fine quartz grains	
D0	100	Homogeneous set of fine-grained layers separated by subparallel beds of variable thickness (0.5–9.0 cm) and differing light and dark tones. This set of layers has a dark rose-coloured appearance on its exposed surfaces	

Appendix 2. Specifications for Borologa's 3D laser modelling

The Borologa 3D model was created by short-range Terrestrial Laser Scanning (TLS) of an area covering 5000 m^2. One hundred and seventy-four scan scenes and *c.* 700 million points were recorded in the field. The 3D mapping was conducted to investigate research questions requiring a range of spatial scales and thus varied in resolution and mapping accuracy across the landscape (higher-resolution mapping was undertaken near the rock shelters; coarser-grainer mapping took place near the cliffline). Model mean values are based on 20 random measurements per item. The detailed 3D mapping workflow can be found in Genuite (2019).

	Ground surfaces and external environment	Borologa 1 rock shelter and nearby blocks	Squares C5–C6–D5–D6–DV–DVI excavation pit
A: Survey method	Short-range TLS + sphere registration	Short-range TLS + sphere registration	TLS-constrained photogrammetry
B: Point cloud accuracy	1 cm	1 mm	1 mm
C: Point cloud density	2 cm	6 mm	2 mm
D: Mesh accuracy	2 cm	3 mm	
E: Delaunay 3D triangle mean size	8 cm	1.2 cm	
F: Mapping tool	Faro Focus 3D 360 (2012)	Faro Focus 3D 360 (2012)	NIKON D 800 camera + 50 mm

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