



HAL
open science

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

Jean-Jacques Delannoy, Bruno David, Kim Genuite, Robert Gunn, Damien Finch, Sven Ouzman, Helen Green, Peter Veth, Sam Harper, Robert J Skelly

► **To cite this version:**

Jean-Jacques Delannoy, Bruno David, Kim Genuite, Robert Gunn, Damien Finch, et al.. Investigating the Anthropic Construction of Rock Art Sites Through Archaeomorphology: the Case of Borologa, Kimberley, Australia. *Journal of Archaeological Method and Theory*, 2020, 27 (3), pp.631 - 669. 10.1007/s10816-020-09477-4 . halshs-03115553

HAL Id: halshs-03115553

<https://shs.hal.science/halshs-03115553>

Submitted on 8 Feb 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Journal of Archaeological Method and Theory

Investigating the anthropic construction of rock art sites through archaeomorphology: the case of Borologa, Kimberley, Australia --Manuscript Draft--

Manuscript Number:	JARM-D-19-00149R1	
Full Title:	Investigating the anthropic construction of rock art sites through archaeomorphology: the case of Borologa, Kimberley, Australia	
Article Type:	SI: Art in the Making	
Keywords:	archaeomorphology; Kimberley; landscape architecture; Rock Art; 3D modelling	
Corresponding Author:	Bruno David MONASH UNIVERSITY Clayton, Victoria AUSTRALIA	
Corresponding Author Secondary Information:		
Corresponding Author's Institution:	MONASH UNIVERSITY	
Corresponding Author's Secondary Institution:		
First Author:	Jean-Jacques Delannoy	
First Author Secondary Information:		
Order of Authors:	Jean-Jacques Delannoy	
	Bruno David	
	Kim Genuite	
	Robert Gunn	
	Damien Finch	
	Sven Ouzman	
	Helen Green	
	Peter Veth	
	Sam Harper	
	Balanggarra Aboriginal Corporation	
	Robert J. Skelly	
Order of Authors Secondary Information:		
Funding Information:	Australian Research Council (LP150100490)	Not applicable
	Monash University	Not applicable
Abstract:	<p>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, re-structure 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 re-think what have traditionally been distinguished as "natural" versus "cultural" dimensions of</p>	

archaeological landscapes and rock art sites.

1
2 **Investigating the anthropic construction of rock art sites through archaeomorphology:**
3 **the case of Boroloka, Kimberley, Australia**

4
5 Jean-Jacques Delannoy^{1,2}, Bruno David^{2,3}, Kim Genuite¹, Robert Gunn³, Damien Finch⁴,
6
7 Sven Ouzman⁵, Helen Green⁴, Peter Veth^{2,5}, Sam Harper⁵, Balangarra Aboriginal
8
9 Corporation⁶ and Robert J. Skelly³

10
11
12 ¹ Laboratoire EDYTEM, Université Savoie Mont Blanc, F-73376 Le Bourget du Lac Cedex,
13
14 France

15
16 jean-jacques.delannoy@univ-smb.fr (ORCID: <https://orcid.org/0000-0002-2815-4920>)
17
18 kim.genuite@univ-smb.fr

19
20
21 ² Australian Research Council Centre of Excellence for Australian Biodiversity and Heritage,
22
23 Canberra, Australia

24
25
26
27 ³ Monash Indigenous Studies Centre, 20 Chancellors Walk, Monash University, Clayton
28
29 Campus, Vic. 3800, Australia

30
31 bruno.david@monash.edu (ORCID: <https://orcid.org/0000-0002-8567-6135>)
32
33 gunnb@activ8.net.au (ORCID: <https://orcid.org/0000-0002-7565-8697>)
34
35 robert.skelly@monash.edu (ORCID: <https://orcid.org/0000-0002-3578-0604>)

36
37
38 ⁴ School of Earth Sciences, University of Melbourne, Parkville, 3010 Victoria, Australia
39
40 helen.green@unimelb.edu.au (ORCID: <https://orcid.org/0000-0002-7842-6007>)
41
42 dfinch@student.unimelb.edu.au (ORCID: <https://orcid.org/0000-0002-9447-5685>)

43
44
45 ⁵ Centre for Rock Art Research and Management, M257, School of Social Sciences, Faculty
46
47 of Arts, Business, Law and Education, The University of Western Australia, 35 Stirling
48
49 Highway, Crawley, WA 6009, Australia

50
51 sven.ouzman@uwa.edu.au (ORCID: <https://orcid.org/0000-0002-9379-2996>)
52
53 peter.veth@uwa.edu.au (ORCID: <https://orcid.org/0000-0002-1717-6390>)
54
55 sam.harper@uwa.edu.au (ORCID: <https://orcid.org/0000-0002-1590-2387>)

56
57
58 ⁶ c/o Kimberley Land Council, Wyndham, Western Australia 6740, Australia
59
60
61
62
63
64
65

Abstract

1
2 Archaeologists usually see, and understand, rock shelters as taphonomically active, but pre-
3 existing, physical structures onto which people undertake a variety of actions including rock
4 art. Our aim in this paper is not only to document the changes undergone by rock shelters, but
5 also to identify traces of anthropic actions that have intentionally led to these changes. Recent
6 research in northern Australia provides empirical evidence that for thousands of years
7 Aboriginal peoples altered the physical shape of rock shelters by removing masses of rock to
8 create alcoves, re-structure internal spaces, and create stone-worked furniture. Through
9 archaeomorphological research, this paper presents evidence from Boroloka in Australia's
10 Kimberley region, where hard quartzite monoliths were shaped and engaged as architectural
11 designs by Aboriginal people prior to painting many surfaces, making us re-think what have
12 traditionally been distinguished as "natural" versus "cultural" dimensions of archaeological
13 landscapes and rock art sites.
14
15
16
17
18
19
20
21
22
23
24

25 **Keywords:** archaeomorphology; Kimberley; landscape architecture; rock art; 3D modelling
26
27
28

Acknowledgements

29 We thank Augustine Unghango, Balangarra Aboriginal Corporation members and
30 Kwini Traditional Owners for permission and partnership to work on their lands. This paper
31 was carried out as part of the Australian Research Council's "Kimberley Visions: Rock Art
32 Style Provinces in Northern Australia" project (LP150100490). We thank Gael Cazes, Andy
33 Gleadow, Pauline Heaney, Cecilia Myers, Maria Myers, Susan Bradley and the staff at Theda
34 and Doongan Stations; Kimberley Foundation Australia, Dunkeld Pastoral Pty Ltd, and the
35 Western Australian Department of Biodiversity, Conservation and Attractions. Thanks to
36 EDYTEM and the Université Savoie Mont Blanc, the Monash Indigenous Studies Centre at
37 Monash University, Archaeology at the University of Western Australia. Thank you also to
38 the Boroloka excavation and rock art recording teams: Isaac Barney, Frank Boulden, Leigh
39 Douglas, Adrian French, Paul Hartley, Brigid Hill, Lucas Karadada, Madeleine Kelly,
40 Lorraine Lee, Robin Maher, William Maraltidj, Michael Morlumbin, Ken Mulvaney, Nick
41 Sundblom, Patrick Tataya, Gareth Unghango, Jeremy Unghango, Scott Unghango, Ian Waina,
42 Rowan Waina and Uriah Waina. This work was conducted under a research agreement with
43 the Kimberley Land Council and Balangarra Aboriginal Corporation. The Western
44 Australian Department of Planning, Lands and Heritage (formerly Aboriginal Affairs)
45 provided a s16 permit.
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1
2 **Introduction**

3
4 Like stone artefacts and other items of material culture, rock art offers insights into
5 past cultural practices and their patterns and trends. Rock art has two great advantages over
6 most other types of artefacts. First, its malleability and symbolism offer enhanced possibilities
7 for an archaeology of cognition. Second, its fixity on rock allows for an archaeology of place,
8 for a phenomenological archaeology of how people are connected *in* places. Yet despite being
9 anchored on rock, by itself the rock art only offers a partial avenue of enquiry into relations
10 between people and the locations in which the art was undertaken. For rock art adequately to
11 inform on cultures of emplacement, we also need to venture beyond the art onto the place
12 itself. Place is the where “on which the concrete things of a given landscape repose: where
13 ‘things’ may be humanly constructed” (Casey 2001:418). For such a place-based (in Casey’s
14 term, “placial”) archaeology to occur, and as previously argued by a number of researchers
15 across the world (e.g., Bradley 1997; Chippindale and Nash 2004; Gjerde 2010; Meirion-
16 Jones et al. 2011), we need to go beyond a myopic focus on the art, sundered from its
17 surroundings, and look both more closely and more broadly at its physical settings. Here we
18 present an *archaeology of the materiality of place* by investigating in new ways how rock
19 surfaces, sites and landscapes were socially engaged, and in doing so how they were actively
20 constructed at nested spatial scales. Our aim is to find out how, by engaging with their
21 materiality, anthropic actions intentionally led to physical changes to sites.
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37

38 **Archaeomorphology: A question of method**

39
40 At three large rock shelter and rock art sites in Australia (Nawarla Gabarnmang: e.g.,
41 David et al. 2017; Delannoy et al. 2017), Spain (La Garma: Arias and Ontañon 2012) and
42 France (Chauvet Cave: Delannoy et al. 2012, 2018), a closely integrated archaeological and
43 geomorphological examination of the rock walls, ceilings, present floors and buried deposits
44 found conclusive signs that people had profoundly altered each site’s rock matrix more than
45 10,000 years ago. This signaled that the sites had not only been occupied or otherwise used,
46 but that each site’s material layout could be investigated as Pleistocene architecture
47 engineered by both planning and cultural engagement. These findings alerted us of the need to
48 study whole sites and landscapes as expressions of cultural design and social practice that
49 could, in turn, shed more light on the meaningfulness of the rock art and smaller and usually
50 more portable artefacts that they contain and that we are more accustomed to study.
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

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

15
16 Archaeomorphology investigates human engagements with, and in, place by studying
17 the spatial distribution, characteristics and life history of fixed and movable objects. It asks
18 how one object in one place at a site relates to another in another place at that site, and how
19 they got to be where they are. For example, which part of a rock outcrop did a rock now lying
20 on the floor come from, and what factors, including modes of transport, could have caused the
21 rock to be in its current position? To do this, every object and set of objects is examined both
22 archaeologically and geomorphologically, be it by one person with expertise in both fields, or
23 several researchers working and communicating in an integrated way on a shared question.
24 Archaeomorphological research, in many ways akin to geoarchaeology, also differs from the
25 latter by treating the material world as socially engaged: the aim of archaeomorphology is to
26 determine through combined archaeological and geomorphological methods the nature and
27 effects of social and cultural engagements with the material world.

28
29 In addition to the standard archaeological and geomorphological skills it employs, an
30 indispensable tool of archaeomorphology is three-dimensional (3D) laser modelling, which is
31 used to investigate the layout of sites and objects and their changing configurations through
32 time. These 3D models were made using short-range Terrestrial Laser Scanning (TLS),
33 enabling individual rocks to be digitally “picked up”, rotated and accurately refitted onto the
34 rock surfaces from which they originated (for technical information on how such 3D models
35 are made using TLS, see Jaillet et al. 2018; for an example, see Barker et al. 2017). They
36 enable the viewing and study of spatial patterns at scales not normally possible with more

1 conventional means. For example, digital 3D models enable us to look “through” rock pillars
2 and rock walls to compare floor configurations on either side (e.g., David et al. 2017), or to
3 ask how the development or removal of speleothems affected patterns of air flow through
4 cave passageways and mineral accretions on their painted walls (e.g., Delannoy et al. 2018).
5 Most importantly, archaeomorphology explores how people may be implicated in physical
6 changes to the place.
7
8
9

10 We here demonstrate the value of archaeomorphology to rock art research by
11 undertaking a detailed study of two areas of Borologa 1, a densely painted rock shelter on a
12 mushroom-shaped monolith in northwestern Australia’s Kimberley region. Despite a rich
13 ethnography and ongoing cultural knowledge of the art, much of the earlier rock art of this
14 region is enigmatic, both in terms of its age, and how it relates to past Indigenous cosmologies
15 and site use.
16
17
18
19
20
21
22

23 **Borologa in its landscape setting**

24 The Borologa rock shelters lie in Balangarra Country, of the Kwini-speaking peoples
25 of the east-central Kimberley region of northwestern Australia. The sites are on the northern
26 bank of the Drysdale River, just at the exit of a deep gorge incised into the hard quartzites of
27 the Carson Plateau (Kimberley Sandstone Group, of the Lower Proterozoic; Gellalty et al.
28 1965) (Fig. 1). Topographically slightly higher than the river, the Borologa site complex
29 consists of three large quartzite boulders (Borologa 1-3), each with rock art on its walls under
30 shallow overhangs (Fig. 2). The three shelters are at the base of an uneven, rock-strewn slope
31 that emanates from a rocky escarpment above and that extends to the river below. The shelters
32 are aligned at the base of the slope, slightly above an ancient alluvial terrace. That terrace is
33 clearly evident on both sides of the river, testimony of a significant phase in the valley’s
34 geological history (Fig. 3).
35
36
37
38
39
40
41
42
43
44

45 Located behind the terrace, the Borologa rock shelters (geologically “floats”) eroded
46 from the cliffline and came to lie in their current positions sometime after the Drysdale
47 River/*marraran* (Kwini word for “river”) had already incised the valley, destabilised the slope
48 and accumulated the flood deposits of the ancient terrace. The river’s wet season high water
49 levels and dry season low levels are clearly visible below the site (Figs 2 and 3). The
50 protected position of the three shelters above peak floodwaters is further evident by the
51 presence of accumulated aeolian sands at the mouth of the gorge and in front of Borologa 1,
52 the eastern-most rock shelter. Here a thick layer of wind-borne deposits has covered the upper
53
54
55
56
57
58
59
60
61
62
63
64
65

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

levels of the ancient terrace. That aeolian sand layer also lies above the current floodplain, where it remains undisturbed by floodwaters (Fig. 3).

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

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

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

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., Walsh 2000; 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 earliest to recent times (see also Taçon et al. 1997), 2) Irregular Infill Animal, 3) Gwion Gwion, consisting of 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 dates 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

1 decorated, has 446 individual motifs on 40 distinct art panels that extend to all sides of the
2 boulder except the northern, weathered side. The distribution of motif styles is as follows:

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

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

15
16
17
18
19
20
21
22
23
24
25
26
27
28 **Fig. 4** Examples of rock art panels from Borologa. A: Art Panel E4 dominated by
29 Static Polychrome figures, Borologa 1. B: Art Panel B1 dominated by Wanjina
30 figures, Borologa 1. C: Art Panel B1 dominated by Tassel Gwion Gwion figures,
31 Borologa 2. D: Art Panel B1 (Borologa 2) after D-stretch enhancement. E: Art
32 Panel G dominated by Static Polychrome figures, Borologa 3 (photos and digital
33 enhancement by Robert Gunn and Leigh Douglas)

34
35
36
37
38
39
40
41 At Borologa 1, a major panel (Art Panel B1) contains numerous superimposed
42 Wanjina paintings on an overhanging ceiling. Archaeological excavations were undertaken
43 under this overhang in 2016 and 2017, with the aim of finding now-buried exfoliated or
44 otherwise collapsed pieces of rock and associated archaeological deposits that could shed
45 light on the art's antiquity (David et al. 2019). Adjacent archaeological excavations were also
46 undertaken in 2016, at the edge of that same overhang. In addition to archaeological evidence
47 such as stone artefacts and occupational horizons, individually and together each of these
48 excavations revealed useful details on the history of the site's rock matrix, including the rock
49 surfaces that now bear the paintings (see below).

50
51
52
53
54
55
56
57
58
59 **How the Borologa sites attained their present positions and configurations**

1 The three Borologa sites differ in size and topographic position from many of the other
2 rock shelters on the edge of the plateau. The Borologa boulders, like those further upslope,
3 originated from the collapse of rock escarpments further up the plateau. Some of these
4 boulders are particularly imposing, measuring hundreds of cubic metres, as are sets of
5 adjoining boulders that have calved from cliff-lines and rolled or slid a few tens of metres
6 downslope.
7
8
9

10 More modest in size (5-6 m high), the Borologa 1-3 boulders align along the foot of
11 the slope. They all sit on a bedrock surface that appears to have acted as a landing platform,
12 blocking their further downhill movement (Genuite 2019) (Fig. 5). This bedrock surface
13 backs slightly above the ancient alluvial terrace, indicating that it was probably formed during
14 an earlier phase of incision by the Drysdale River.
15
16
17
18
19
20

21 **Fig. 5 Geomorphological context of the three Borologa sites (artwork: Jean-**
22 **Jacques Delannoy and Kim Genuite)**
23
24
25

26
27 Even though they are relatively well-aligned compared with the tilted blocks further
28 up the slope, there are slight but important differences in the layout of the three Borologa
29 boulders. Borologa 2 and 3 are both strongly tilted downwards towards the thalweg (the line
30 of lowest elevation of the valley floor of the Drysdale River), following the same direction as
31 the slope on which they sit. This orientation is not as pronounced at Borologa 1, and that
32 difference had important implications for the development of overhangs and human
33 habitability (Fig. 6). Borologa 2 and 3 thus contain low, shallow overhangs (0.8-1.2 m from
34 bedrock to overhang), whereas Borologa 1 developed a much higher (1.8-3.0 m), wider (5 m
35 from overhang to back wall) and longer (7 m length along the overhang parallel to back wall)
36 overhang facing the river. A small overhang facing Borologa 2 also formed at Borologa 1. It
37 is in the voids under these overhangs that Borologa's many extant rock paintings are found.
38
39
40
41
42
43
44
45
46
47
48

49 **Fig. 6 Comparative topography of the three Borologa boulders (artwork: Jean-**
50 **Jacques Delannoy)**
51
52
53

54
55 Fine sediments of alluvial and/or aeolian origins are only present on the downslope
56 periphery of the three rock shelters. Upslope to the side and back are many blocks either
57 tumbled down the slope or detached from the edges of the rock shelters themselves. A large
58
59
60
61
62
63
64
65

1 boulder near the eastern edge of Borologa 3 thus came from the latter when an overhang
2 collapsed, in much the same way that Borologa 2 became detached from Borologa 1 and
3 subsequently tilted until it came to abut against the bedrock (Fig. 5). In each case, the boulder
4 became isolated and attained its present position in the landscape sometime before the rock
5 paintings were made on the current walls of Borologa 1 and 2. We know this because in both
6 sites the art could only have been made after the now-painted rock walls of the outer
7 overhangs came into existence. This tells us that when the first paintings were made, the
8 orientation and landscape setting of the two sites were much like they are now.

9
10
11
12
13
14 Many large blocks can be seen under the outer edges of the overhangs at each of the
15 three Borologa sites, with the exception of the major overhang at Borologa 1. This exception
16 is also the overhang that contains the most densely painted ceiling, Art Panel B1 with its
17 many Wanjina paintings (Fig. 7). Here the few small blocks on the sandy floor are
18 incommensurate with the considerable mass vacated under the extensive flat ceiling. Had that
19 cavity already formed when the Borologa 1 boulder landed in its current position at the base
20 of the hill? Or are the collapsed blocks buried beneath in soft sediments? If they are buried in
21 stratified deposits, can we date their collapse? And how does the history of human occupation
22 and of the art articulate with the ceiling's collapse? To answer these questions, archaeological
23 excavations (David et al. 2019) and archaeomorphological investigations were undertaken
24 under the edge of the painted ceiling.
25
26
27
28
29
30
31
32
33
34
35

36 **Fig. 7** Southern side of Borologa 1. It is along this edge that the overhanging
37 ceiling of Art Panel B1 developed. Note the paucity of blocks on the floor under
38 and in front of the overhang, in contrast to the rock debris on the eastern side
39
40
41
42 (photo: Jean-Jacques Delannoy)
43
44
45

46 **Evidence from the archaeological excavations**

47 Three pits were excavated¹ in 2016-2017. Contiguous Squares C5-C6-D5-D6-D7-DV-
48 DIV were positioned beneath Art Panel B1, Squares E4, F5 and G5 along the outer edge of
49 the overhang (Fig. 8) (see David et al. 2019 for details of excavation methods).
50
51
52
53
54
55
56
57
58

59 ¹ Squares C5-C6-D5-D6-DV-DVI-D7 were excavated by Bruno David; Squares E4, F5 and G5 were excavated
60 by Peter Veth and Sven Ouzman, as part of the Australian Research Council's *Kimberley Vision* Linkage project.
61
62
63
64
65

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

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

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) thick. 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 inclined towards the Drysdale River (“6” on Fig. 9). While the gravels each measure a few centimetres long, their size increases with depth (“7” on Fig. 9). Both gravel components on Figure 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 quarzitic 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.

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

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.
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” on Fig. 9)

1 resting in angular discordance on the underlying blocks and sandy matrix rich in
2 pisolites. The angle of both the gravel surfaces and the layer in which they lie
3 indicates a slope of 10-15° dipping towards the south. The angled edges of Block 3
4 and other blocks of similarly moderate size were formed by fragmentation during the
5 collapse of the old overhang. This contrasts with the rounded edge of the visible parts
6 of Block 4, which came from the outer edge of the former overhang that had
7 weathered as a result of exposure to the elements.

- 8
9
10
11
12 4. Following the deposition of a layer of smaller gravels (“7” on Fig. 9) over the
13 collapsed blocks and gravel slope, sedimentation changed significantly. Aeolian sands
14 now become predominant, with 80-100 cm of sand covering the underlying rocky
15 layers in Square F5. These sands accumulated as a result of the “Venturi Effect”
16 caused by the nearby gorge, being the increased pressure and velocity that resulted
17 when fine particles of sediment were forced by wind through the gorge, redepositing
18 as winds slowed down at the exit of the gorge. Aeolian sands continue to be deposited
19 in this manner today, especially during the dry season when strong winds blow down
20 the valley.
21
22
23
24
25
26
27
28

29 Square F5’s stratigraphy thus brings initial answers as to why rockfall is absent beneath
30 and beyond Art Panel B1’s overhang: the rocks are now buried by sand. The Borologa 1
31 boulder had clearly undergone changes after landing in its current position. The buried layers
32 show that two phases of overhang collapse took place; these events are relatively old, as
33 suggested by their successive coverage by aeolian deposits. But this is only the start of what
34 we can say, as the stratigraphy in the neighbouring excavation squares, together with the
35 distribution of other rocks to the north of the sand sheet, reveal additional details.
36
37
38
39
40
41

42 This first set of observations is replicated by the sequence in Squares E4 and contiguous
43 Squares C5-C6-D5-D6-DV-DVI-D7, closer to Art Panel B1 (Fig. 10). Here the base of the
44 excavations again reveals blocks collapsed from an old overhang (Square E4) and from an
45 ancient ceiling (Squares DV-DVI-D5-D6-D7-C5-C6) that correspond with the second phase
46 of collapse evident in Square F5. Across all the excavated squares, these rocky layers angle
47 down southward toward the thalweg of the Drysdale River, as previously noted for Square F5.
48 Similarly, the gravels visible at the base of Square E4, continuing into Square F5, begin
49 immediately below the edge of the site’s current overhang. The gravels are largely absent
50 from the mass of collapsed blocks that came from the ceiling above Squares DV-DVI-D5-D6-
51 D7-C5-C6. This spatial partition of the gravels indicates that they mainly resulted from
52 erosion (gravitational collapse, thermoclastic exfoliation, etc.) of the upper surfaces and outer
53
54
55
56
57
58
59
60
61
62
63
64
65

1 edge of the overhang. This is due especially to the weakening of the edge of the shelter
2 following collapse of the old overhang (process of mechanical readjustment), and not from
3 the formation of the cavity and ceiling that now houses Art Panel B1. The production of these
4 gravels corresponds with a specific phase in the site's evolution: their near-absence in the
5 overlying aeolian sands indicates a marked slowing down of the boulder's geological
6 breakdown. The onset of pronounced aeolian sedimentation under the overhang and in front
7 of the site also marks a major phase in the environmental and geomorphological history of the
8 broader landscape. Aeolian sand accumulation at the site potentially relates to decreased
9 strength of the Indonesian-Australian summer monsoon in the Late Holocene (Denniston et
10 al. 2013), with "very dry conditions" interpreted for the Kimberley from coarsely dated pollen
11 records after c. 2750 cal BP (McGowan et al. 2012:2), and from oscillations in the wet-dry
12 phases of mound springs after c. 2600 cal BP (Field 2010; Field et al. 2017).

23 **Fig. 10 Stratigraphic drawing of the west wall of Squares F5-E4-DV-D5-C5, with**
24 **back-plotted radiocarbon dates on individual pieces of charcoal (artwork: Jean-**
25 **Jacques Delannoy, Bruno David and Kara Rasmanis)**

30 *Archaeological evidence from Squares DV-DVI-D5-D6-D7-C5-C6*

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

1
2 **Fig. 11** Large grinding stone moved, positioned and stabilised horizontally with
3
4 chock blocks under one corner, Squares C6-D6-DVI (photos and artwork: Jean-
5
6 Jacques Delannoy)
7
8

9 The archaeological excavations revealed the presence of camp fires immediately
10 above the collapsed strata of the old overhanging ceiling at the base of Squares DV-DVI-D5-
11 D6-D7-C5-C6. Here charcoal is present, the surface of the rock is burnt black and strongly
12 reddened for some depth, and exhibits heat-cracking. Radiocarbon dating of charcoal on the
13 rock surface at the very base of the sand layer effectively dates both the antiquity of this
14 occupation phase and the commencement of aeolian sand deposition to c. 2500-2700 cal BP,
15 with the collapse of the underlying ceiling slabs taking place sometime earlier (David et al.
16 2019). This onset of aeolian sedimentation c. 2500-2700 cal BP at Borologa 1 corresponds
17 well with a period of peak aridity beginning c. 2600-2750 cal BP across the Kimberley (Field
18 2010; McGowan et al. 2012; see above). This means that the physical setting fronting Art
19 Panel B1 was slightly different to now, as the floor consisted of large collapsed rock slabs
20 with expansive flat surfaces. Those collapsed slabs came from the ceiling or outer southern
21 side of the overhang. The height from floor to ceiling was then much greater than the height
22 of the alcove of Art Panel B1 is today. The distance to the ceiling has gradually decreased as
23 aeolian sediments have built up underfoot.
24
25
26
27
28
29
30
31
32
33
34
35

36 Bayesian modelling of the radiocarbon dates indicates that this part of the site then
37 saw a series of occupational events dated to within 2110-2370 cal BP, 1160-2080 cal BP,
38 760-1110 cal BP, 500-630 cal BP, and 120-480 cal BP (David et al. 2019). Each of these
39 occupational phases was separated by a hiatus variably lasting between 110 and 660 years.
40 The past 500-630 years saw much shorter spacing between occupations, within an
41 archaeological timescale at times giving the appearance of near-continuous occupation.
42
43
44
45
46
47

48 Finding out what the site looked like during its various phases of occupation requires
49 additional information on where the buried and surface blocks came from. This is the subject
50 of the next archaeomorphological analysis.
51
52
53

54 **Archaeomorphological investigations**

55 The paucity of blocks under the overhangs of the three Borologa boulders leads us to
56 question how the blocks that do occur got there. To do so, the thickness, petrographic
57
58
59
60
61
62
63
64
65

1 characteristics, and joints (e.g., frequency and amplitude of ripple-marks) of each rock
2 stratum making up the boulders were analysed in the field. In addition, in the laboratory thin
3 sections, mineralogical characterizations and quantifications of major chemical elements were
4 made of rock strata considered of special importance for this study (Appendix A; Fig. 12;
5 Delannoy et al., in preparation).
6
7
8
9

10 **Fig. 12** Side view of the west of Borologa 1, showing the boulder's rock strata
11 (D4-D25) that sit on those of the underlying bedrock (D0-D2U) (artwork: Jean-
12 Jacques Delannoy)
13
14
15
16

17 *The large excavated grinding stone*

18 The bedrock base (rock strata D0-D2) at Borologa 1 is lithologically distinctive from
19 the overlying boulder's rock strata (D4-D25). Although today it is hardly visible, rock stratum
20 D3 belongs with the latter and constitutes its base. In contact with the underlying bedrock, it
21 has been strongly compressed by the weight of the overlying rock mass.
22
23
24
25
26

27 None of the excavation squares reached bedrock, as boulders at the base of the squares
28 prevented further excavation. Given that the bedrock is deeper and thus precedes the layer of
29 aeolian sands and underlying rockfall, at least 2 m of bedrock would have been exposed to the
30 elements prior to the collapse of the outer overhang of Art Panel B1 (Fig. 12).
31
32
33
34

35 Petrographic analyses were also undertaken on the blocks found on the present ground
36 surface and in the excavations, enabling them to be matched with the Borologa 1 boulder's
37 rock strata (Fig. 13). The large blocks at the bottom of Square F5 correspond with an old
38 overhang that extended considerably further out along rock strata D13 and D14 than is the
39 case today. Their stratigraphic positioning indicates that the thick rock stratum D13
40 underwent a first episode of gravitational collapse, with collapsed blocks rolling down a slope
41 that was much steeper than it is today. A second collapse, mainly of rock stratum D14, led to
42 the retreat of the overhang to approximately where it is today. The sloping sediments of the
43 angular gravels in the lower levels of Square E4 sit over the blocks at the base of Squares F5
44 and DV-DVI-D5-D6-D7-C5-C6 (Fig. 13). This suggests that the gravels were deposited soon
45 after overhang collapses involving the lower (D5-D6) and upper (D14) rock strata, as well as
46 after the fall of a section of the rock stratum D4 ceiling that once covered part of Art Panel
47 B1. The gravels seen in the excavations represent a mechanical readjustment of the edge of
48 the overhang, mainly at rock strata D12 to D7. The morphology of Borologa 1's southern
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1
2 overhang, along with its Wanjina Art Panel B1 ceiling, largely formed after these undated
3 collapses, but before the aeolian sand layer had begun to accumulate (i.e., sometime before c.
4 2500-2700 cal BP).
5
6

7 **Fig. 13** Stratigraphic drawing of excavation Squares F5-E4-DV-D5-C5 under and
8 beyond the extant southern overhang of Borologa 1, showing which rock strata
9 the buried roof-fallen blocks came from (artwork: Jean-Jacques Delannoy)
10
11
12
13

14 The large grinding stone revealed in excavation Squares D5-D6-DV-DVI (Fig. 11) has
15 the same thickness, highly compacted fine quartz grain matrix, and light shade without dark
16 venules as rock stratum D6. But its isolated position and artificially raised flat orientation on
17 an ancient archaeological floor signals that it does not lie in its original position. Initially we
18 suspected that it may have originated from rock strata D5 and D6 of the overhang
19 immediately above it. But these rock strata had collapsed during earlier times, prior to the
20 accumulation of the aeolian sands in which the block now lies. And those collapsed rock
21 strata D5-D6 stretched uninterrupted across the base of the Squares DV-DVI-D5-D6-D7-C5-
22 C6 excavation pit, so it could not be duplicated by the isolated block higher up in the sand
23 layer. The stratigraphic sequence in adjacent Squares E4 and F5 also showed that here there
24 are no signs of rock strata D5 and D6 beyond the lower part of the ancient overhang (Fig. 13).
25 Moreover, there is no trace of the reddening (other than surface traces of ochre) on the large
26 grinding stone, which had affected all of the collapsed rock strata D5-D6 surface below the
27 aeolian sand in Squares DVI-D5-D6-D7-C5-C6. We thus looked elsewhere for the origin of
28 the large grinding stone.
29
30
31
32
33
34
35
36
37
38
39
40
41

42 Three metres to the west of Squares DVI-D5-D6-D7-C5-C6, collapsed blocks from
43 rock stratum D6 can be seen on the floor beneath the remnant overhang (orange blocks on
44 Fig. 14). These blocks are either stuck in a recess at the base of bedrock stratum D0, or found
45 among a rocky extension of this bedrock stratum slightly to the south. The fallen blocks have
46 the same geological characteristics as the large grinding stone found in the excavation. With
47 the aid of the 3D laser model, the individual collapsed blocks on the floor, along with the
48 grinding stone found in the excavation, were digitally extracted, measured and repositioned
49 onto their matching surfaces as unambiguously conjoining refits (Appendix B). In doing so,
50 the relative chronology of the collapsed blocks could be worked out by their relative positions
51 in the now-reassembled palaeo-overhang. This made it possible to determine that the large
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1 grinding stone found in the excavations (Block A in Fig. 14) conjoins perfectly with Block B
2 as part of a larger set of collapsed blocks that together refit onto the rock stratum D6 scar on
3 the extant overhanging ceiling.
4

5 Archaeomorphology conclusively shows that Block A had been moved a distance of at
6 least 3 m sometime following its collapse from the boulder, and positioned flat with the aid of
7 chock rocks on the ground surface immediately in front of what is now Art Panel B1. No
8 other collapsed block from rock stratum D6 possesses cupule-like depressions (which could
9 theoretically be found as dissolution marks on rock surfaces), further supporting the anthropic
10 nature of the shallow cupule on the ground and ochre-stained surface of Block A. No
11 transport agent other than people could have carried and balanced the rock to its position as
12 found in the excavation.
13
14
15
16
17
18
19
20

21 **Fig. 14** Repositioning of the large grinding stone buried mainly in Square D6 onto its
22 originating rock overhang 3 m away (artwork: Jean-Jacques Delannoy)
23
24
25
26

27 *The blocks on the eastern slope of Borologa 1*

28
29 The blocks lying on the present floor of Borologa 1 were investigated following the
30 same methods. Our aim was again to determine where they came from and how they got to lie
31 in their current positions, so as to better understand both their and the Borologa 1 boulder's
32 formation history.
33
34
35

36 Geomorphological mapping of the Borologa landscape (Fig. 15) revealed a range of
37 rocks along the Drysdale River's northern bank. As noted, Borologa 1-3 constitute the front of
38 a complex of massive boulders that slipped down the slope towards the ancient thalweg of the
39 Drysdale River. We note that the bedrock surface on which the three boulders came to rest
40 descends towards the Drysdale River in a series of stepped benches. Although alluvial and
41 then aeolian sediments largely conceal this underlying bedrock, a small "valley" descending
42 down the slope reveals the outcropping bedrock and further confirms that nowhere does the
43 base of the Borologa 1 excavation squares correspond with the level of the bedrock (Figs 15
44 and 16).
45
46
47
48
49
50
51
52

53 At Borologa 1, collapsed blocks are found mainly along its northern and northeastern
54 perimeter. We note the presence of many collapsed blocks along the edges of Borologa 2 and
55 3. There are few such blocks between Borologa 1 and Borologa 2 to the west and along
56 Borologa 1's southern perimeter, where we have argued that the overhang collapse is buried
57 beneath aeolian sands. Between Borologa 1 and Borologa 2, the blocks at ground level mainly
58
59
60
61
62
63
64
65

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

derive from fragmentation of the bedrock, which 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 perimeter 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 southeastern edges of the overhang attracted our attention. Here we focus on two sectors: the southeastern and SSW sections of Borologa 1.

Fig. 15 Geomorphological map of the three Borologa sites (artwork: 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: Jean-Jacques Delannoy)

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 2110-2370 cal BP. Slightly to the northeast of the excavation squares, a quartzite slab 1.7 m long × 1.0 m 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 15 and 8). 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 signals an anthropic installation: indeed, the natural fall of an overhanging slab that included this small section, totaling 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 mudwasp 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 9303-9530 cal BP (95.4% probability on Calib 7.10 using IntCal13 curve selection, with median of c. 9400 cal BP; Reimer et al. 2013) (Table 1; for sampling methodology, see Finch et al. 2019). The radiocarbon date signals that the slab must have detached sometime before c. 9300 cal BP.

Table 1 Radiocarbon date on mudwasp 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(8M)	35.04 ± 0.24	8420 ± 60

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. This means that the repositioning of the horizontally installed slab from its landing position took place sometime after the slab fell ≥ c. 9300 cal BP but no later than c. 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

1
2 by people, like the installed horizontal slab from rock stratum D4, indicate that the overall site
3 gradually took shape as a result of ongoing human engagements with its material matrix.
4

5 **Fig. 17** Southeastern edge of Borologa 1 with anthropically moved and flaked
6 blocks (photos: Jean-Jacques Delannoy)
7
8
9

10
11 **Fig. 18** Repositioned slab beneath the southeastern overhang of Borologa 1. A:
12 side view of the boulder, slab, and hill-slope. B: Rock stratum D4 slab conjoined
13 in its original position on the ceiling, as it would have laid before it fell. C: View of
14 the repositioned slab on the ceiling, from ground level. D: View of rock stratum
15 D4 slab's current position on the ground (purple), projected vertically up to the
16 ceiling. In red is the slab's original attached position prior to falling down. The
17 arrow indicates how people rotated the slab into its current position after it fell
18 from the ceiling (artwork: Jean-Jacques Delannoy)
19
20
21
22
23
24
25
26
27

28 **Fig. 19** Sample location of remnant mud wasp nest dated to 8420 ± 60 BP
29 (OZW423U2), subimposed under a striped painted motif on Art Panel B1. The
30 radiocarbon pretreatment method is detailed in Finch et al. (2019) (photos:
31 Damien Finch)
32
33
34
35
36
37

38 **Fig. 20** The densely painted Wanjina ceiling of Art Panel B1, Borologa 1, showing
39 where the rock stratum D4 slab currently lying horizontally on the ground
40 originally came from (infilled red), the edge of remnant rock stratum D4 on the
41 ceiling (dotted line), and the radiocarbon-dated mudwasp nest (photo: Robert
42 Gunn; artwork: Jean-Jacques Delannoy)
43
44
45
46
47
48
49

50 **Fig. 21** Repositioning of blocks fallen after the detachment and anthropic
51 removal of rock stratum D4 at the southern end of Borologa 1 (see Figs 17 and
52 18). A: Side view of the studied area. B: View up from ground level to the ceiling,
53 with Blocks 1, 2, 4 and the rock stratum D4 slab repositioned in their original
54 positions prior to falling. C: Blocks 1-3 conjoined in their original positions. Note
55 that prior to their collapse, Blocks 1-3 were attached to bedrock strata D0-D2
56
57
58
59
60
61
62
63
64
65

1
2 and not to the ceiling, nor did they then obstruct access to the ceiling with the
3 still-attached slab (artwork: Jean-Jacques Delannoy)
4

5 *Borologa 1's SSW alcove*
6

7 Under the overhang that marks the western edge of Borologa 1, there is evidence at
8 ground level of blocks that fell from the ceiling (brown blocks on Fig. 8) as well as other
9 blocks that do not seem to have come directly from the overlying walls and ceilings. Our
10 attention is drawn to this area by the presence of a 2 m-deep alcove (measured from the inner
11 edge of the outer overhang to its inner extremity) whose internal margins contain a range of
12 motifs on two distinct art panels (Fig. 22). Art Panel E9 includes several unidentified Gwion
13 Gwion figures, an Elegant Action Figure overlying a white geometric design, Kimberley
14 Stout figures, and an overlying yellow hand stencil. Art Panel E10 includes a set of fresh-
15 looking red hand prints and a row of underlying Elegant Action Figures. Together these
16 motifs represent a broad range of Kimberley rock art styles including Gwion Gwion, which
17 are one of the older, possibly terminal Pleistocene, rock art styles. In contrast, the outer face
18 of the isolated block (Art Panel E11) bears a Wanjina image overlying several indistinct
19 images also from the more recent periods.
20
21
22
23
24
25
26
27
28
29
30

31
32
33 **Fig. 22** SSW edge of Borologa 1, showing details of the worked alcove. A: Alcove
34 with the evacuated blocks on the ground, as they are today (the lighter-coloured
35 blocks). B: View inside the alcove. C: Negative flaking scars made along the base
36 of the isolated block *before* it fell from the ceiling (photos: Jean-Jacques
37 Delannoy)
38
39
40
41
42
43

44 An isolated quartzite block, 1.6 m long × 65 cm wide, sits on the flat surface of the
45 outer edge of the alcove. Its lower edge is raised by small slabs and it exhibits clear flaking
46 impact scars. A flat piece of rusted iron of a kind typically used to make “shovel-nose” spear
47 points across the region during the early European-contact period of the late 1800s has also
48 been placed under the block, and a quartzite rock on top of it. At the back of the block are a
49 number of small quartzite blocks each measuring between 19 and 25 cm long and 10 cm
50 thick. Both the larger block and the small pieces have a distinctive granular texture. A group
51 of 12 rocks, each 2.5-3.0 cm thick and with identical petrographic characteristics, are aligned
52 on the rock floor against the internal edge of the alcove that contains the paintings and hand
53
54
55
56
57
58
59
60
61
62
63
64
65

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

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 on 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 to ask not just about the presence and movements of rocks, but to consider also 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 “string” of blocks positioned on the exposed D1-D0 bedrock (Figs 8 and 24). Some 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

1
2
3
4 form of flaking scars and partly removed blocks (Fig. 25). These lines of evidence confirm
5 that this alcove space was the location of purposeful human action that involved a sequence of
6 steps:

- 7 1) Progressive removal of rock stratum D2M.
- 8 2) As the width of the alcove was cleared, the blocks from rock stratum D4 were
9 removed.
- 10 3) This chaîne opératoire or production sequence was repeated until the alcove space
11 attained its current size.
12
13

14 Today's isolated blocks (Block 1 on Fig. 25 and the moved block on Fig. 24) in the alcove
15 mark the unfinished anthropic expansion of the alcove space. It was only at the end of this
16 process of evacuation of blocks that the paintings and hand prints on the inner edge of the
17 alcove could have been made, and it is from this inner location that remnant but partly
18 evacuated Block 1 originally came.
19
20
21
22
23
24

25 **Fig. 23** Repositioned fallen and moved block from the SSW alcove of Borologa 1.
26 A, B: Side view and view up from the ground with the current position of the
27 blocks projected up onto the rock. C, D: Side view and view up from the ground
28 with the remnant block conjoined onto its original position against the ceiling
29 and side wall, prior to its detachment and evacuation from the alcove by people
30 (artwork: Jean-Jacques Delannoy)
31
32
33
34
35
36
37
38

39 **Fig. 24** Conjoining of anthropically moved blocks in the northern part of the
40 alcove on the west side of Borologa 1 (photos and artwork: Jean-Jacques
41 Delannoy)
42
43
44
45

46 **Fig. 25** Repositioned fallen and evacuated blocks from the SSW alcove of
47 Borologa 1. A: View upwards from the ground with the present position of rock
48 stratum D4 blocks projected upwards onto the alcove's ceiling. B: View upwards
49 from ground level with the conjoined rock stratum D4 blocks repositioned onto
50 their original alcove surface. C: The fallen and evacuated blocks digitally
51 conjoined back together with the help of the 3D laser scans finding clearly
52 matching surface sizes and morphologies. D: Side view of the alcove prior to the
53 fall and evacuation of rock stratum D4 (artwork: Jean-Jacques Delannoy)
54
55
56
57
58
59
60
61
62
63
64
65

1
2 **Discussion**

3 A focused archaeomorphological study of Borologa enabled a hitherto unimagined
4 dimension of the history of rock art-making in this part of northern Australia. While the art
5 creates a highly visual expression of past cultural activity that immediately calls on our
6 attention as researchers, it was by focusing as much on the canvas, on the rock that supports
7 the art, that past human activities relating to the formation of the subsequently painted art
8 panels was revealed. It enabled a differently nuanced and longer-term biography for
9 Borologa.
10

11 The narrative generated through a combined archaeological and geomorphological
12 approach also begs a multi-scale viewing that shifts between the minutiae of each rock and a
13 broader landscape perspective, with each spatial scale informing the other scales. Beginning
14 in geological time, Borologa’s present environment was established as the Drysdale River
15 incised through the quartzite plateau, destabilising its developing slopes. This caused large
16 masses of rock such as the Borologa boulders to slide down (Genuite 2019). Cosmogenic
17 dates obtained from slid and rolled blocks on the upper parts of the slope (Fig. 3) have dated
18 such movements to c. 90,000-130,000 years ago (Cazes 2019). Given the lay of the land and
19 location of the source rock outcrops near and at the top of the plateau, the blocks at the
20 bottom of the slope were among the first to have slid or rolled down, with progressively
21 younger blocks found up-slope. The three Borologa boulders are thus considerably older than
22 100,000 years old. Once settled on their landing bedrock base (rock strata D2-D0),
23 mechanical and equilibrium readjustments led to the detachment of Borologa 2 from Borologa
24 1, and of a large section from Borologa 3.
25

26 In the absence of direct dates, it is more difficult to determine the age of the upper
27 alluvial terrace but it, too has its genesis in geological time, given that it lies higher than – and
28 thus predates – the current Drysdale River channel.
29

30 It is this general landscape setting that people encountered when they first came to
31 Borologa. The three rock shelters experienced many occupational events, as indicated by the
32 archaeological excavations, rock art, and evidence of workings of the shelters’ rock walls and
33 ceilings. The earliest evidence of people comes in the form of the Irregular Infill Animal and
34 Gwion Gwion paintings that on regional stylistic grounds have long been theorized to be
35 terminal Pleistocene in age (e.g., Lewis 1988). A recent program of radiocarbon dating mud
36 wasp nests lying under (giving maximum ages for the paintings) and over (minimum ages)
37 Gwion Gwion paintings “support[s] the proposition that the Gwion motifs in this study were
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1 painted between 12-13 ka cal BP”, including one painting with dated mud wasp nests both
2 under and over the art, securely bracketing its age within the period c. 11,500-12,600 cal BP
3 (Finch et al. in press). One other painting has a minimum age of c. 17,000 cal BP, suggesting
4 that while most of the Gwion Gwion paintings in this region were painted over a relatively
5 short period of time, some Gwion Gwion motifs may be more than 4000 years older (Finch et
6 al. in press).
7
8
9

10
11 The most recent activities at Borologa relate to the time of the Wanjina figures and
12 include the inclusion of a metal bar beneath a block at Borologa 1, and date to the end of the
13 nineteenth or beginning of the twentieth century CE. These findings are also consistent with
14 the radiocarbon dates obtained on a mudwasp nest at Borologa 1, signaling that a massive slab
15 (parts of which are visible at the base of excavation Squares C5-DVI) fell sometime before c.
16 9300 cal BP. They are also consistent with the mineral encrustation of a low-lying rock c.
17 7200 cal BP (6260 ± 70 BP (OZW427U1) on calcium oxalate) at Borologa 3 (Delannoy et al.,
18 in preparation). The timing of the wasp nest and mineral encrustation at the two sites confirm
19 that the physical environment of the Borologa sites has remained similar for at least the past c.
20 9300 years. The changes relating to the deposition of aeolian sediments in front of Borologa 1
21 are more recent.
22
23
24
25
26
27
28
29
30

31 The high spatial resolution archaeomorphological study of two key areas of Borologa
32 1 emphasises that this densely painted site is also an anthropically constructed and mediated
33 architectural space that developed through time as a result of planned and coordinated
34 engagements with the materiality of the rock. These rock-workings often preceded the
35 painting episodes. For example, before the Elegant Action and Kimberley Stout Figures (both
36 styles thought to be Late Pleistocene or Early Holocene in age) were painted in the SSW
37 alcove, and before the Kimberley Stout figures and Wanjina were painted on the ceiling in the
38 southeastern part of the site, the rock had been hollowed out to create alcoves (Fig. 26). These
39 two areas are not the only ones to have involved stone-working at Borologa. The
40 northwestern margin of Borologa 1, and the entire southern margin of Borologa 3 show
41 significant signs of anthropic transformation (for details, see Delannoy et al., in preparation).
42
43
44
45
46
47
48
49
50
51
52

53 **Fig. 26** The SSW and southeastern sections of Borologa 1 presented in this paper,
54 with some of their art panels and blocks moved by people (artwork and photos:
55 Jean-Jacques Delannoy and Robert Gunn)
56
57
58
59
60
61
62
63
64
65

1 The physical matrix of the SSW, southern and southeastern sections of Borologa 1
2 were worked by people well before the accumulation of aeolian sands c. 2500-2700 cal BP.
3 Collapsed ceilings and edges of shallow overhangs have been found below the aeolian sands
4 but remain undated and blocks from these rockfalls were moved by people in the past (Figs
5 14, 17, 22 and 24). Irrespective of their age, these stone-workings not only led to the creation
6 of new cavities with fresh rock surfaces, and to the creation of new site furniture (e.g., ochre
7 grinding stone and horizontal slab) as focal locations of social activity; they also changed how
8 walls and ceilings could be accessed at a time well before the deposition of aeolian sands
9 (Figs 27 and 28). Purposeful installations such as the positioned horizontal rock stratum D4
10 slab on the floor of the southeastern edge of the site, and the evacuation of blocks from the
11 SSW alcove, enhanced access to rock surfaces in these two locations where the highest extant
12 art panels occur immediately above the horizontal slab and worked alcove.
13
14
15
16
17
18
19
20
21
22

23 **Fig. 27** The southeastern side of Borologa 1's life history through time, as
24 reconstructed from geomorphological, archaeological and archaeomorphological
25 evidence (artwork: Jean-Jacques Delannoy)
26
27
28
29
30

31 **Fig. 28** The SSW side of Borologa 1 through time, as reconstructed from
32 geomorphological, archaeological and archaeomorphological evidence (artwork:
33 Jean-Jacques Delannoy)
34
35
36
37
38

39 Beyond these apparent associations between the painted high walls or ceilings and
40 physical modifications through stone-working, it is now also clear that both Borologa 1 and
41 Borologa 3 have undergone substantially more anthropic stone-working than just the two
42 examples presented here (for further details, see Delannoy et al., in preparation). The
43 magnitude of human engagements with the rock revealed here is easily lost if we don't
44 consider the total mass of rock that people worked on. Taking into account only the manually
45 evacuated rock visible at ground level and that found in the archaeological excavations from
46 these two areas, c. 3.5 tonnes of rock were manually extracted and, in some cases, further
47 moved to new selected locations by people. More than 2.5 tonnes of currently visible rock
48 was manually removed from the SSW alcove alone, including the 270 kg block moved to, and
49 abandoned at, the edge of the alcove. In total, nearly 4.5 tonnes of rock were moved by people
50 at Borologa 1, 2 and 3 combined (Delannoy et al., in preparation).
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

1 Comparing these findings with those of Nawarla Gabarnmang on the Arnhem Land
2 plateau 700 km to the east sheds further valuable light on past social relations across the two
3 regions. Much like the alcove of Borologa 1, where a large block was left only partly
4 evacuated on the rock shelf, so, too, at Nawarla Gabarnmang do we find unfinished stone-
5 workings, with large blocks having been abandoned along their paths out of the site. In both
6 cases the extraction of large blocks to create cavities, and the cessation of unfinished works
7 within these densely painted sites, date to Late Pleistocene times. At Nawarla Gabarnmang,
8 the cessation of massive rock-workings dates to c. 11,000 cal BP. As at Borologa, this stone-
9 working predates the 1391 extant motifs on 42 ceiling panels and many of the c. 500 motifs
10 on the pillars, which are overwhelmingly Late Holocene in age (Castets 2017; Delannoy et al.
11 2017, 2018; Gunn 2018). At Borologa 1, the wasp nest radiocarbon date indicates that the
12 large painted rock surface of the southeastern alcove formed more than c. 9300 cal BP: the
13 ceiling could only have been painted after the evacuation of the rock from its cavity. But the
14 vast majority of paintings are more recent, as indicated by the presence of the oldest style on
15 top of the wasp nest, absence of the earliest recognisable Kimberley styles (e.g., Irregular
16 Infill Animal, Tassel Gwion Gwion etc.), and the predominance of Late Holocene Wanjina
17 figures. In the SSW alcove the rock must also have been extracted during Late Pleistocene or
18 Early Holocene times, for both Elegant Action and Kimberley Stout figures were painted in
19 the hollowed-out cavity. Both at Nawarla Gabarnmang and at Borologa, it is the extraction of
20 rock at a massive scale, and with this the creation of new alcoves and rock surfaces, that set
21 the foundation for new artworks. Those two regions were connected during this period by a
22 land bridge that became submerged with post-glacial rising sea levels near the Pleistocene-
23 Holocene boundary. Art styles on either side of this land bridge, from the Kimberley (e.g.,
24 Irregular Infill Animal, Gwion Gwion) in the west to Arnhem Land (e.g., Large Naturalistic
25 Animals, Dynamic figures) in the east, were iconographically comparable when the two
26 regions were linked by a land bridge, but began to differentiate stylistically with rising seas
27 that eventually separated them in the Early Holocene (Lewis 1988). Significantly, a common
28 practice of massive stone-working to hollow-out rock shelters can now be shown also to
29 signal this shared community of culture across this broad landscape during the land bridge
30 phase of the Late Pleistocene.

31 The Borologa physical and cultural landscape, like landscapes everywhere, is not and
32 has never been fixed. This is not just a statement of geological scale or process but also one of
33 the “anthropo-scene”. It would be an archaeological shortcoming to treat rock art sites as
34 made up of “natural” caves or rock shelters onto which “cultural” artworks were passively
35

1 placed. Rather, as the Borologa case demonstrates, through social engagements physical
2 landscapes are culturally shaped, and it is a key role of archaeology to try to determine the
3 specific forms of such engagements and landscape constructions. Landscapes are “the
4 arrangement in physical space of artifacts and activity” (Duncan 1976:391). To understand
5 the art let us try to better understand when and how the rock canvas that supports it was
6 created. After all, it is this engagement with the rock that from the onset enabled the art to be
7 put in place.

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

18 **References**

- 19
20 Arias, P., & Ontañón, R. (2012). La Garma (Spain): Long-term human activity in a karstic
21 system. In K. A. Bergsvik & R. Skeates (Eds), *Caves in context: The cultural*
22 *significance of caves and rockshelters in Europe* (pp. 101–117). Oxford: Oxbow
23 Books.
24
25
26
27 Barker, B., Lamb, L., Delannoy, J.-J., David, B., Gunn, R., Chalmin, E., Castets, G., Aplin,
28 K., Sadier, B., Moffat, I., Mialanes, J., Katherine, M., Geneste, J.-M., & Hoerle, S.
29 (2017). Archaeology of the ‘*Genyornis*’ site, western Arnhem Land: Determining the
30 age of the ‘*Genyornis*’ painting. In B. David., P. S. C. Taçon, J.-J. Delannoy & J.-M.
31 Geneste (Eds), *The archaeology of rock art in western Arnhem Land, northern*
32 *Australia* (pp. 423–496). Terra Australis 47. Canberra: ANU Press.
33
34
35
36
37
38 Bradley, R. (1997). *Rock Art and the Prehistory of Atlantic Europe: Signing the Land*.
39 London: Routledge.
40
41
42 Casey, E. S. (2001). Body, self, and landscape: A geophilosophical inquiry into the place-
43 world. In P. C. Adams, S. Hoelscher, & K. E. Till (Eds), *Textures of place: Exploring*
44 *humanist geographies* (pp. 403–425). Minneapolis: University of Minnesota Press.
45
46
47 Castets, G. (2017). Apports de l’analyse des matières colorantes et colorées dans l’étude
48 intégrée d’un site orné. Unpublished PhD thesis, Université Grenoble Alpes,
49 Grenoble.
50
51
52
53 Cazes, G. (2019). Landscape evolution of the Kimberley region, NW Australia, and the dating
54 of Aboriginal rock art with cosmogenic nucleides. Unpublished PhD thesis, University
55 of Wollongong, Wollongong.
56
57
58 Chippindale, C., & Nash, G. (2004). *The Figured Landscapes of Rock-Art: Looking at*
59 *Pictures in Place*. Cambridge: Cambridge University Press.
60
61
62
63
64
65

- 1 David, B., & Chant, D. (1995). Rock art and regionalization in north Queensland prehistory.
2 *Memoirs of the Queensland Museum*, 37(2), 357–528.
- 3 David, B., Delannoy J.-J., Gunn, R., Chalmin, E., Castets, G., Petchey, F., Aplin, K.,
4 O’Farrell, M., Moffat, I., Mialanes, J., Geneste, J.-M., Barker, B., Sadier, B.,
5 Katherine, M., Manataki, M., & Pietrzak, U. (2017). Dating painted Panel E1 at
6 Nawarla Gabarnmang, southern Arnhem Land plateau. In B. David., P. S. C. Taçon,
7 J.-J. Delannoy & J.-M. Geneste (Eds), *The archaeology of rock art in western Arnhem*
8 *Land, northern Australia* (pp. 245–302). Terra Australis 47. Canberra: ANU Press.
- 9 David, B., Delannoy, J.-J., Petchey, F., Gunn, R. G., Huntley, J., Veth, P., Genuite, K., Skelly,
10 R. J., Mialanes, J., Harper, S., Ouzman, S., Heaney, P., & Wong, V. (2019). Dating
11 painting events through by-products of ochre grinding: Borolaga, Kimberley,
12 Australia. *Australian Archaeology*, 85(1), 57–94.
- 13 Delannoy J.-J., Geneste, J.-M., Jaillet, S., Boche, E., & Sadier, B. (2012). Les aménagements
14 et structures anthropiques de la grotte Chauvet-Pont d’Arc: Apport d’une approche
15 intégrative géomorpho-archéologique. *Karsts, Paysages et Préhistoire*, 13, 43–62.
- 16 Delannoy J.-J., David B., Geneste, J.-M., Gunn, R., & Katherine, M. (2017). Engineers of the
17 Arnhem Land plateau: Evidence for the origins and transformation of sheltered spaces
18 at Nawarla Gabarnmang. In B. David., P. S. C. Taçon, J.-J. Delannoy & J.-M. Geneste
19 (Eds), *The archaeology of rock art in western Arnhem Land, northern Australia* (pp.
20 197–244). Terra Australis 47. Canberra: ANU Press.
- 21 Delannoy J.-J., David, B., Gunn, R., Geneste, J.-M., & Jaillet, S. (2018).
22 Archaeomorphological mapping: Rock art and the architecture of place. In B. David,
23 & I. J. McNiven (Eds), *The Oxford handbook of the archaeology and anthropology of*
24 *rock art* (pp. 833–856). Oxford: Oxford University Press.
- 25 Denniston, R. F., Wyrwoll, K.-H., Polyak, V. J., Brown, J. R., Asmerom, Y., Wanamaker Jnr,
26 A. D., LaPointe, Z., Ellerbroek, R., Bathelmes, R., Cleary, D., Cugley, J., Woods, D.,
27 & Humphreys, W. F. (2013). A stalagmite record of Holocene Indonesian-Australian
28 summer monsoon variability from the Australian tropics. *Quaternary Science Reviews*,
29 78, 155–168.
- 30 Duncan Jnr., J. S. (1976). Landscape and the communication of social identity. In A.
31 Rapoport (Ed.), *The mutual interaction of people and their built environment* (pp.
32 391–401). The Hague: Mouton Publishers.
- 33 Field, E. (2010). Unlocking the Kimberley’s past: The applicability of organic spring deposits
34 for reconstructing late Quaternary climatic and environmental change. Unpublished

1 PhD thesis, School of Earth and Environmental Sciences, The University of
2 Queensland, St. Lucia.

- 3 Field, E., McGowan, H. A., Moss, P. T., & Marx, S. K. (2017). A late Quaternary record of
4 monsoon variability in the northwest Kimberley, Australia. *Quaternary International*,
5 449, 119–135.
6
7
8
9 Finch, D., Gleadow, A., Hergt, J., Levchenko, V. A., & Fink, D. (2019). New developments
10 in the radiocarbon dating of mud wasp nests. *Quaternary Geochronology*, 51, 140–
11 154.
12
13
14 Finch, D., Gleadow, A., Hergt, J., Levchenko, V. A., Heaney, P., Veth, P., Harper, S.,
15 Ouzman, S., Myers, C., & Green, H. (in press). 12,000-year old Aboriginal rock art
16 from the Kimberley region, Western Australia. *Science Advances*.
17
18
19 Gellaly, D. C., Sofoulis, J. L., & MacGovern, J. L. (1965). *Drysdale-Londonderry (Western*
20 *Australia): Australia 1:250,000 geological series – SDR5-9.5*. Perth: Bureau of
21 Mineral Resources Geology and Geophysics.
22
23
24
25 Genuite K. (2019). Paléogéographies et reconstitution géomorphologique 3D: Application
26 aux environnements de sites ornés. Unpublished PhD thesis, Université Grenoble
27 Alpes, Grenoble.
28
29
30
31 Gjerde, J. M. (2010). Rock art and landscapes: Studies of Stone Age rock art from northern
32 Fennoscandia. Unpublished PhD thesis, University of Tromsø, Tromsø.
33
34
35 Green, H., Gleadow, A., Finch, D., Hergt, J., & Ouzman, S. (2017). Mineral deposition
36 systems at rock art sites, Kimberley, northern Australia – field observations. *Journal*
37 *of Archaeological Science: Reports*, 14, 340–352.
38
39
40
41 Gunn, R. G. (2018). *Art of the ancestors: Spatial and temporal patterning in the ceiling rock*
42 *art of Nawarla Gabarnmang, Arnhem Land, Australia*. Oxford: Archaeopress.
43
44
45 Gunn, R. G., David, B., Douglas, L., Delannoy, J.-J., Harper, S., Heaney, P., Ouzman, S., &
46 Veth, P. (in press). ‘Kimberley Stout Figures’: A proposed new motif type in
47 Kimberley rock art, northwestern Australia. *Australian Archaeology*.
48
49
50
51 Jaillet, S., Delannoy, J.-J., Monney, J., & Sadier, B. (2018). 3-D modelling in rock art
52 research: Terrestrial laser scanning, photogrammetry and the time factor. In B. David,
53 & I. J. McNiven (Eds), *The Oxford handbook of the archaeology and anthropology of*
54 *rock art* (pp. 811–831). Oxford: Oxford University Press.
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
- Meirion Jones, A., Freedman, D., O'Connor, B., Landin-Whymark, H., Tipping, R., & Watson, A. (2011). *An Animate Landscape: Rock Art and the Prehistory of Kilmartin, Argyll, Scotland*. Oxford: Windgather Press.
- McGowan, H. A., Marx, S. K., Moss, P. T., & Hammond, A. (2012). Evidence of ENSO mega-drought triggered collapse of prehistory Aboriginal society in northwest Australia. *Geophysical Research Letters*, 39(22), 1–5.
- Monney, J., & Jaillet, S. (2019). Fréquentations humaines, ornementation pariétale et processus naturels: Mise en place d'un cadre chronologique pour la grotte aux Points d'Aiguèze. *Karstologia*, 73, 49–62.
- Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Buck, C. E., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M. & van der Plicht, J. (2013). IntCal13 and Marine13 radiocarbon age calibration curves, 0-50,000 years cal BP. *Radiocarbon*, 55(4), 1869–1887.
- Ross, J., Westerway, K., Travers, M., Morwood, M. J., & Hayward, J. (2016). Into the past: A step towards a robust Kimberley rock art chronology. *PLoS ONE*, 11(8), e0161726. doi:10.1371/journal.pone.0161726.
- Taçon, P. S. C., Fullagar, R., Ouzman, S., & Mulvaney, K. (1997). Cupule engravings from Jinmium-Granilpi (northern Australia) and beyond: Exploration of a widespread and enigmatic class of rock markings. *Antiquity*, 71(274), 942–965.
- Veth, P., Myers, C., Heaney, P., & Ouzman, S. (2018). Plants before farming: The deep history of plant-use and representation in the rock art of Australia's Kimberley region. *Quaternary International*, 489, 26–45.
- Welch, D. (1993). The early rock art of the Kimberley, Australia: Developing a chronology. In J. Steinberg, A. Watchman, P. Faulstich & P. S. C. Taçon (Eds), *Time and space: Dating and spatial considerations in rock-art research* (pp. 13–21). Occasional AURA Publication 8. Melbourne: Australian Rock Art Research Association.
- Welch, D. (2015). *Aboriginal paintings of Drysdale River National Park, Kimberley, Western Australia*. Coolalinga: David M. Welch.
- Welch, D. (2016). *From Bradshaw to Wandjina: Aboriginal paintings of the Kimberley Region, Western Australia*. Coolalinga: David M. Welch.

Captions for Figures

1
2 **Fig. 1** Location of Borologa, Drysdale River, Kimberley, Australia (artwork: Jean-Jacques
3 Delannoy)
4

5 **Fig. 2** Location of the three Borologa rock shelters in its Drysdale River valley setting (photo:
6 Jean-Jacques Delannoy)
7

8
9 **Fig. 3** Landscape features downstream of the Drysdale River gorge, showing the location of
10 Borologa (cartography: Kim Genuite)
11

12 **Fig. 4** Examples of rock art panels from Borologa. A: Art Panel E4 dominated by Static
13 Polychrome figures, Borologa 1. B: Art Panel B1 dominated by Wanjina figures,
14 Borologa 1. C: Art Panel B1 dominated by Tassel Gwion Gwion figures, Borologa 2.
15 D: Art Panel B1 (Borologa 2) after D-stretch enhancement. E: Art Panel G dominated
16 by Static Polychrome figures, Borologa 3 (photos and digital enhancement by Robert
17 Gunn and Leigh Douglas)
18
19
20
21
22

23 **Fig. 5** Geomorphological context of the three Borologa sites (artwork: Jean-Jacques Delannoy
24 and Kim Genuite)
25
26

27 **Fig. 6** Comparative topography of the three Borologa boulders (artwork: Jean-Jacques
28 Delannoy)
29
30

31 **Fig. 7** Southern side of Borologa 1. It is along this edge that the overhanging ceiling of Art
32 Panel B1 developed. Note the paucity of blocks on the floor under and in front of the
33 overhang (photo: Jean-Jacques Delannoy)
34
35

36 **Fig. 8** High resolution archaeomorphological map of Borologa 1 (artwork: Jean-Jacques
37 Delannoy)
38
39

40 **Fig. 9** Details of the geomorphology of Square F5 (artwork and photos: Jean-Jacques
41 Delannoy)
42
43

44 **Fig. 10** Stratigraphic drawing of the west wall of Squares F5-E4-DV-D5-C5 (artwork: Jean-
45 Jacques Delannoy, Bruno David and Kara Rasmanis)
46

47 **Fig. 11** Large grinding stone moved, positioned and stabilized horizontally with chock blocks
48 under one corner, Squares C6-D6-DVI (photos and artwork: Jean-Jacques Delannoy)
49
50

51 **Fig. 12** Side view of the west of Borologa 1, showing the boulder's rock strata (D4-D25) and
52 sitting on those of the underlying bedrock (D0-D2U) (artwork: Jean-Jacques
53 Delannoy)
54
55

56 **Fig. 13** Stratigraphic drawing of excavation Squares F5-E4-DV-D5-C5 under and beyond the
57 extant southern overhang of Borologa 1, showing which rock strata the buried roof-
58 fallen blocks came from (artwork: Jean-Jacques Delannoy)
59
60
61
62
63
64
65

1 **Fig. 14** Repositioning of the large grinding stone found buried mainly in Square D6 onto its
2 originating rock overhang 3 m away (artwork: Jean-Jacques Delannoy)

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

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

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

9 **Fig. 18** Repositioned slab beneath the southeastern overhang of Borologa 1. A: side view of
10 the boulder, slab, and hill-slope. B: Rock stratum D4 slab conjoined in its original
11 position on the ceiling, as it would have laid before it fell. C: View of the repositioned
12 slab on the ceiling, from ground level. D: View of rock stratum D4 slab's current
13 position on the ground (purple), projected vertically up to the ceiling. In red is the
14 slab's original attached position prior to falling down. The arrow indicates how people
15 rotated the slab into its current position after it fell from the ceiling (artwork: Jean-
16 Jacques Delannoy)

17 **Fig. 19** Sample location of remnant mud wasp nest dated to 8420 ± 60 BP (OZW423U2),
18 subimposed under a striped painted motif on Art Panel B1. The radiocarbon
19 pretreatment method is detailed in Finch et al. (2019) (photos: Damien Finch)

20 **Fig. 20** The densely painted Wanjina ceiling of Art Panel B1, Borologa 1, showing where the
21 rock stratum D4 slab currently lying horizontally on the ground originally came from
22 (infilled red), the edge of remnant rock stratum D4 on the ceiling (dotted line), and the
23 radiocarbon-dated mudwasp nest.

24 **Fig. 21** Repositioning of blocks fallen after the detachment and anthropic removal of rock
25 stratum D4 at the southern end of Borologa 1 (see Figs 17 and 18). A: Side view of the
26 studied area. B: View up from ground level to the ceiling, with Blocks 1, 2, 4 and the
27 rock stratum D4 slab repositioned in their original positions prior to falling. C: Blocks
28 1-3 conjoined in their original positions (artwork: Jean-Jacques Delannoy)

29 **Fig. 22** SSW edge of Borologa 1, showing details of the worked alcove. A: Alcove with the
30 evacuated blocks on the ground, as they are today (the lighter-coloured blocks); B:
31 View inside the alcove. C: Negative flaking scars made along the base of the isolated
32 block *before* it fell from the ceiling (photos: Jean-Jacques Delannoy)

33 **Fig. 23** Repositioned fallen and moved block from the SSW alcove of Borologa 1. A, B: Side
34 view and view up from the ground with the current position of the blocks projected up

1 onto the rock. C, D: Side view and view up from the ground with the remnant block
 2 conjoined onto its original position against the ceiling and side wall, prior to its
 3 detachment and evacuation from the alcove by people (artwork: Jean-Jacques
 4 Delannoy)
 5
 6

7 **Fig. 24** Conjoining of anthropically moved blocks in the northern part of the alcove on the
 8 west side of Borologa 1 (photos and artwork: Jean-Jacques Delannoy)
 9

10 **Fig. 25** Repositioned fallen and evacuated blocks from the SSW alcove of Borologa 1. A:
 11 View upwards from the ground with the present position of rock stratum D4 blocks
 12 projected upwards onto the alcove's ceiling. B: View upwards from ground level with
 13 the conjoined rock stratum D4 blocks repositioned onto their original alcove surface.
 14 C: The fallen and evacuated blocks digitally conjoined back together with the help of
 15 the 3D laser scans finding clearly matching surface sizes and morphologies. D: Side
 16 view of the alcove prior to the fall and evacuation of rock stratum D4 (artwork: Jean-
 17 Jacques Delannoy)
 18
 19
 20
 21
 22
 23
 24

25 **Fig. 26** The SSW and southeastern sections of Borologa 1 presented in this paper, with some
 26 of their art panels and blocks moved by people (artwork and photos: Jean-Jacques
 27 Delannoy and Robert Gunn)
 28
 29
 30

31 **Fig. 27** The southeastern side of Borologa 1 through time, as reconstructed from
 32 geomorphological, archaeological and archaeomorphological evidence (artwork: Jean-
 33 Jacques Delannoy)
 34
 35

36 **Fig. 28** The SSW side of Borologa 1 through time, as reconstructed from geomorphological,
 37 archaeological and archaeomorphological evidence (artwork: Jean-Jacques Delannoy)
 38
 39
 40
 41

42 **Appendix A** Basic petrographic description of Borologa 1's rock strata

43
 44
 45
 46
 47
 48
 49
 50
 51
 52
 53
 54
 55
 56
 57
 58
 59
 60
 61
 62
 63
 64
 65

Rock stratum	Thickness (cm)	Petrographic characteristics
D25		
D24		
D23		
D22		
D21		
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	Homogeneous set of sub-layers with fine grains and moderate compaction, characterised by cross-bedded light- and grey-colours. These layers are separated by four micro-joints of clearly distinguishable horizontal strata.
		D: 25 cm	
		C: 22 cm	
		B: 12 cm	
	A: 20 cm		
D12	25-15	Homogeneous light grey with clearly distinguishable fine bedding; the base is marked by a layer of dark compact layer of variable thickness	
D11	B: 30	Two 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 that sub-divides in two sub-layers. 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-colour horizontal level	
D7	35-40	Homogeneous set of micro-layers characterised with oblique beds (relative 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 three layers: <ul style="list-style-type: none"> • Upper layer (28 cm thick): alternating light-coloured and grey beds (medium to fine grains) • Middle layer (12 cm thick): thin, light coloured of coarse-grained alternating beds (2-3 cm) • 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 sub-parallel 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 B 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 m². One hundred and seventy-four scan scenes and c. 700 billion points were recorded in the field. The 3D mapping was conducted to investigate research questions requiring a range of spatial scales, and thus vary in resolution and mapping

accuracy across the landscape (higher resolution mapping was undertaken near the rock shelters; coarser-grainer mapping took place near the cliff-line). 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
A: Survey method	Short-range TLS + sphere registration
B: Point cloud accuracy	1 cm
C: Point cloud density	2 cm
D: Mesh accuracy	2 cm
E: Delaunay 3D triangle mean size	8 cm
F: Mapping tool	Faro Focus 3D 360 (2012)
	Borologa 1 rock shelter and nearby blocks
A	Short-range TLS + sphere registration
B	1 mm
C	6 mm
D	3 mm
E	1.2 cm
F	Faro Focus 3D 360 (2012)
	Squares C5-C6-D5-D6-DV-DVI excavation pit
A	TLS constrained photogrammetry
B	1 mm
C	2 mm
F	NIKON D 800 camera + 50 mm

Figure 1



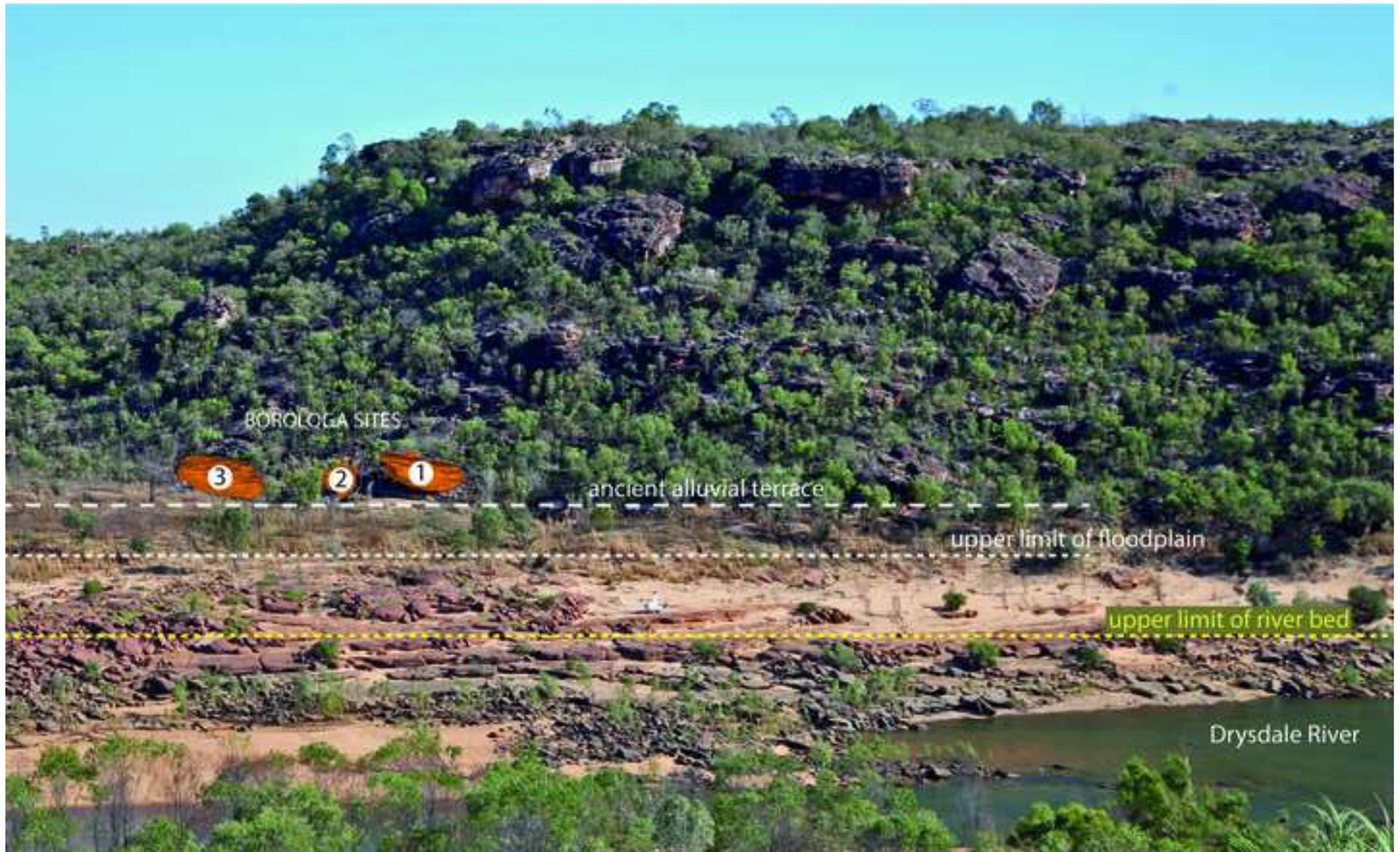
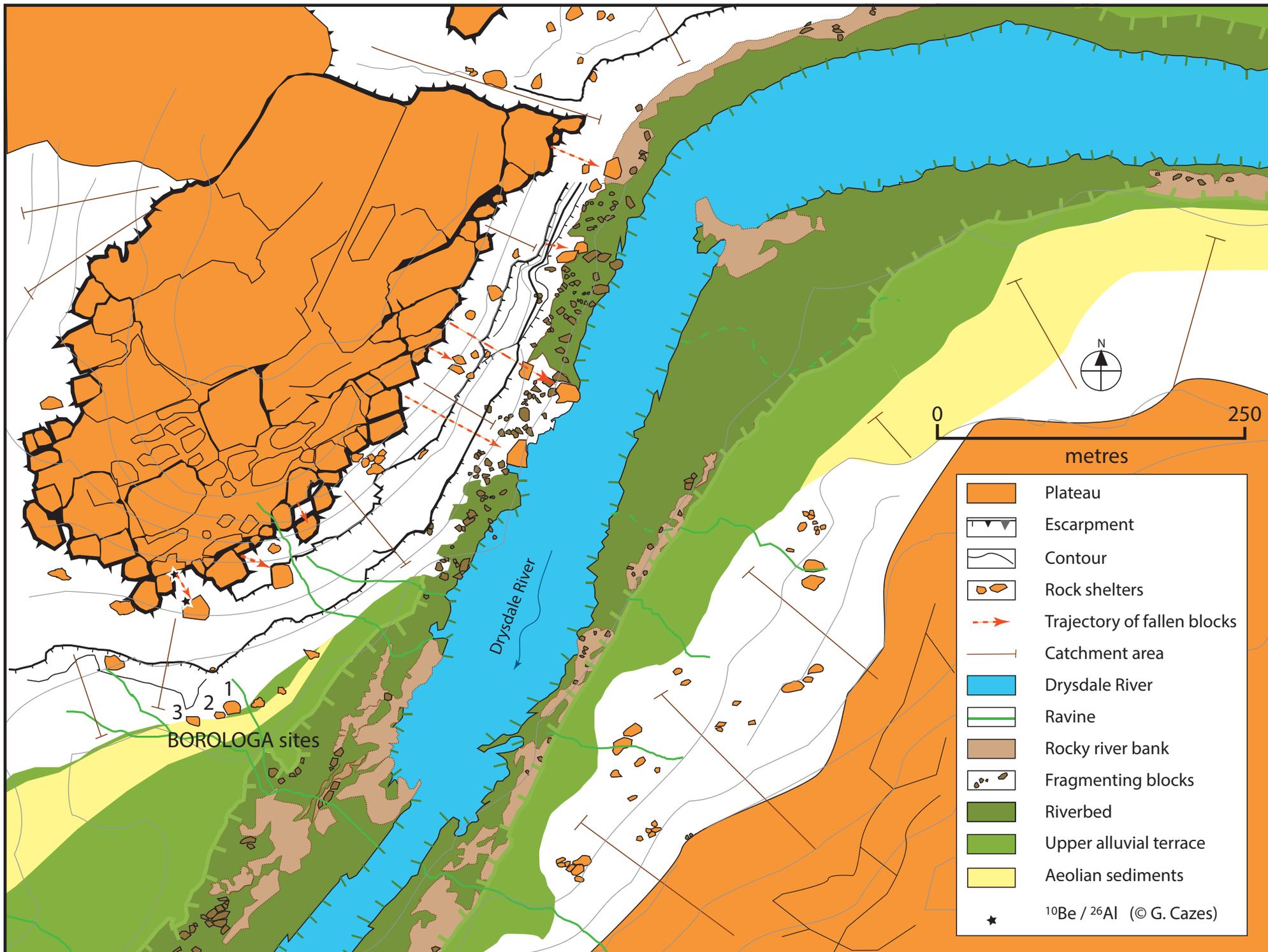
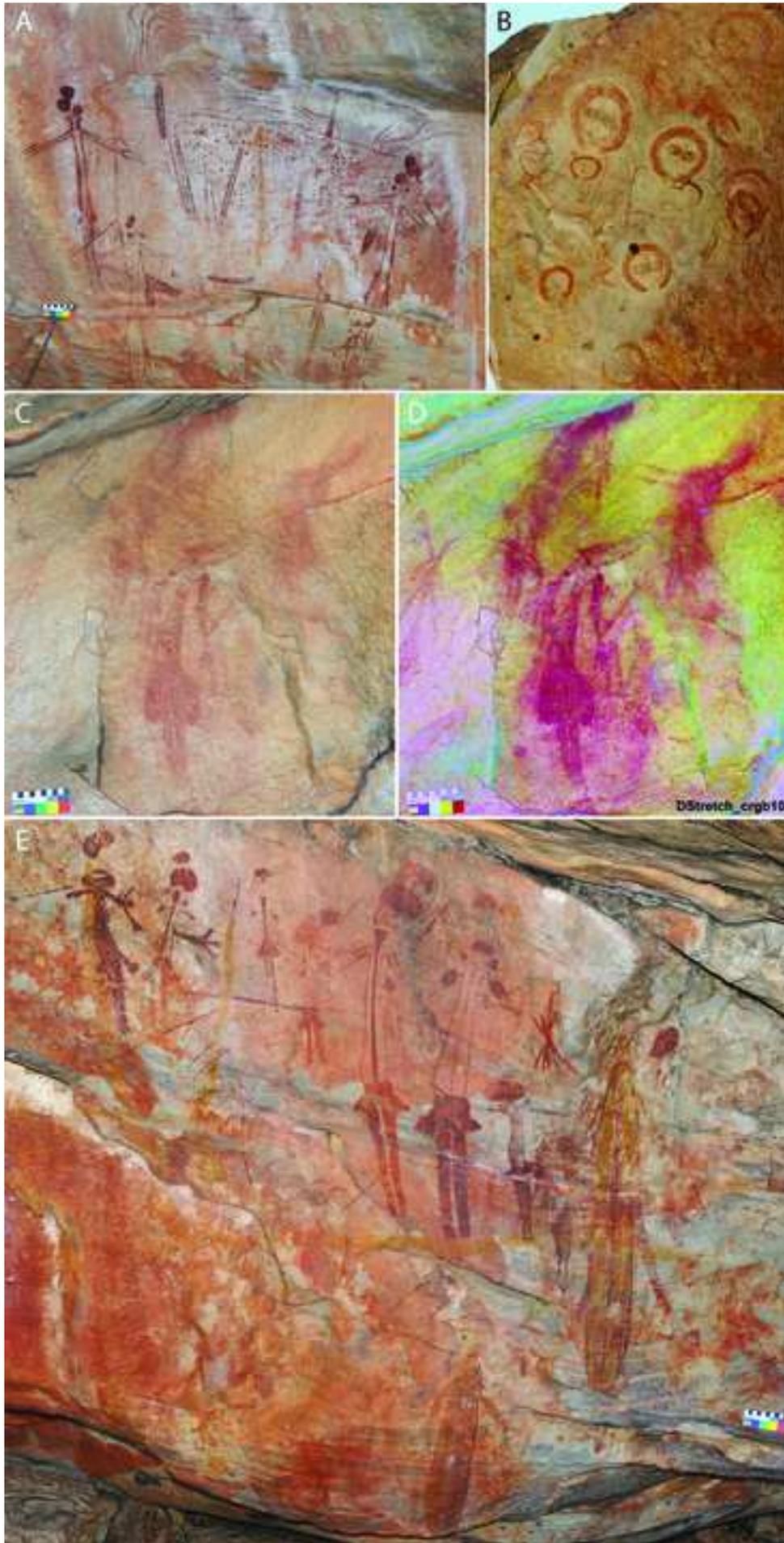
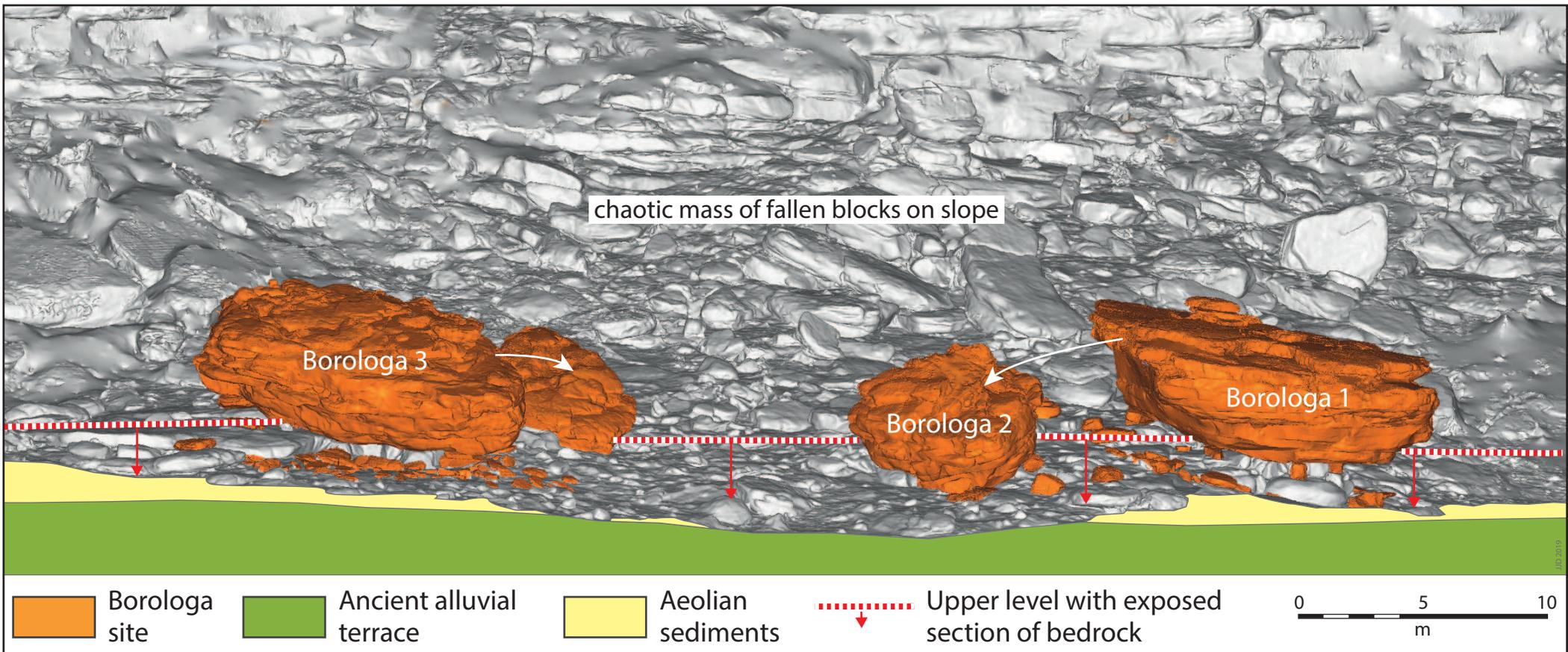


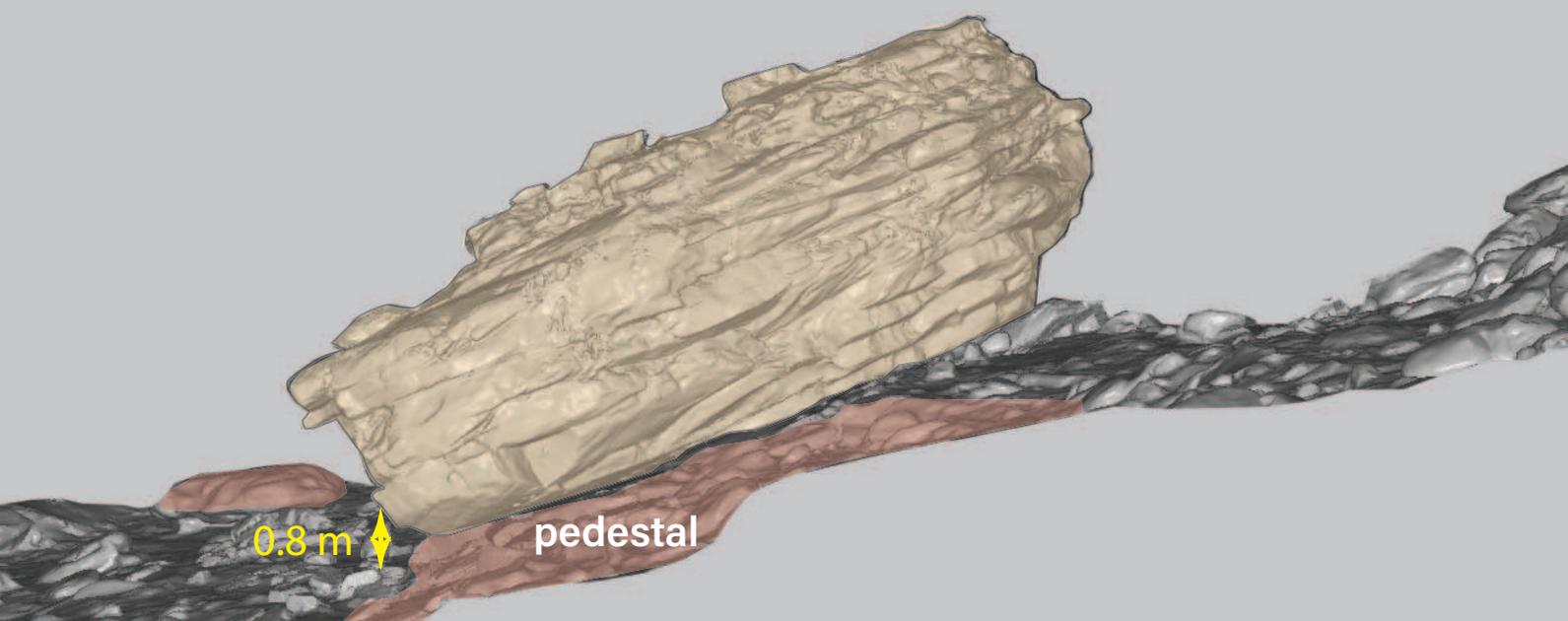
Figure 3



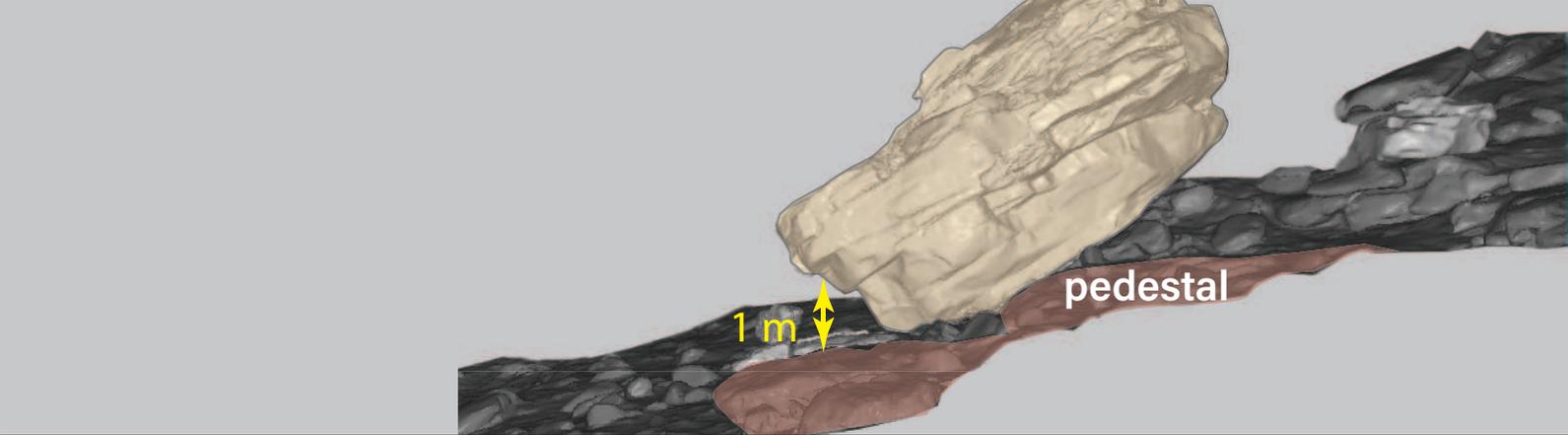




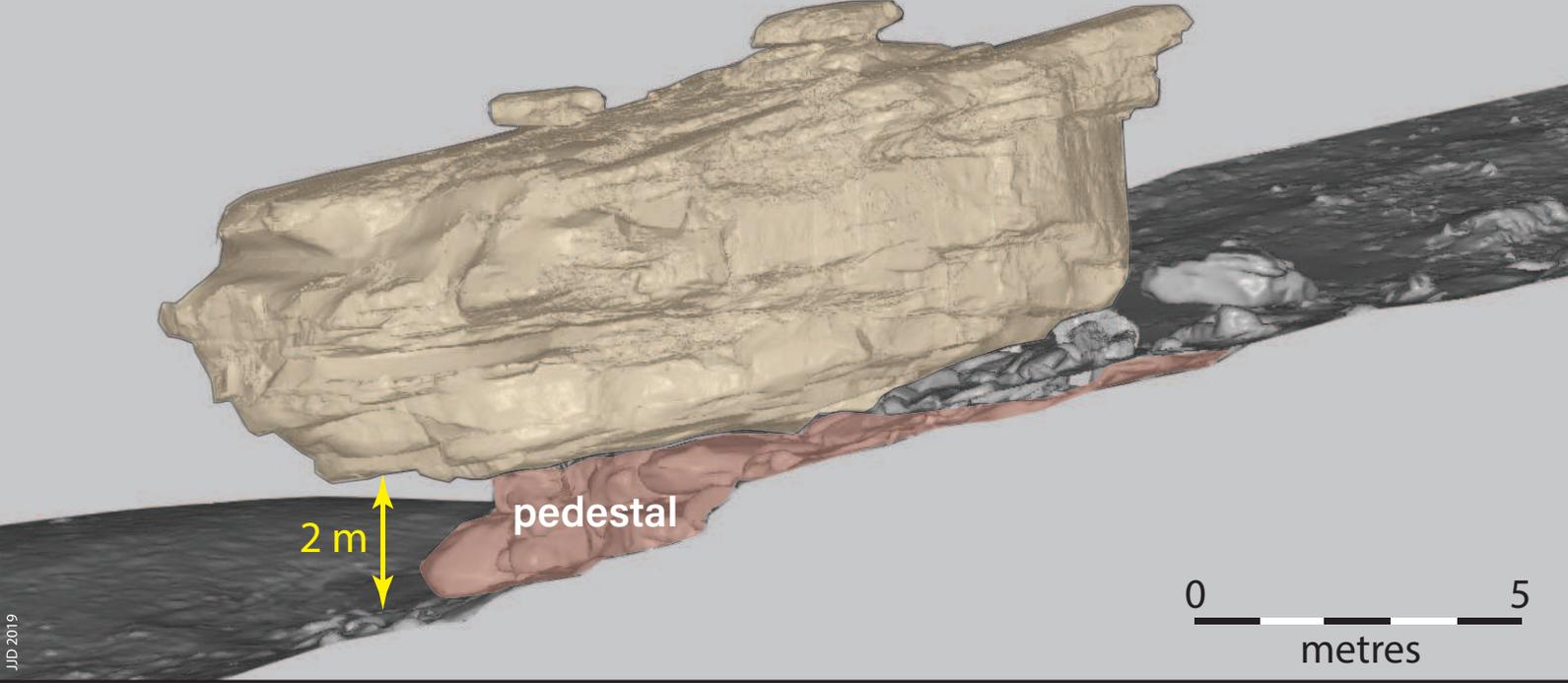
Borologa 3



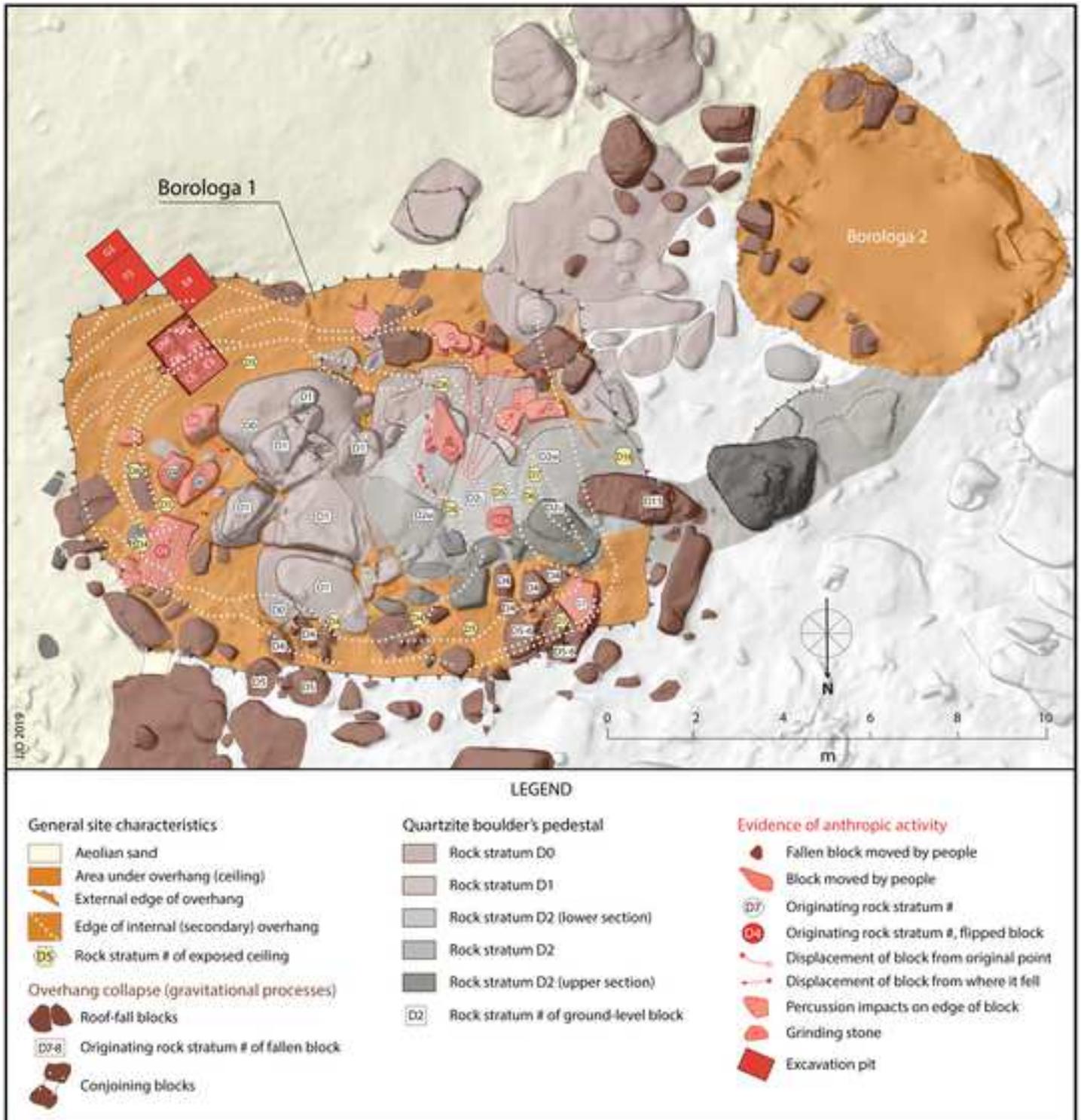
Borologa 2



Borologa 1







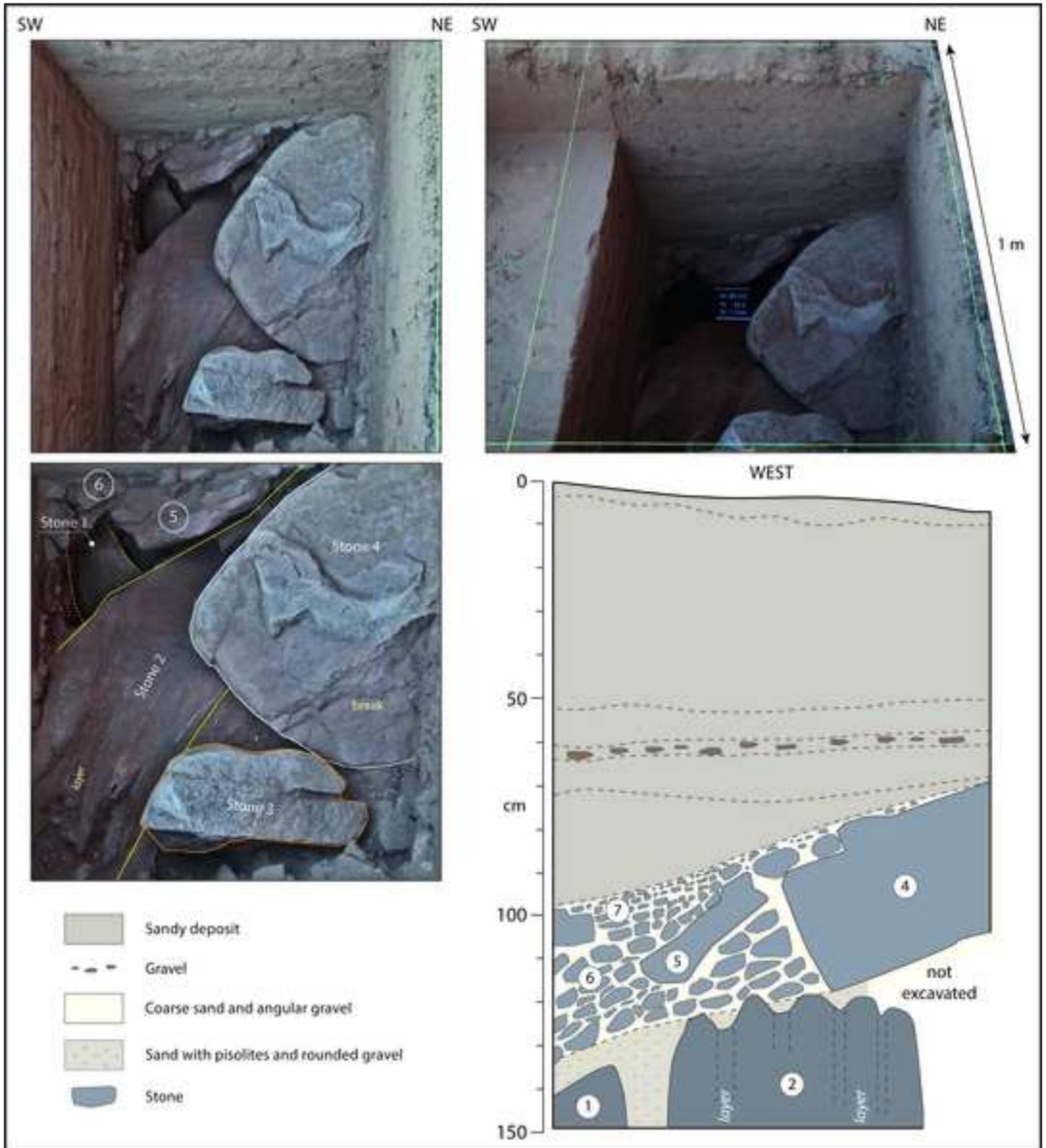
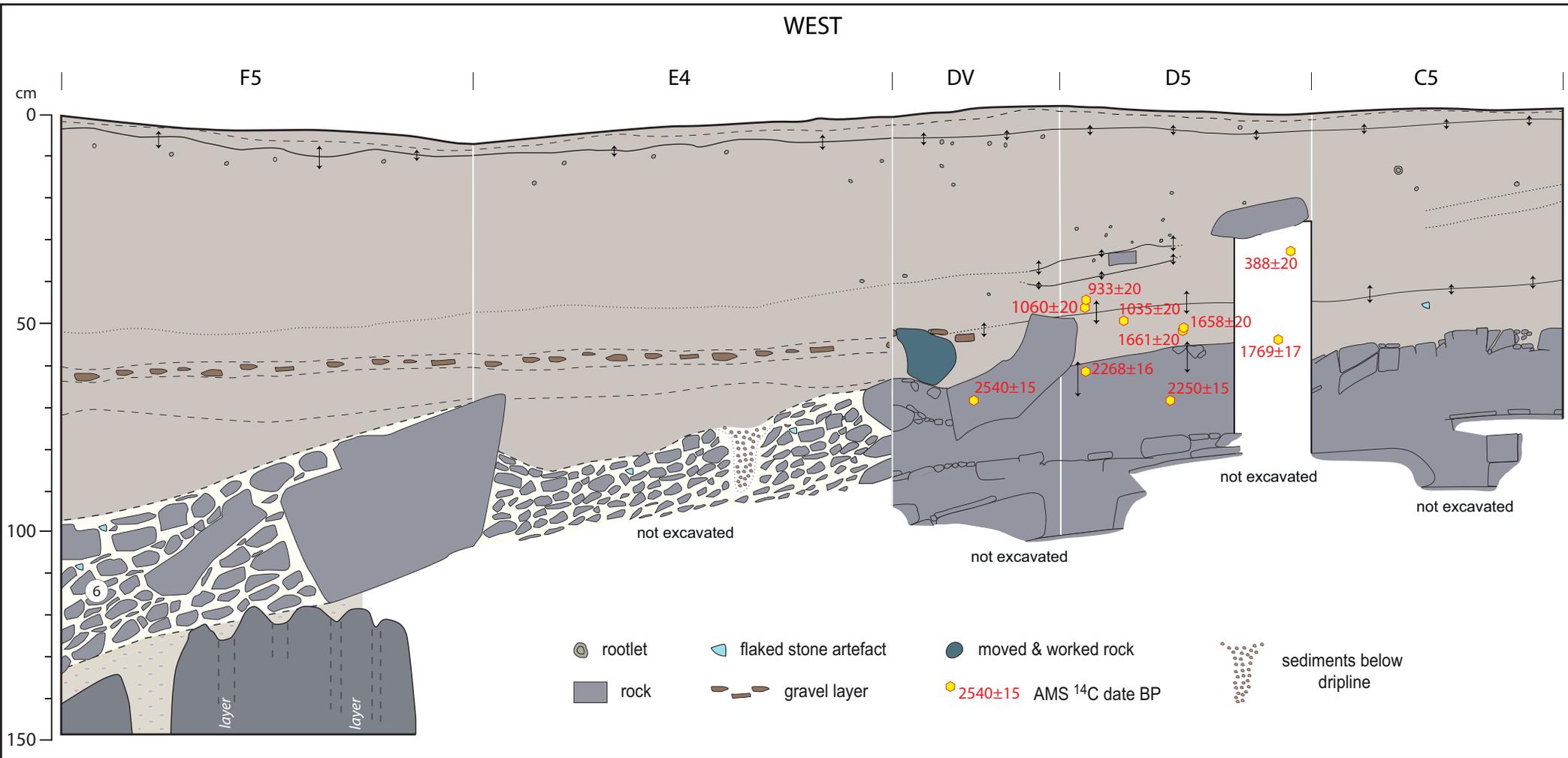
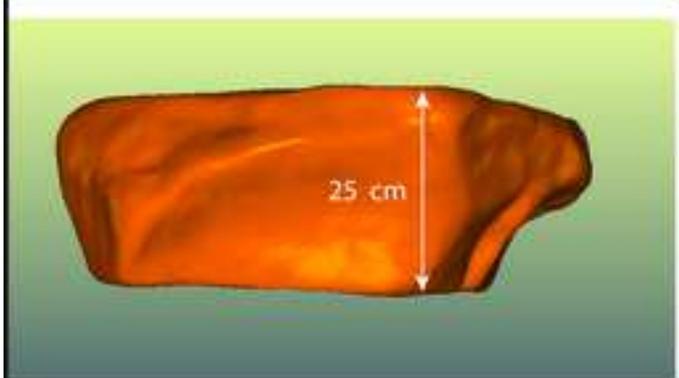
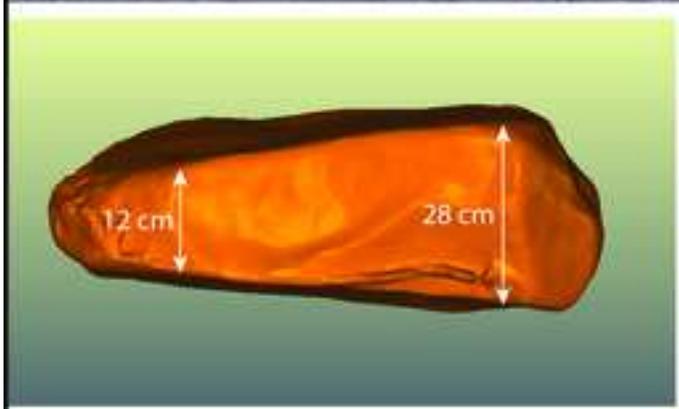
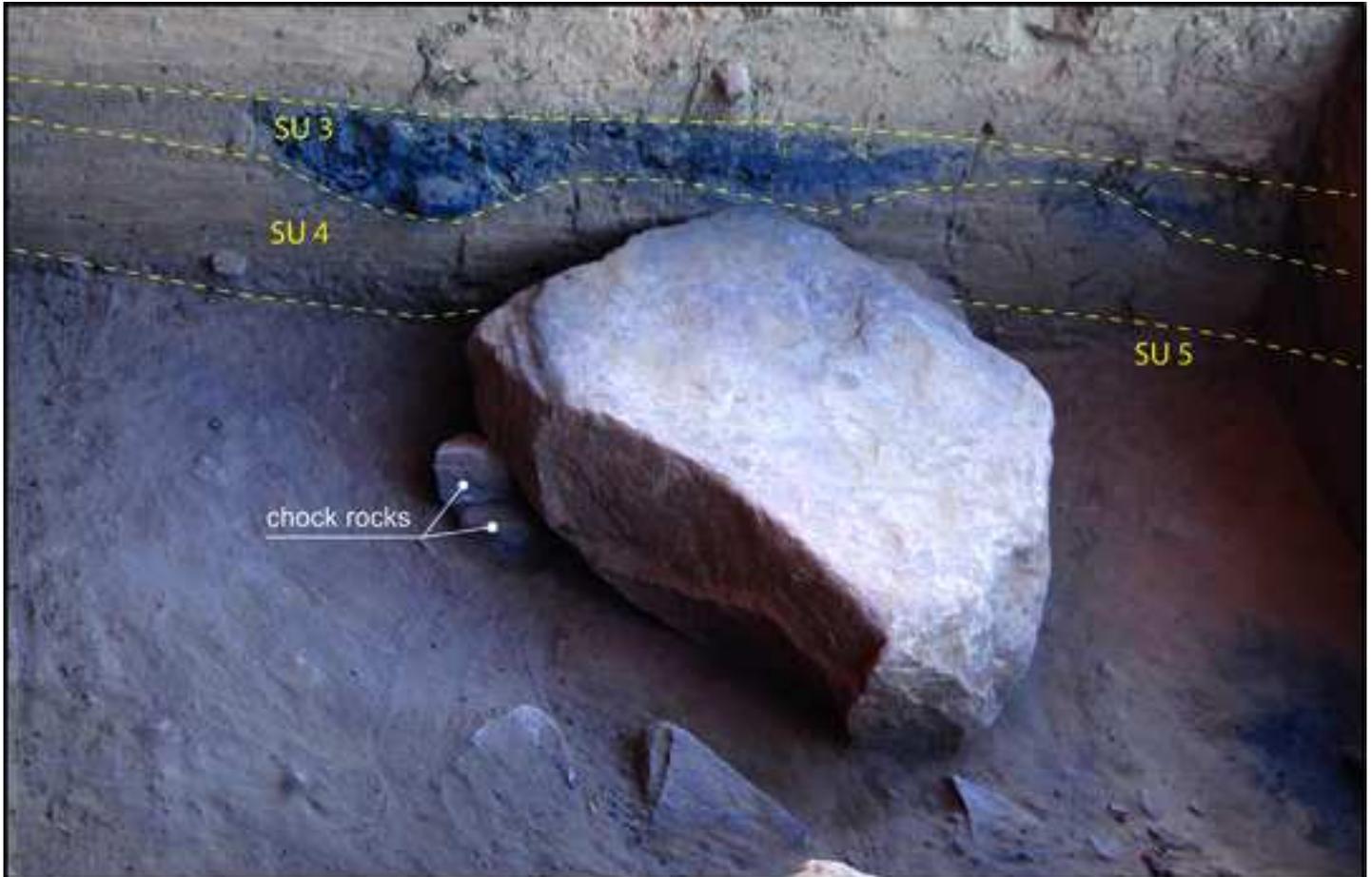
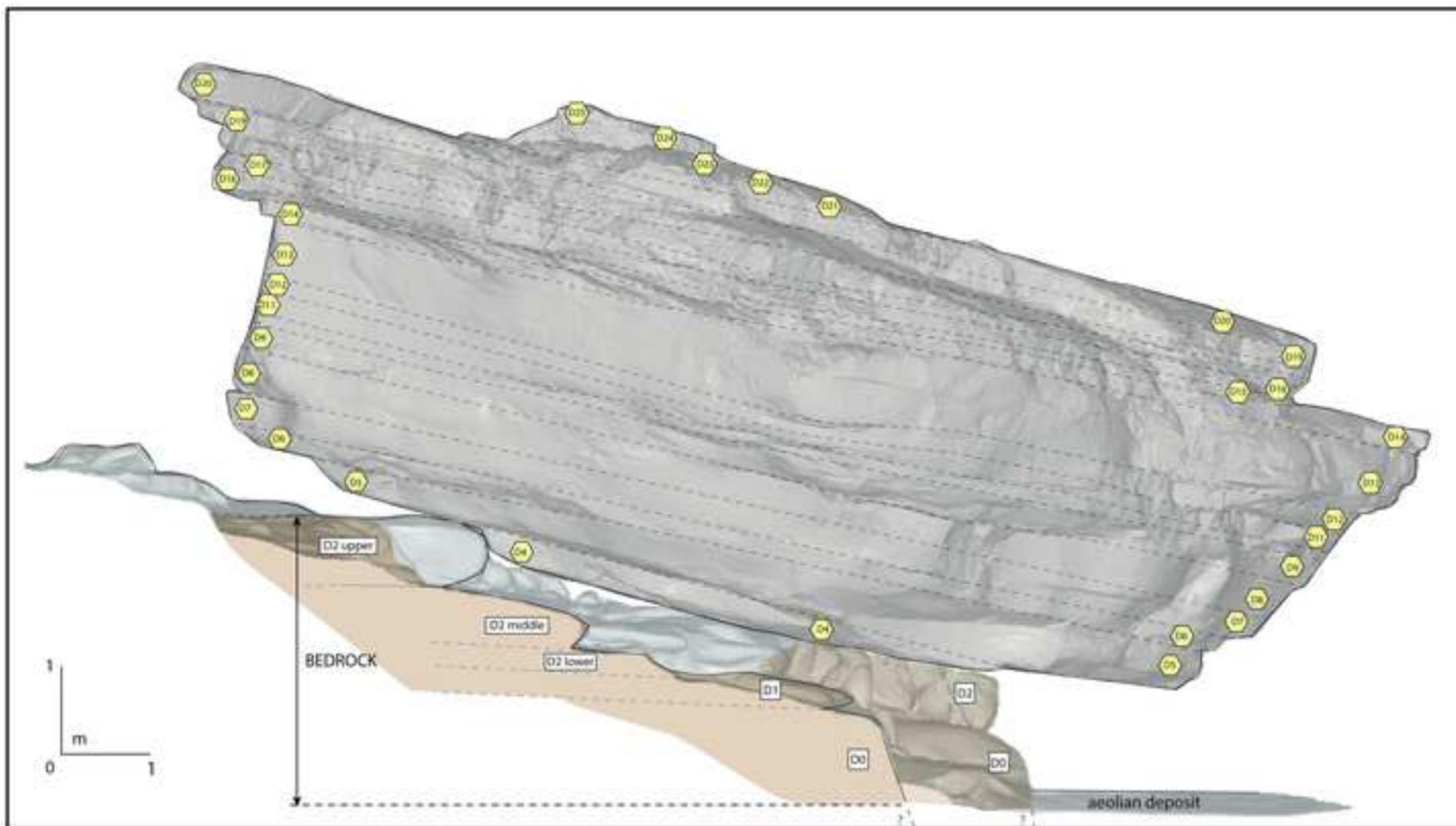


Figure 10







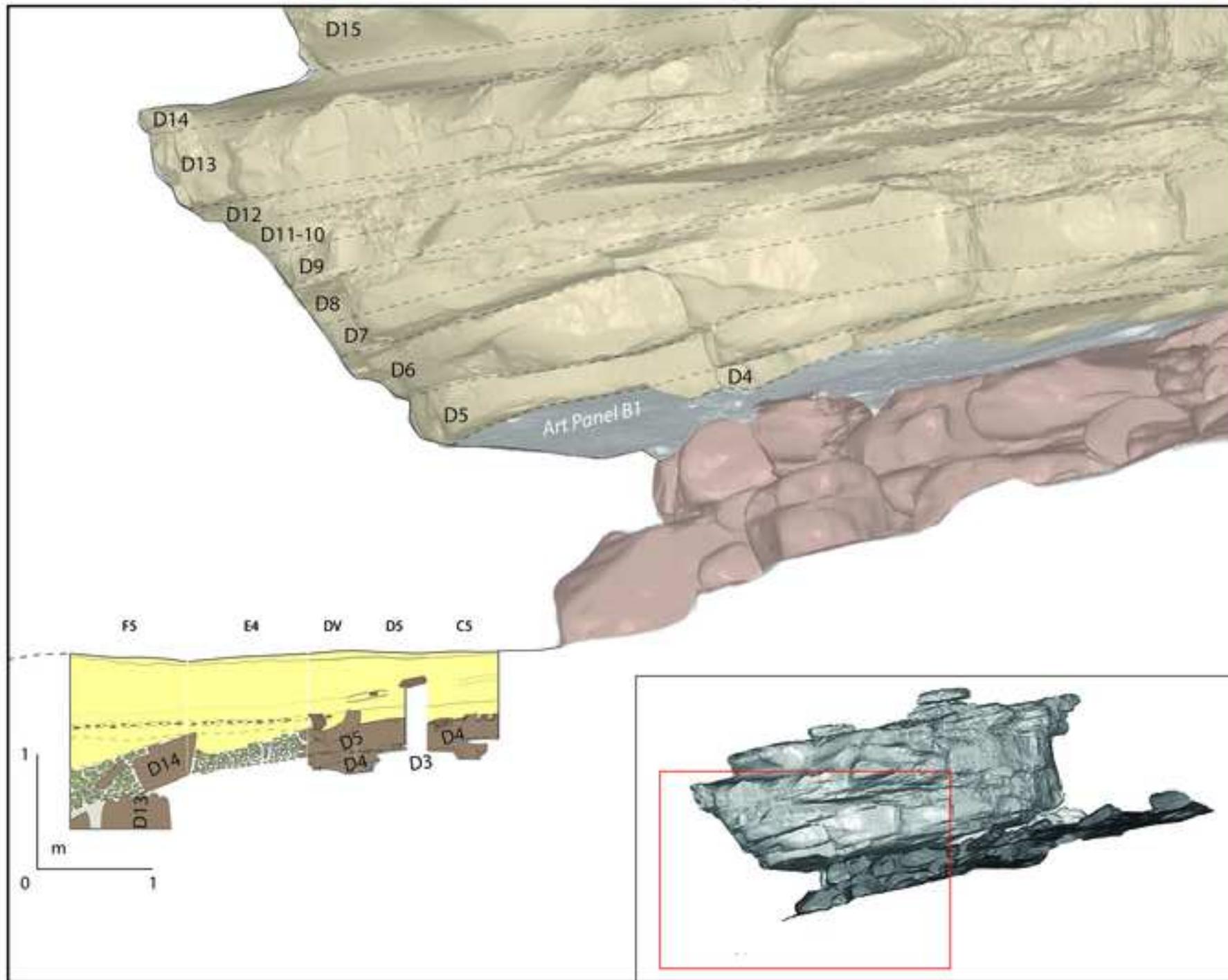
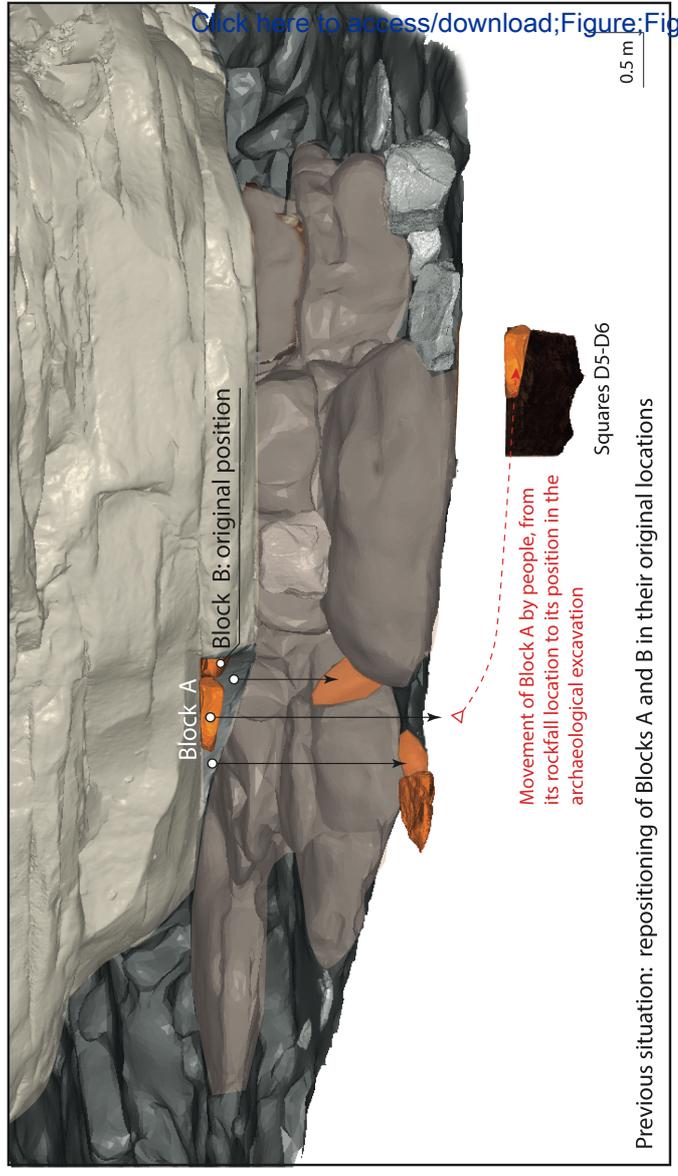
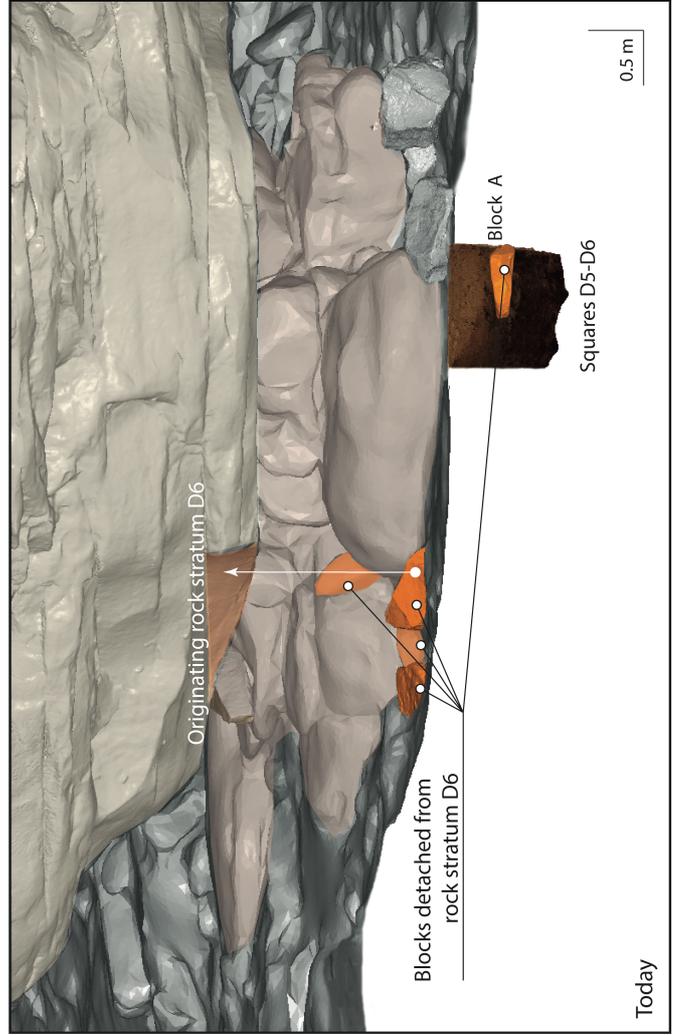
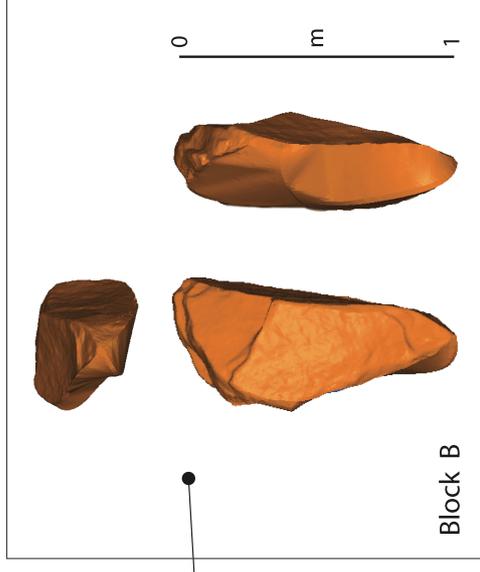
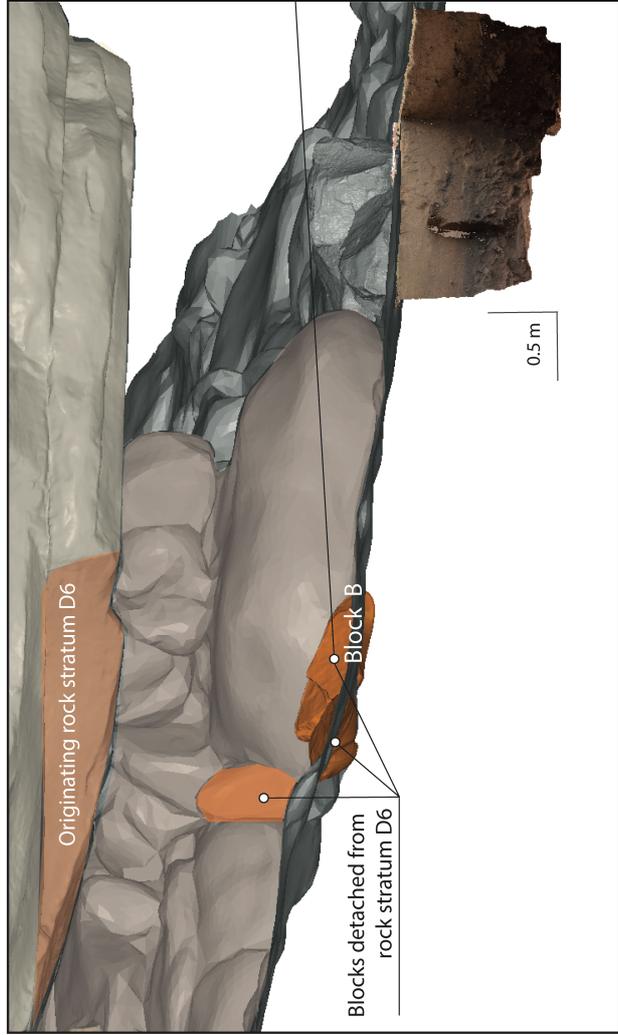
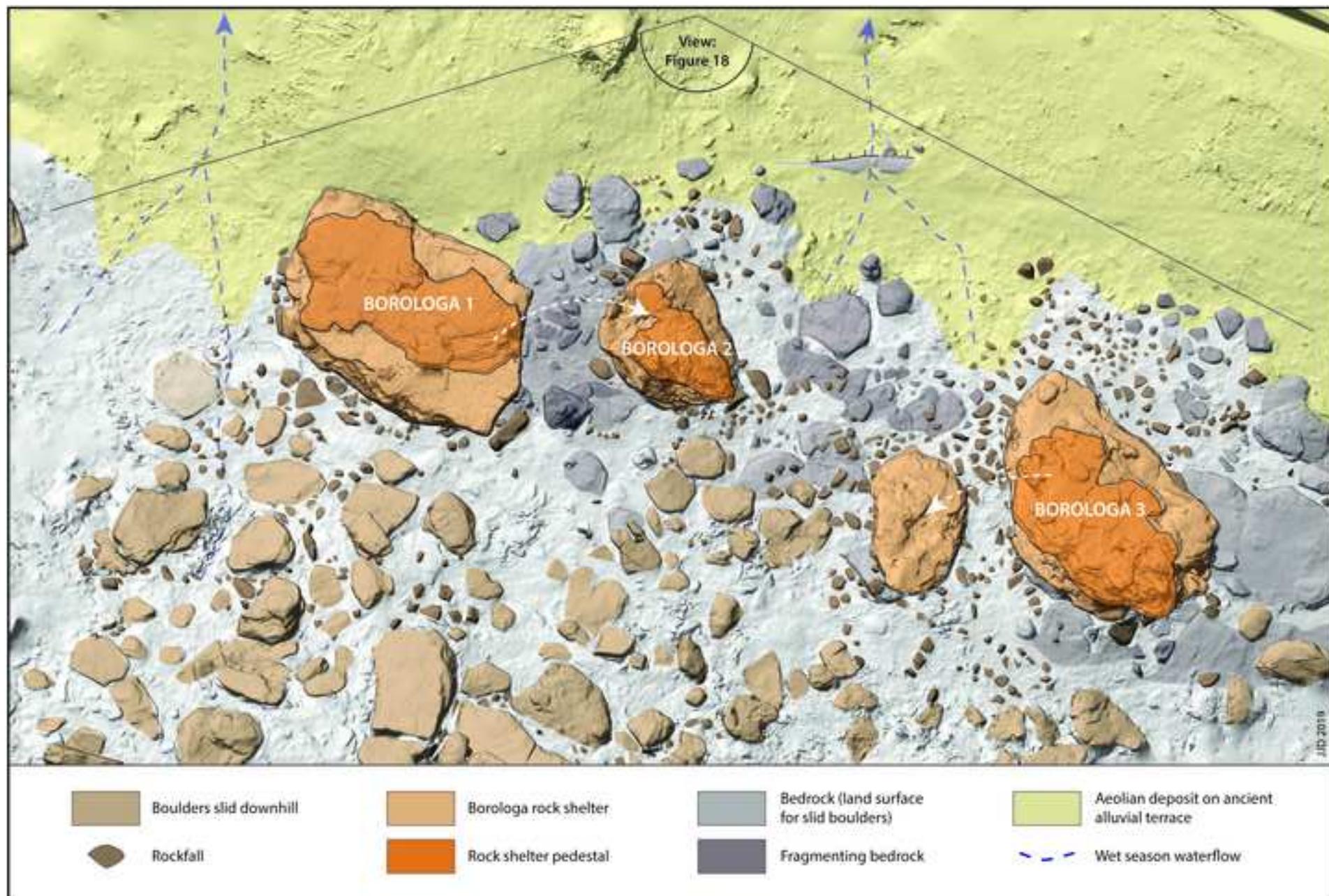
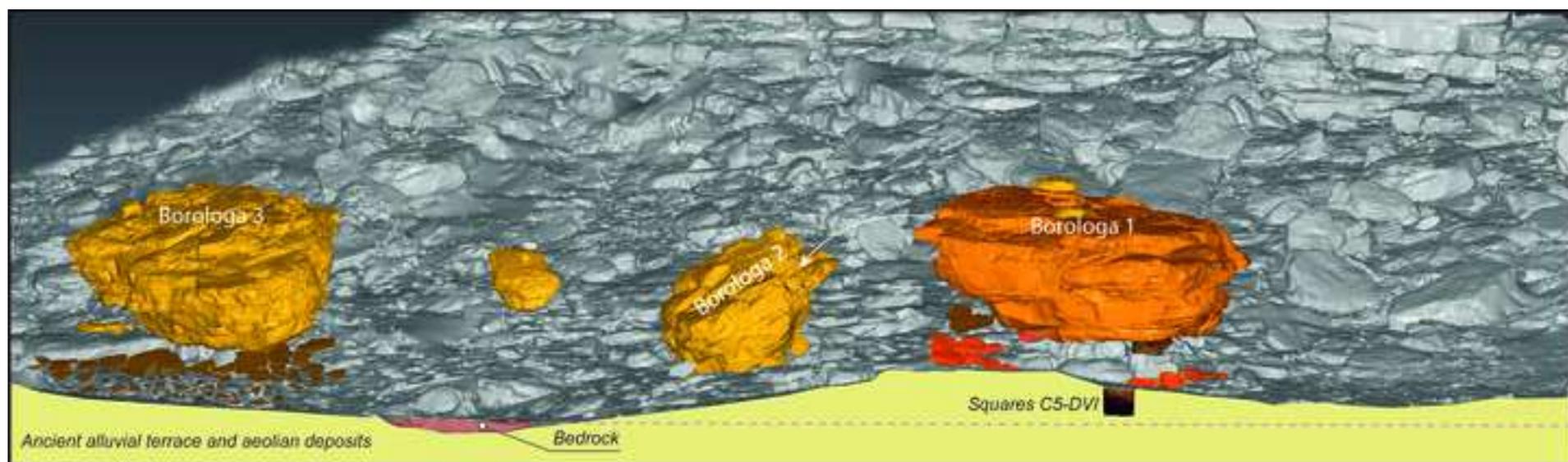


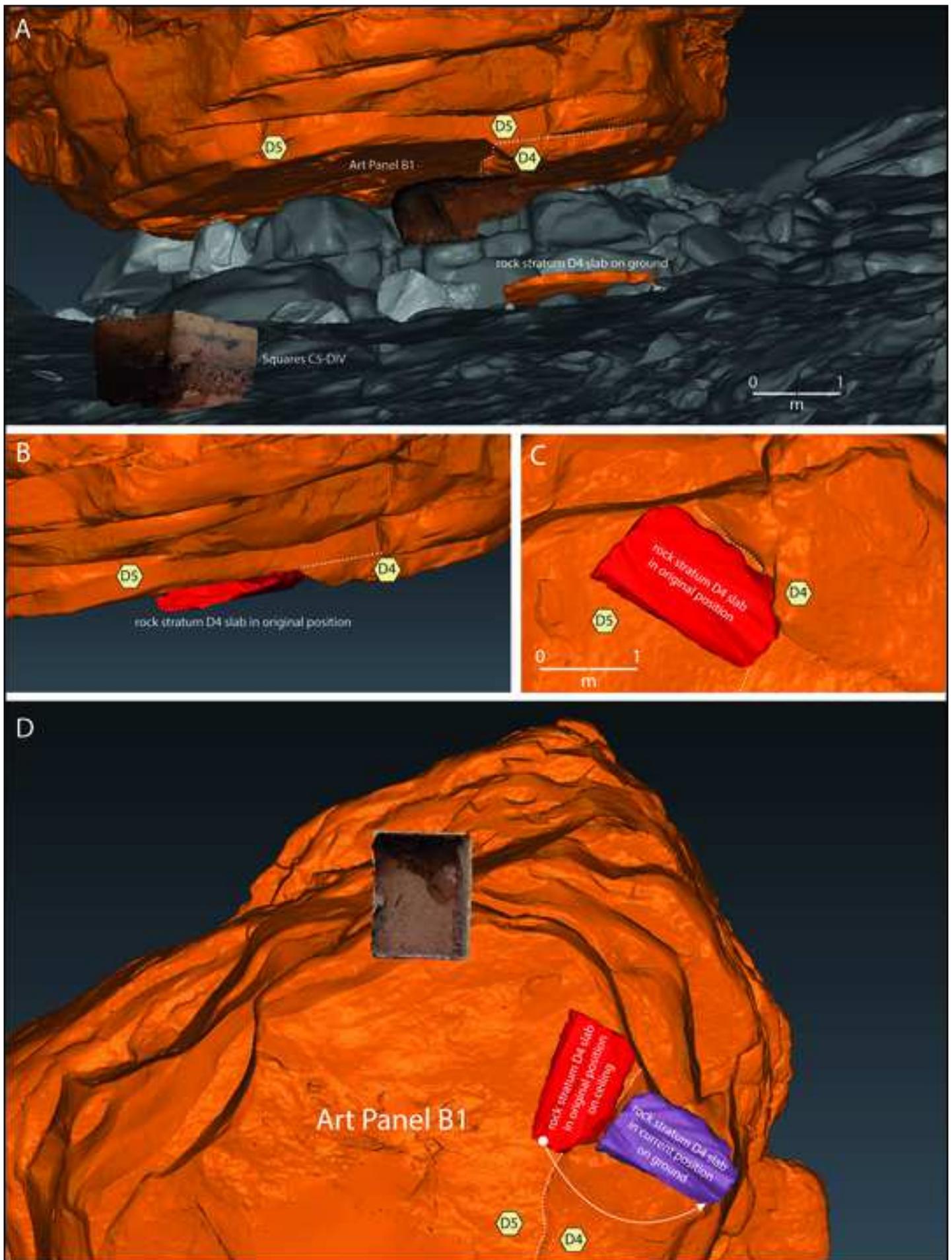
Figure 14

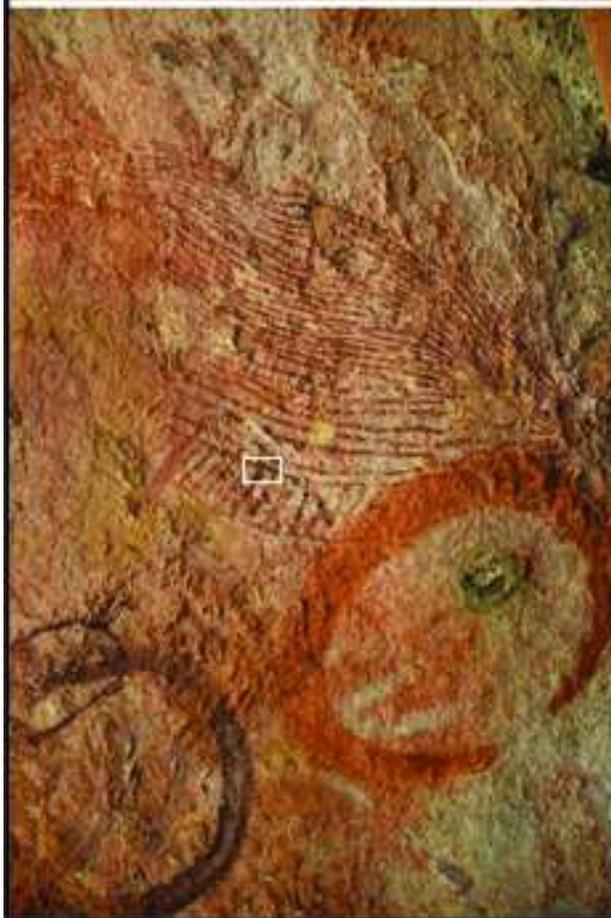




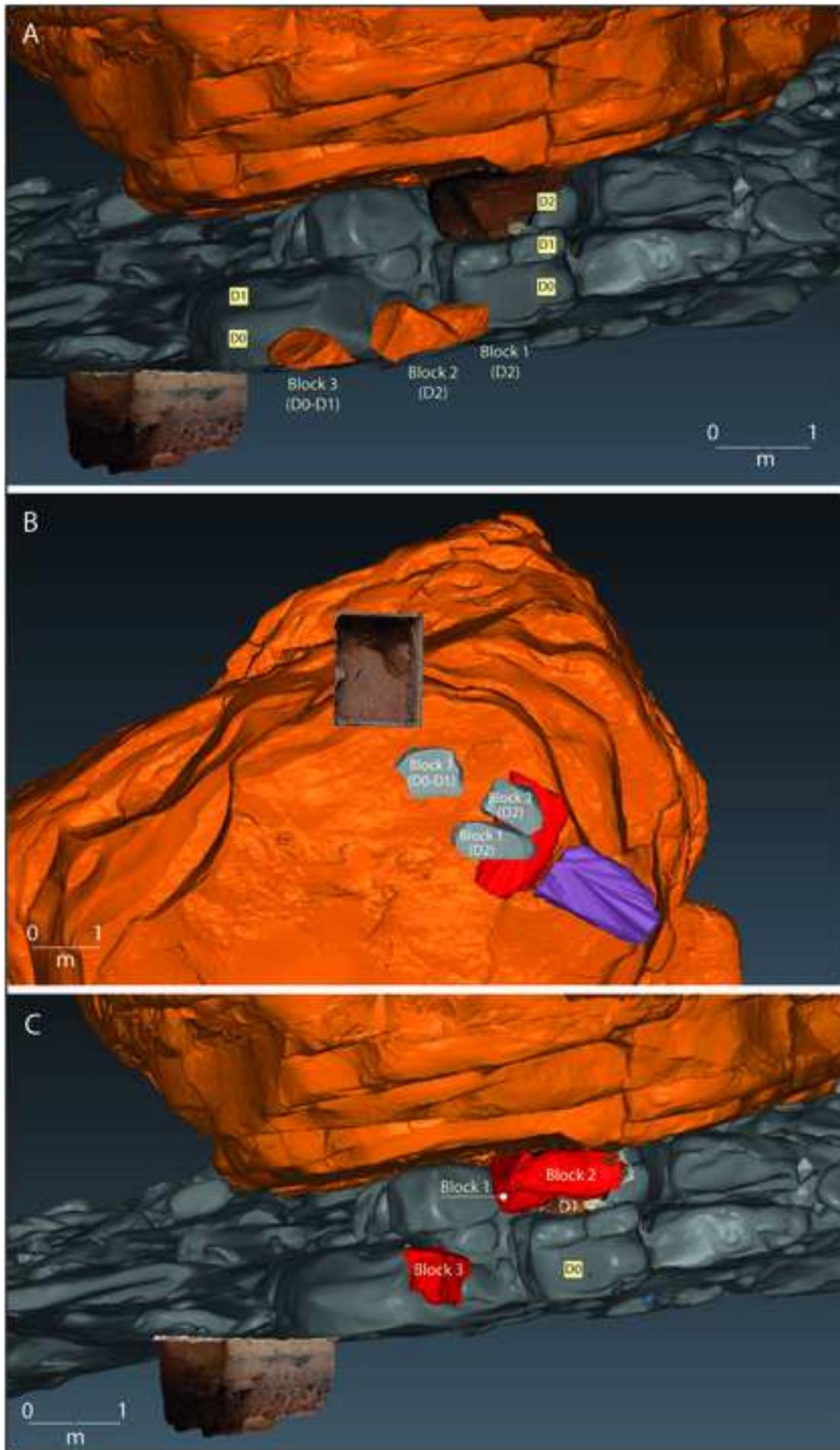


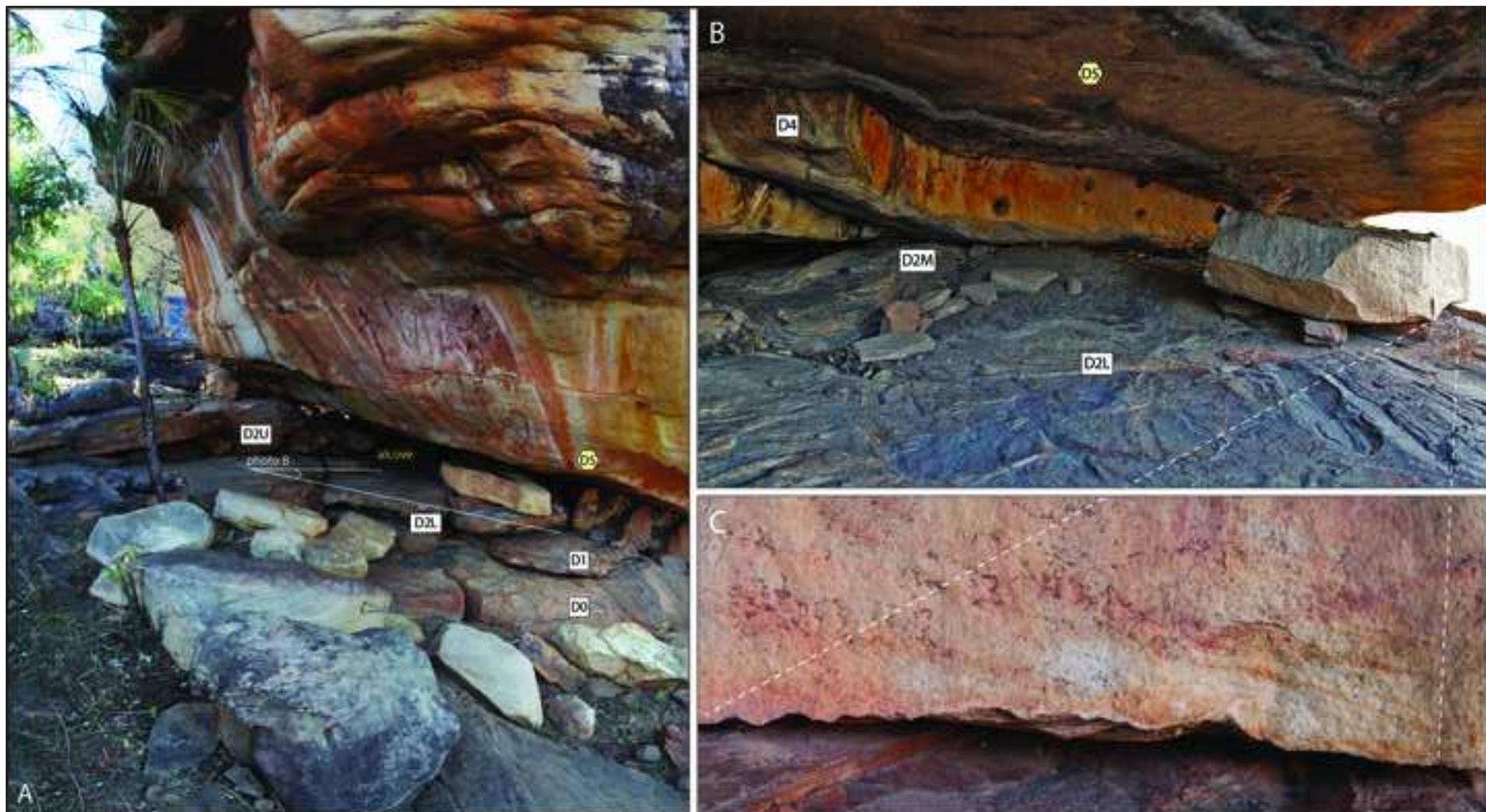


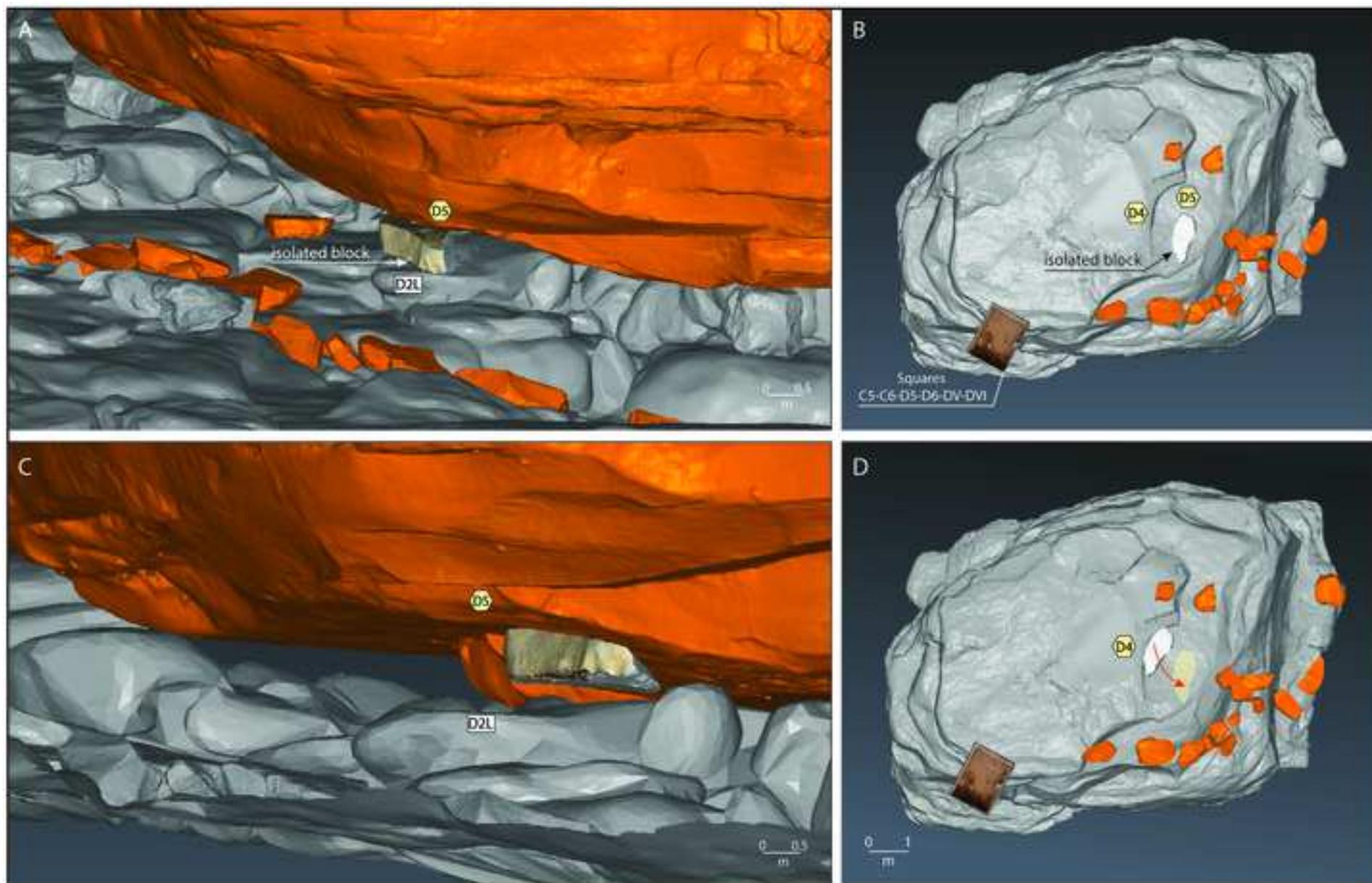


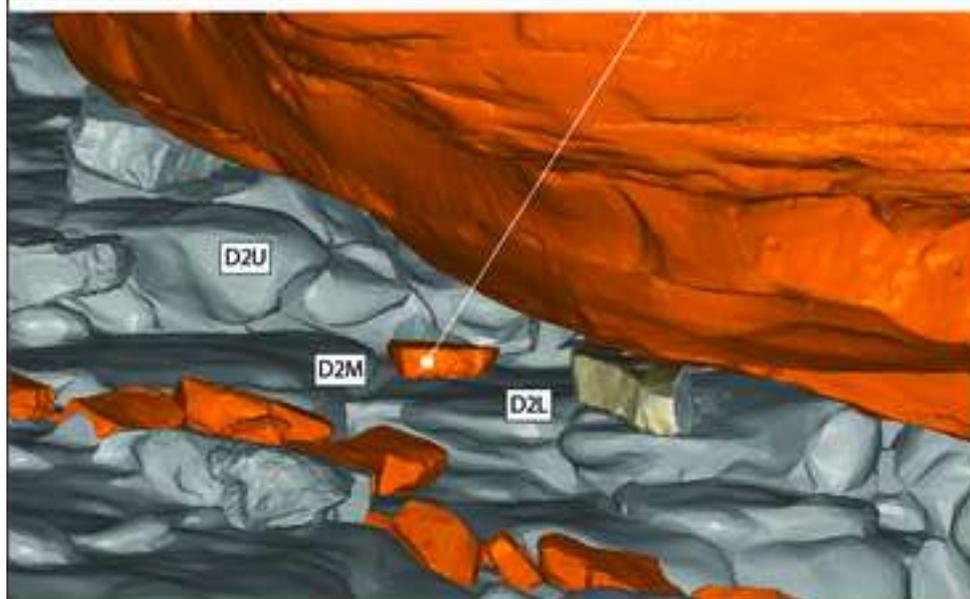


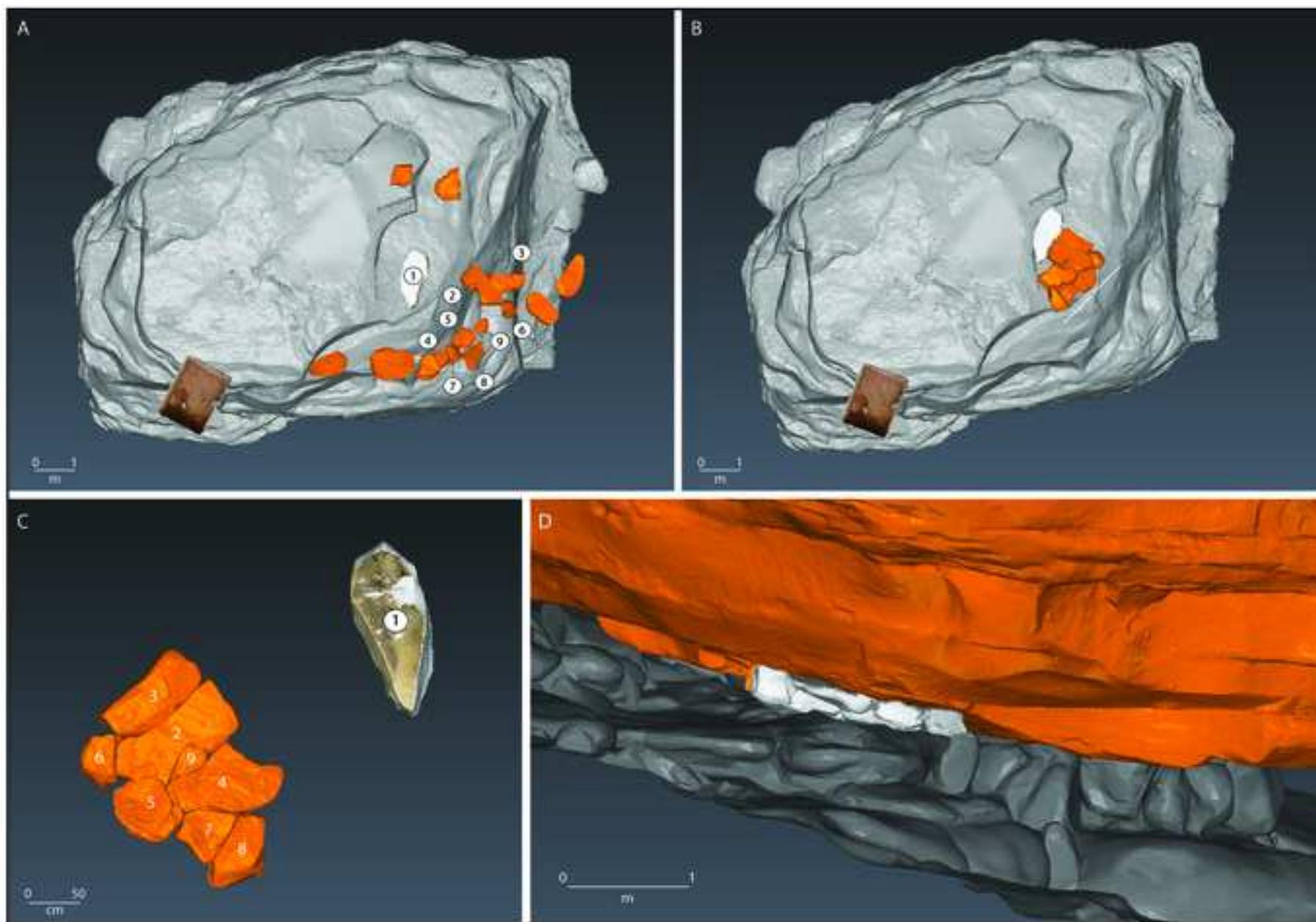


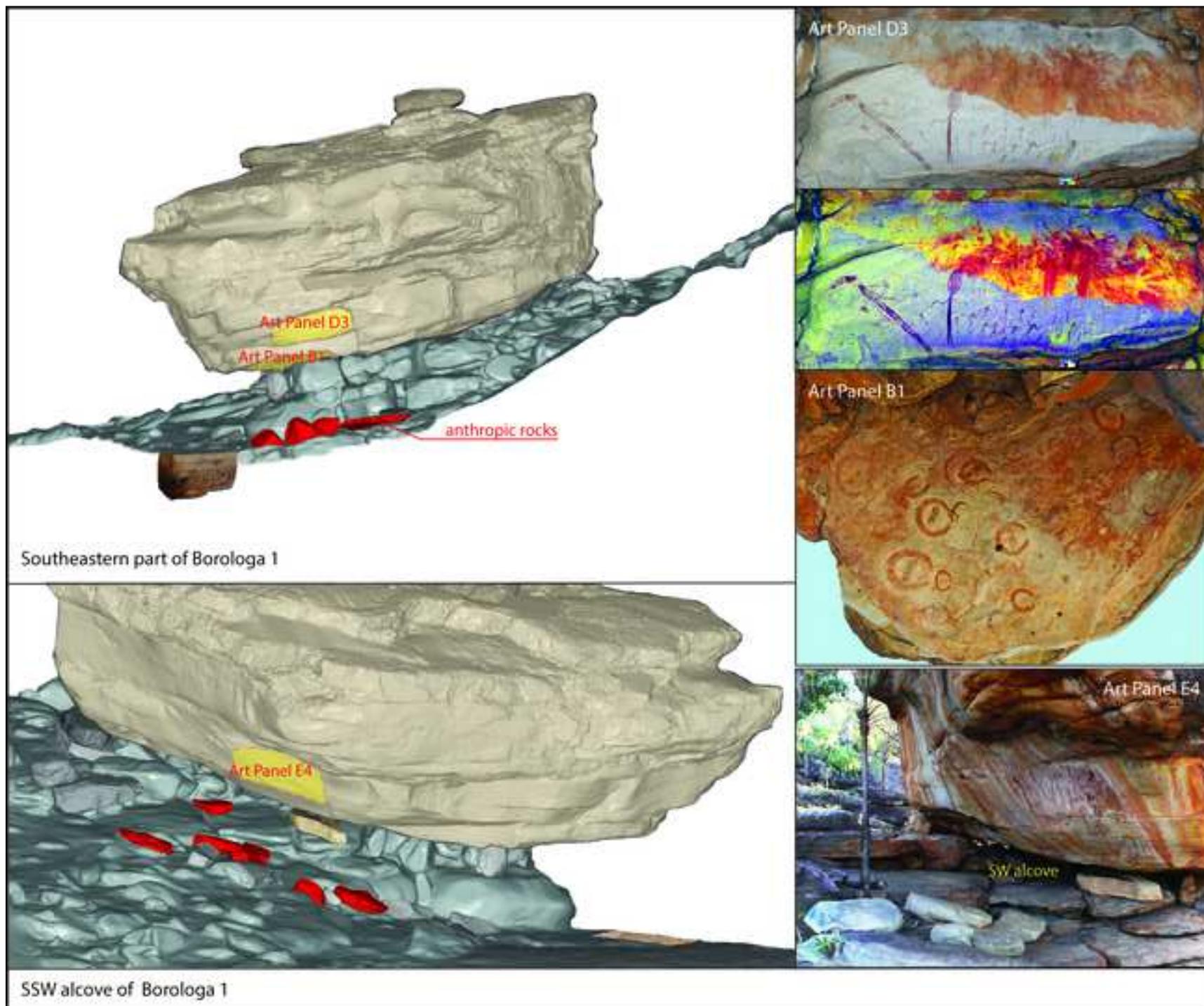


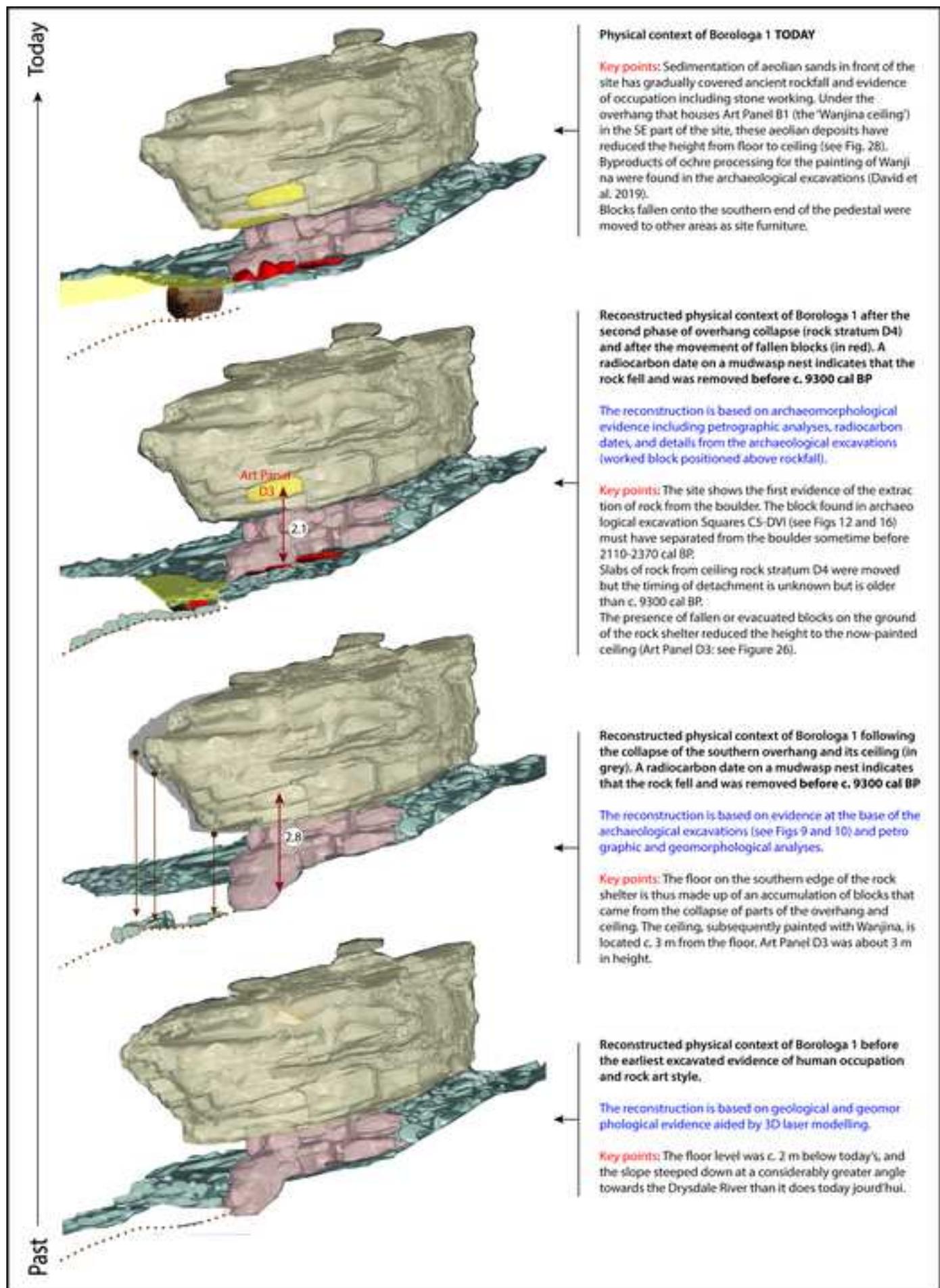




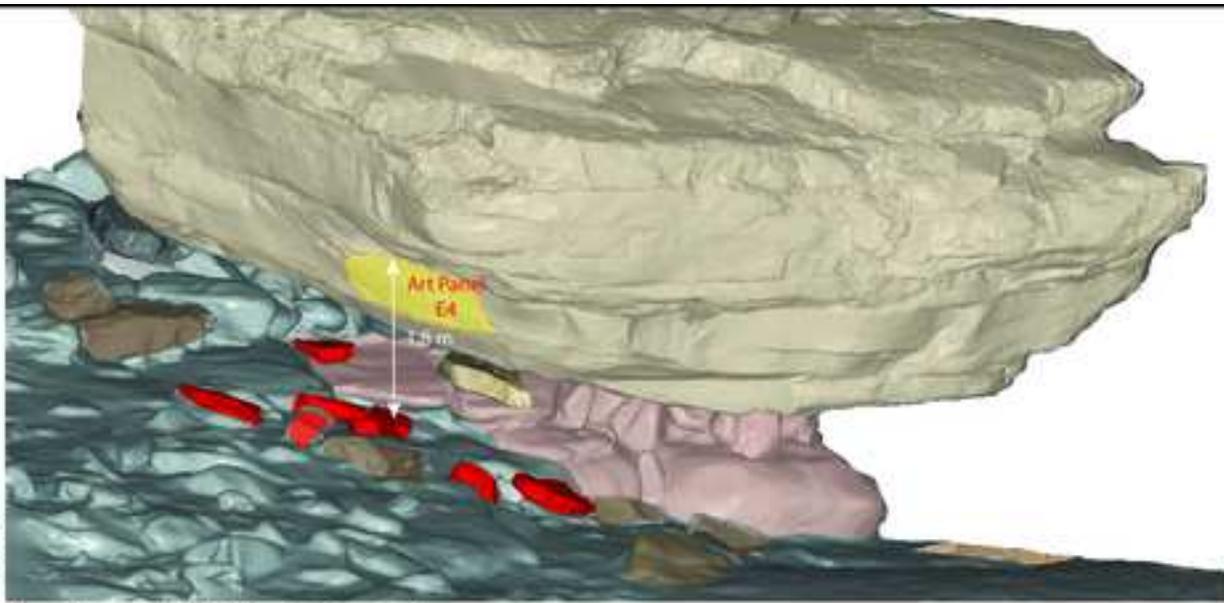








Today



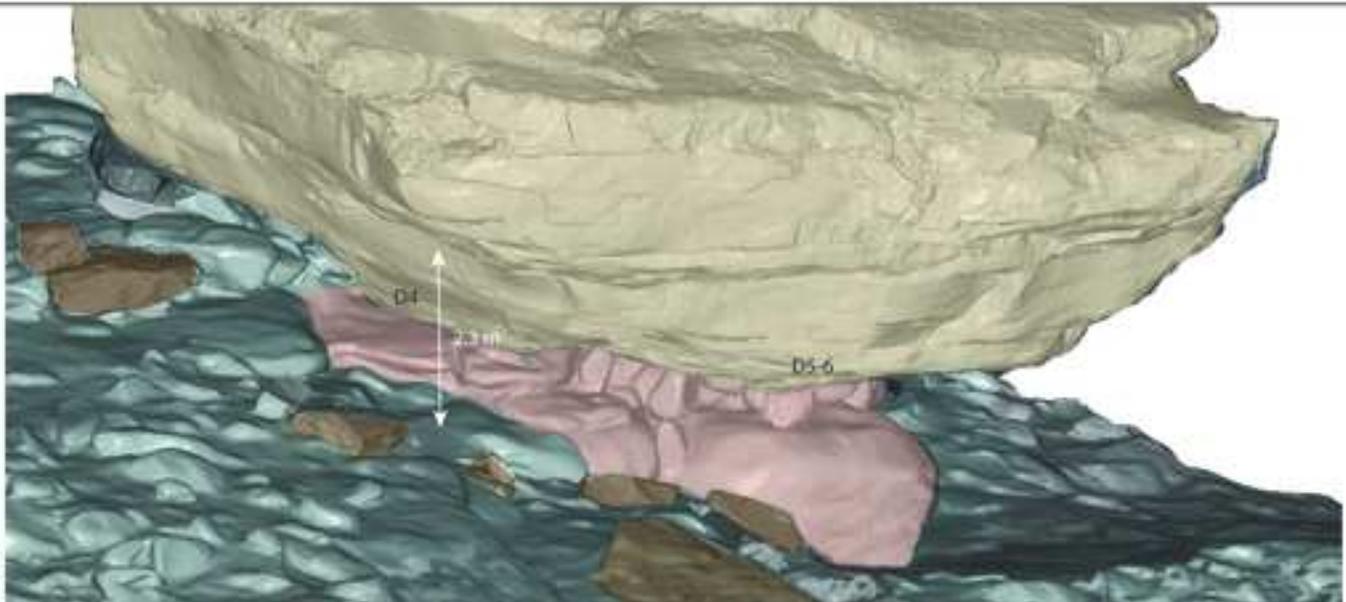
Physical context of WSW side of Borolaga 1 today

Based on geological and archaeomorphological evidence aided by 3D laser modelling.

Key points: Blocks (in red) from rock stratum D4 were evacuated from the alcove onto the hill slope. Some of these blocks were intentionally fragmented into smaller pieces to facilitate their removal. The height from the ground to the highest paintings on Art Panel E4 is reduced to 1.8 m due to the accumulated blocks on the ground.

Aeolian sands have covered the base of some fallen blocks. One large block from rock strata D5-D6 of the edge of the overhang was found at 60 cm depth in the archaeological excavations. This block is testimony to the active reorganising of material space across the site, and to their use for the processing of ochre for painting c. 2110-2370 cal BP.

Past



Physical context of WSW side of Borolaga 1 before the earliest archaeomorphological, archaeological and rock art evidence of human occupation

Based on geological and geomorphological evidence aided by 3D laser modelling.

Key points: The ground at the edge of the site is made up of fragmented bedrock blocks and rockfall from the overhang (in brown). The fallen blocks are on a steeper slope than today's.

Following these rockfalls, the rock walls take on a morphology that is similar to today's: the rock surface of subsequently painted Art Panel E4 had already formed. The height from ground to the highest paintings on Art Panel E4 was 2.3 m.

The alcove in this part of the site did not then exist: rock stratum D4 was still attached to the ceiling. Similarly, rock strata D5-D6 on the edge of the site was also still in place.