Archaeomorphological Mapping: Rock Art and the Architecture of Place

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Abstract and Keywords

Understanding the rock art of a cave or rock shelter requires positioning the art in its landscape setting. This involves both spatial and temporal dimensions because a site's layout changes through time, necessitating an examination of site formation processes. In this chapter, the authors present a new approach—archaeomorphology—that unites archaeological and geomorphological methods to explore the history of the objects and spaces that make up a site. Archaeomorphological mapping allows researchers to track through time the changing configuration of sites, including rock surfaces, the morphogenic forces at work, and, with this, the changing spatial contexts of the art on its surfaces. Archaeomorphology shifts attention away from the site as a 'natural' canvas upon which inscriptions were made to its social engagement as an actively constructed architectural and performative space.

Keywords: aménagement, archaeomorphology, mapping, morphogenesis, site formation, sites as architecture, superimposition, superposition

Introduction

Determining how and when a rock art site formed is essential to understanding how people engaged, and could have engaged, with both the site and its rock art over time. Many researchers have explored morphogenic processes at work on archaeological sites, including human impacts (e.g., Binford 2001; Burns 2005; Butzer 1982, 2008; Heydari 2007; Leroi-Gourhan 1965; Lorblanchet 2010; McFadyen 2008; Schiffer 1976; Theunissen, Balme, & Beck 1998). Some of these studies have focused on how particular landscape features influenced the development of sites nearby, such as how desert canyons affected Ancestral Pueblo ('Anasazi') settlement patterns in the American Southwest (e.g., Lekson 2006). Others have been more concerned with how the actions of people in one area affected site formation elsewhere, such as when anthropic burning of the landscape caused the mobilization and redeposition of soft sediments downwind (e.g., Jones 1985). In each case, changes in the landscape enchained a suite of events that, through time, led to the sites that we now see in, and as, the combined archaeological and geomorphological record.

Articulating site formation processes and the way they have evolved through time often leave material traces, allowing us to work out how a site came to be what it is today. By carefully 'reading' a site's features, it is possible to retrace how it has changed over time. Here, we present a unified archaeological and geomorphological approach that permits us to newly see dimensions of site formation not normally achieved by archaeology or geomorphology alone nor by the mere juxtaposition of both kinds of evidence. We call it 'archaeomorphology', to signal an integrated approach that brings in the specialized skills of both disciplines (Dellanoy, Geneste, Jaillet, Boche, & Sadier 2012; Delannoy et al. 2013). Archaeomorphology does not easily sit within 'geoarchaeology' as it is currently framed, which also combines archaeological and geomorphological practice and ideas, although it expands in many ways on its current understandings. Archaeomorphology aims to determine how landscape features became shaped over time—much like geomorphology and geoarchaeolgy do—except that the actions of people in and foundational social anthropological ideas about landscape are now integrated to a significantly greater degree than more traditional geomorphological and geoarchaeological practices currently allow. By examining landscape features through an integrated combination of archaeological and geomorphological information, and social anthropological notions of 'dwelling' (see later discussion), archaeomorphology reveals what part human actions played in site formation and when.

Studying Rock Art Sites Archaeomorphologically: Observing and Mapping Objects and Spaces

How a researcher approaches a rock art site is important for how we come to understand that site. One of the most effective tools for communicating, compiling, and interpreting evidence of a site's history is mapping, and this is so of archaeomorphology as well. This is partly because maps can illustrate the whole as well as the parts. To be effective, archaeomorphological maps need to be detailed and accurate, capable of representing archaeological and geomorphological information together. They need also to show information on the physical and temporal relationships between objects and whether these objects are fixed or movable. Too often in research, a site is treated in isolation, detached from its broader landscape and thus from the processes that have affected it. In archaeomorphology, we begin by considering a rock art site through its broader geographical landscape rather than by focusing on a single part, such as the isolated site or an art panel. This allows the different objects and spaces, such as individual rocks, rock surfaces (some of which bear art), and the nooks and crannies in the walls of a site, to be identified at varied spatial scales and to determine the types of material evidence available for interpreting site formation processes. Here, the notion of 'superimposition' is important and can be distinguished from 'superposition': 'Superposition' simply indicates that one thing lies on another, such as in the geological principle of the superposition of strata. 'Superimposition' is more, incorporating the idea that the overlying object reworks what was there beforehand; the preexisting item affects what happens next, modifying the original in the process (such as in the hydrological notion that a new drainage pattern superimposes an earlier pattern). This notion of the influence of an object onto what comes later, of the affective nature of preexisting things, is fundamental to the archaeomorphological study of a site and its rock art (because a major aim is to determine what happened through time until we reach the site we see today).

As individual objects, spaces, and areas within a site are noticed, it is important to view each as a component that interrelates with other parts in a context of the site's overall broader landscape. This notion of the site's broader landscape is often bypassed in rock art studies, where the artworks often form the focus of attention. Notions of the 'site' also suffer from a widespread tendency to treat caves and rock shelters as purely 'natural' places rather than architectural wholes. Human agency is not usually thought to have featured in the making of site structures and rock surfaces. However, ongoing research in southern France, northern Spain, Arnhem Land, and the Kimberley in northern Australia —much of which remains unpublished—has brought to light numerous cases where, in addition to making art, people have substantially modified and thereby shaped shelter walls and other site features (see later discussion for details of some of these examples). Here, it is useful to introduce the French term *aménagement*, for there is no exact equivalent in English. The term expresses an important concept: that people don't just manage their surroundings—they don't just modify a preexisting natural world—but rather actively and meaningfully construct places by the way they engage-in-the-world, as in Ingold's (e.g., 2000) notion of *dwelling* and Thomas's (e.g., 2008) notion of *inhabitation*. Aménagement concerns the things that people did, and do, to and in places while inhabiting them, how they construct the physical spaces in which they dwell, creating new landscapes that can be examined at varied spatial scales. Chipping away at the rock is an example of aménagement, as is moving blocks of rock around a site (which we can consider as site 'furniture', for example), as is the making of rock art.

The most effective way of analysing archaeological sites as engaged landscape features is to take a systemic approach because, at any point in time, it is the nature of the interactions between a site's different components that gives the site its particular characteristics, its spatial configuration, and structural pattern. Viewing a rock art site in terms of interactions between components and involving site formation processes leads us to consider the events that shaped it. It also causes us to ask how individual events—physical and behavioural acts—engendered later events.

Many analytical tools can be used to determine how different processes have contributed to the making of a site and its broader landscape. As noted earlier, one of the most useful is mapping because, in addition to identifying and characterizing individual objects, maps can make the 'whole' visible by visually showing spatial relationships between individual components, providing a broader geographical perspective for each. Mapping is a two-stage process. The first stage involves identifying individual objects and establishing their position relative to other, adjacent and more distant objects. The second stage involves visually representing these objects in a dynamic framework (as opposed to the static position in which we normally encounter them at any particular point in time) that can be used to draw up models of what happened at a site through time. It is this two-stage process that enables archaeomorphological mapping to distinguish between the different agents responsible for a site's architecture and to determine the spatial and temporal relationships between the aménagements that have taken place at a site (including relationships between artistic events and other types of site engagement). This two-stage process can guide the observation, data collection, and interpretation of any locality that has been shaped by physical (including anthropogenic) processes, at any spatial scale.

Archaeomorphological Mapping

For a map to be useful, it must be drawn at a scale that is large enough for every relevant object to be shown, along with a legend that explains what each symbol denotes. A map must be decodable, and it must present evidence. Through that evidence, the reader needs to be able to understand as clearly as possible what is there and how each feature relates to the others.

The amount of information provided by a map partly depends on its scale. Choosing an appropriate scale is critical to the map's success as a bearer of useful information because it affects how objects (e.g., contours, symbols) are represented and the range of attributes that can be shown. Archaeomorphological maps need to be large enough in scale to enable all individual objects above a predetermined threshold size to be shown along with particulars of their attributes.

Archaeomorphological maps use a similar approach and similar set of graphic conventions to geomorphological maps. Geomorphological analysis explains the origins of landscape features and deposits by identifying how, and when, processes such as erosion and weathering (removal of materials), transport, and sedimentation (accumulation of materials) took place. Each of these processes can involve chemical, mechanical, gravitational, and/or anthropogenic forces. For rock art sites, archaeomorphological maps can be used to show (1) objects arising from different morphogenic processes, including human activity; (2) the products of premeditated actions on a site's or object's morphology; and (3) where and when across a site these actions took place. Each of these can shed light on the physical and temporal contexts of rock art production.

When mapping, it is important to not prejudice the results from the outset: no object should be considered more important or more trivial than another, nor should one disciplinary interest be given precedence over another because the aim of the map should be to address the questions at hand. Every object is a potential source of information; relationships with adjacent objects need to be analysed and explained using all the available evidence. Most fundamental of such relationships for the elucidation of morphogenic processes—a key concept in geomorphological mapping—are patterns of *superposition* towards the determination of patterns of *superimposition* (Delannoy, Debard, Ferrier, Kervazo, & Perrette 2001; Delannoy, David, Geneste, Gunn, & Katherine 2017*a*; Delannoy et al. 2004; Joly 1977; Leser, Stäblein, Göbel, & Werner 1975).

One of the most useful practical features of geomorphological maps is their ability to represent any visible feature of a site surface (floor, wall, ceiling) using shape symbol, shading, and colour codes to indicate properties such as how features formed and their relative ages (Figure 1). In our renditions, the types of information shown on archaeomorphological maps have been divided into eight main groups relating to topography, hydrology, sediment deposits, erosion and forces of dissolution, palaeontology, archaeology, installations and evidence of site modification, and documentary records and analytical samples. On the maps, individual details are colour-coded so that, within a given group, all details are shown in one colour except in the case of sediment deposits, which cover such a wide array of phenomena that they are further subdivided into three subgroups, each with its own colour: brown for gravitational phenomena and deposits, green for water-related phenomena and deposits, and purple for deposits resulting from chemical processes (concretions, speleothems, etc.) (Figure 2). Different shades of colour are also used to indicate the relative ages of deposits, with lighter shades being used for older deposits (which tend to be fainter in the landscape) and darker shades for more recent ones. The legend shows the number of phases that account for the objects represented on the map, which will depend on the available data, the resolution of the morphogenic analysis, and the map's purpose. Archaeomorphological maps of rock art sites usually differentiate between materials that formed before, during, and after the period(s) the art was made. Finally, the objects shown on the maps are drawn to scale, so their general sizes and footprints can be assessed at a glance.

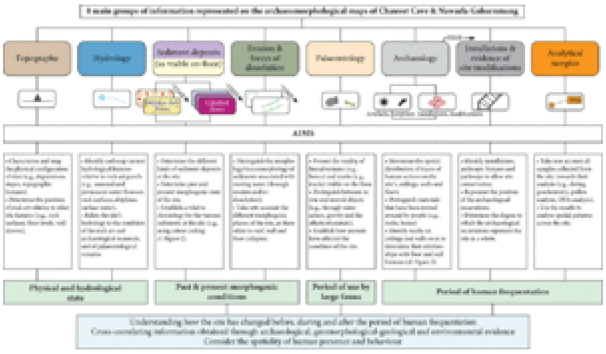

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Figure 1 The eight main groups of information recorded for Chauvet Cave and Nawarla Gabarnmang during archaeomorphological mapping.

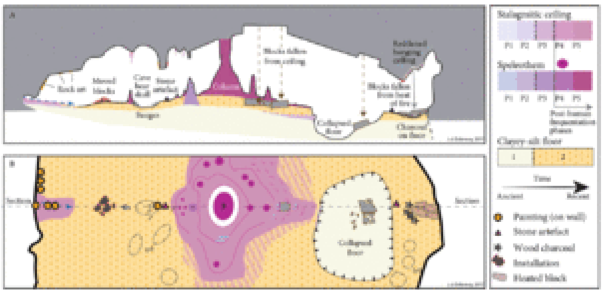

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Figure 2 Example of an archaeomorphological map and section across the map. The major principle underlying archaeomorphological mapping is to examine and interpret a site taking into account its varied lines of evidence in an integrated way, so as to understand the interplay of geomorphological and anthropic site formation processes and events through time.

Image courtesy of Jean-Jacques Delannoy.

Processing information in this way allows the researcher to determine how each object formed, including whether or not human agency is implicated. Archaeomorphological surveys aim to map objects and identify the morphogenic process(es) responsible for their form and position in the landscape; there should be no blank spaces on an archaeomorphological map other than inaccessible areas. This is not so much for the sake of being exhaustive as to enable questions to be asked about each object, its relationships with other adjacent or more distant fixed and movable objects, and the processes that caused them to be located where they are today. The act of representing each one of these objects on a map gives them an existence that requires explanation, and this requires a history. Archaeomorphological maps are tools for examining a site's evolution in relation to the history of human presence.

Archaeomorphological mapping was first undertaken at Chauvet Cave in France and Nawarla Gabarnmang in Australia (e.g., Delannoy et al. 2013). In both cases, a major aim was to determine the extent to which people had modified the site's walls and ceilings in the past and the identification of built installations on the floor, to better understand the morphogenic processes at work, the cultural context of the rock art, and the configuration of the rock surface when the art was done. These archaeomorphological maps were produced by archaeologists and geomorphologists working together for, in essence, the maps are very detailed renditions of combined archaeological and geomorphological information. Each rock and the like is carefully checked by both specialists to determine whether it exhibits any evidence of human modification and exactly where in the site (or beyond) the object originally came from. The maps can also throw light on how sites were modified by people, and hence reshaped, through time (aménagements).

Nevertheless, maps of surface features can only depict objects that are visible on the floor (and, by various graphic devices, on the walls). But there are ways to graphically combine ground-surface maps with information of what lies buried (as revealed by archaeological excavation, for example), on the ceiling, and on cave and rock shelter walls (via cross-sections or maps of the ceiling, for example). These spatial cross-references are necessary steps that allow archaeomorphological maps to consider the site in its three-dimensional (3-D) whole and, indeed, as a four-dimensional space once time is taken into account (see Jaillet et al. this volume). Only by considering these multiple dimensions is it possible to (1) analyse each object in relation to the site's overall shape; (2) identify how an object got to be where it is today (e.g., has it fallen from the ceiling through gravity, or has it been brought from elsewhere by people, or has it been carried into the site by water action, etc.?); and (3) establish when an object attained its present position or when an artwork was made relative to other changes in the physical structure of the site.

Let us now illustrate how the construction of archaeomorphological maps has enabled us to make fundamental new discoveries through two examples of extraordinary rock art sites: Chauvet Cave (Ardèche, France) and Nawarla Gabarnmang (Northern Territory, Australia). We use these complex sites as examples, but this kind of investigative process can be undertaken at any site, from the structurally most simple to the most complex. Both sites contain abundant evidence that their floors, walls, and ceilings have changed over time, but neither standard archaeological nor geomorphological mapping alone would be sufficient to resolve how this has happened. Archaeomorphological mapping revealed many surprises that led us to change our overall approach to the study of rock art sites generally.

Chauvet Cave During the Upper Palaeolithic

The discovery of Chauvet Cave in 1994 caused great excitement among the archaeological community due to the quality, quantity, and age (earliest phase: *c.* 36,000 cal. BP) of its remarkably well-preserved rock paintings (e.g., Clottes 2001; David 2017; Geneste 2005; Quiles et al. 2016). Here, archaeomorphological investigations were developed to determine (1) the exact shape of the cave at the time the paintings were made; (2) how and when the Upper Palaeolithic cave entrance became blocked, effectively sealing it from human access; and (3) how features on and the shape of the cave's floor, walls, and ceilings have changed since then. The archaeomorphological maps were made at a 1:50 scale to allow for the recording of sufficient details (Delannoy et al. 2004, 2012; Delannoy, Sadier, Jaillet, Ployon, & Geneste 2010).

Chauvet Cave began forming more than 5 million years ago (Jaillet, Delannoy, & Sadier 2017). Today, it can be divided into a number of connecting chambers and corridors, each with its characteristic features. Block-strewn floors feature in those sections of the cave closest to the Upper Palaeolithic entrance; open chambers with flat, clayey-silt floors, many with large hanging ceilings, are found deeper on. Some of the cave's more striking features (e.g., descending galleries, hanging ceilings, complex wall morphologies, chemically weathered limestone walls sometimes forming soft 'moonmilk' surfaces) formed early, millions or hundreds of thousands of years ago (well before the arrival of people on the scene). Others are more recent (e.g., the scree deposit at the cave entrance, sinkholes, speleothems) (Figure 3).

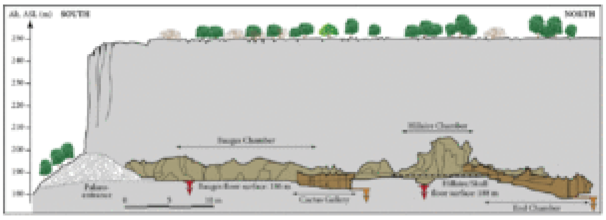

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Figure 3 Cross-section through the underground terrain of Chauvet Cave, showing spatial relationship of key features.

Image courtesy of Jean-Jacques Delannoy.

As we began to research the long history of human engagements in the cave, it became clear that fundamental questions needed to be answered about the cave's structure: when and how did individual features such as piles of rock and speleothems form? Were those features contemporaneous with one or more phases of painting activity, thereby helping better understand both the physical and cultural context of the artworks? How different to today was the cave in Upper Palaeolithic times? What condition were the walls in when the art was made, and how distinct in their surface textures and the like were the decorated panels from the surrounding walls? How easy would it have been for people to move through the cave, taking into account the rocks, speleothems, ceiling height, width across walls, sinkholes, soft deposits, and so forth? Put more simply, what has changed and what has remained the same over the millennia?

Archaeomorphological mapping showed that three major changes in the physical layout of the cave postdate the period of human presence:

1. There is a large sinkhole in the floor of the Hillaire Chamber that lies directly below finger flutings on the ceiling above. These finger marks must have been made before the floor collapsed as this part of the ceiling is now inaccessible (Figure 4). Similar conclusions can be made for other sinkholes elsewhere in the cave.
2. One of Chauvet Cave's most striking features are the many speleothems on its floors (e.g., stalagmites, columns, rimstones) and walls (e.g., stalagmitic columns, shawls). Such concretions formed in five phases, although most belong to the most recent, late glacial and Holocene phases (Phases IV and V). Given that the entrance of the cave became sealed as a result of a series of cliff collapses that ended *c.* 21,500 years ago, these latest concretions must postdate the period of human entry (Genty 2017; Genty, Blamart, & Ghaleb 2005). These details are important for they show that the Upper Palaeolithic cave chambers and passageways would have been more open for human and animal traffic than they are today; some of the more constricted galleries and art panels would also have been more open of view (Figure 5). What is more, the absence of sinkholes and of the more recent speleothems means that people would have moved through the cave more freely, affecting the choice of where to make the art. The Upper Palaeolithic cave did nevertheless contain some concretions (those formed during Phases I, II, and III, before the first arrival of people *c.* 36,000 cal. BP). We know this because of the presence of cave bear claw marks on concretions and of paintings that follow the shape of stalagmites; for example, the red mammoth in the Brunel Chamber (Figure 6).
3. Identifying the size, shape, and position of the cave's Upper Palaeolithic entrance was more difficult than mapping the Upper Palaeolithic cave itself (the latter needed to determine when sinkholes and speleothems formed). Finding precisely where the Upper Palaeolithic entrance was remained a priority for it would reveal how easily the cave could be seen from outside (see Jaillet et al. this volume) and how deep into the cave sunlight could penetrate.

Eventually, the entrance was discovered by archaeomorphological mapping that incorporated geomorphological attributes of the floors and ceilings, soft sediments and rock debris at floor level, results of archaeological excavations, and chronometric dates on speleothems and rock scars (Delannoy et al. 2010; Sadier et al. 2012). In addition to revealing that the cave's Upper Palaeolithic entrance became sealed as a result of a series of cliff collapses ending around 21,500 years ago, as mentioned earlier, the combined evidence also showed (1) the level of the Aurignacian floor (e.g., through the presence of hearths and stone artefacts, some of which became buried); (2) that large fires had once burned near the cave entrance (e.g., the ceiling is now heat-reddened); (3) that cold air entered the cave during glacial times (e.g., there is evidence of frost shattering); (4) how much and how far direct and subdued sunlight was able to penetrate into the cave (Delannoy, Jaillet, Monney, & Sadier 2017*b*; Ferrier et al. 2014) (Figure 7); (5) the distribution of red art relative to the Upper Palaeolithic entrance; (6) the pathways followed by cave bears; and (7) the state of the cave's various chambers, corridors, and rock surfaces before and after the cave became sealed.

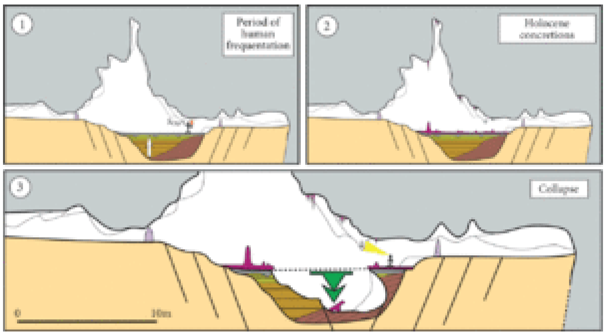

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Figure 4 The Hillaire Chamber, showing the development of the large sinkhole that post-dates the period of human activity (including finger flutings on the ceiling above the sinkhole).

Image courtesy of Jean-Jacques Delannoy.

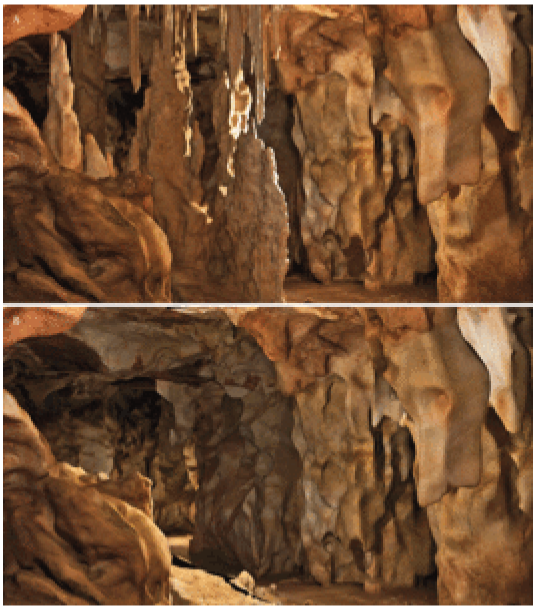

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Figure 5 3-D model of the entry into the Cactus Gallery. A: today. B: During Upper Palaeolithic times.

Images by Benjamin Sadier.

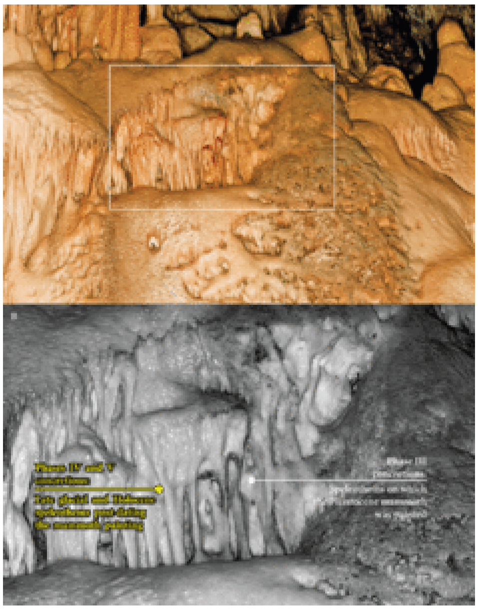

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Figure 6 Example of how understanding the history of wall concretion formation allows a better understanding of contexts of art-making: the “Small Mammoth” of the Brunel Chamber.

Images courtesy of Jean-Jacques Delannoy.

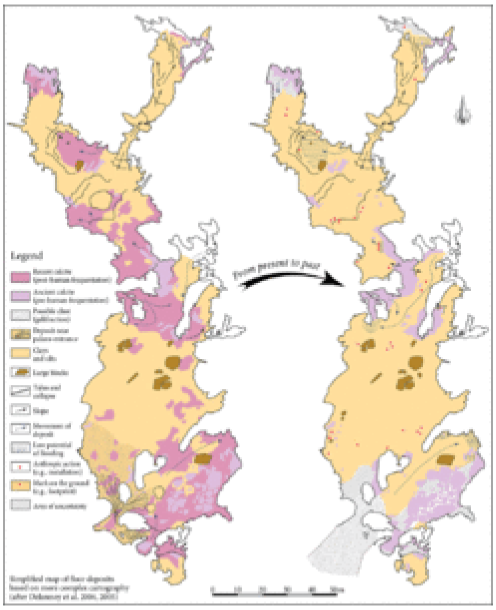

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Figure 7 Structural changes in the material matrix of Chauvet Cave. Left: The cave as it is today. Right: As it was at the time of its Upper Palaeolithic frequentation by people.

Image courtesy of Jean-Jacques Delannoy.

By examining cave features one at a time and determining the order in which they had formed, the Upper Palaeolithic underground landscape could thus be reconstructed. Other than those just described, few features appear to have changed since then. The overall layout is the same: the same blocks that currently lie near the entrance were then also there (as shown by marks left by cave bears), and the floors sloped in the same way (as shown by the slide marks of cave bears and by installations built by people at floor level, such as steps fashioned from modified slabs of rock). But there was then a marked difference in the cave’s microclimate and hydrology between the cave’s initial and deeper chambers. This final point is important because it throws light on why the art near the entrance, which is mostly red, is so different from that deeper in the cave, which is mostly black. In Upper Palaeolithic times, when the large, semicircular entrance was still open, air could circulate freely through the cave as far as the passageway known as ‘The Sill’ (a natural constriction midway in the cave). As a result, humidity would escape from the more proximal chambers, causing clays on the walls to dry and exfoliate onto the floor, exposing the light, whitish-grey limestone beneath. All the red art in this proximate section of the cave was made directly on this light-coloured limestone. In contrast, the air beyond The Sill was more humid, allowing films of damp clay and weathering products to cover the walls of the deeper chambers. Upper Palaeolithic artists could thus use other techniques there, such as finger fluting and other means of scraping away the clay to expose clean, light-coloured backgrounds in patterned ways and to mix charcoal powder with the clay to produce grey shadings. Archaeomorphological studies show that, in these sections of the cave, the earliest instances of clay removal on the walls were caused by bears rubbing against and clawing at the walls. These claw marks may have inspired the later finger tracings.

The information revealed about the cave's Upper Palaeolithic environment and microclimate, and about the features that postdate the sealing of the cave entrance, provides a clear picture of Chauvet Cave's overall geography for those times of human use (Figure 8). The large palaeo-entrance, perched high above the Ardèche Valley and overlooking the Pont d'Arc, a spectacular natural rock formation that arches across the river (Figure 9), was a prominent feature of the Upper Palaeolithic landscape. Its wide open berth allowed light to flood the initial art galleries and penetrate deep into the cave all the way to a network of large stalagmites in the Brunel Chamber, beyond which limited, subdued sunlight continued to reach until the latter parts of the vast Bauges Chamber where no light reaches. While hearths are present in these early sections of the cave, the only palaeontological remains beyond the reach of subdued light are of cave bears, animals known to frequent and hibernate in places of total darkness. There is a connection between sunlit areas and the art—one that largely mirrors that of the air flow—with mostly red art in areas lit by direct or subdued sunlight and mostly black art in areas of complete darkness, although we do not know if there is any original causal relation between the two. While parts of the cave were more open and thus easier to traverse because of a paucity of speleothems at floor level during Upper Palaeolithic times, walking through the cave would also have been more difficult because less light would have reflected off the walls and the clay floor would have been wetter and more slippery (preserved footprints show where people and animals had slipped). In addition, there would have been a greater contrast in colour between the floor and walls, especially near the cave entrance, and the angle of view of some spaces and walls would have been very different from now. Such factors have to be taken into account when interpreting possible pathways through the cave and the distribution and visibility of art panels.

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Figure 8 The Pont d'Arc above the Ardèche River, a geologically ancient archway in the valley floor below Chauvet Cave.

Photo by Stéphane Jaillet.

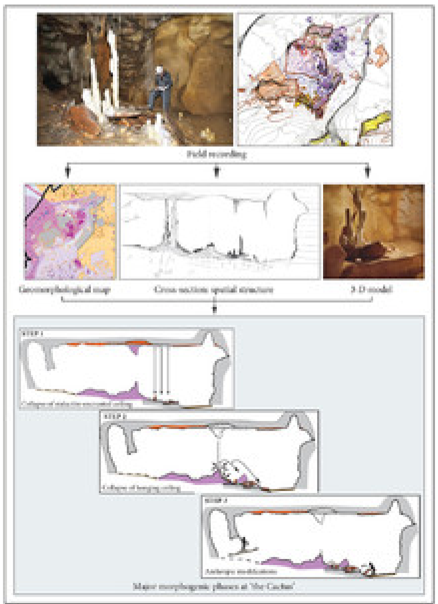

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Figure 9 The sequence of steps involved in archaeomorphological mapping, here applied to "the Cactus", Chauvet Cave.

Image courtesy of Jean-Jacques Delannoy.

Archaeomorphology as a Tool for Identifying Anthropogenic Structures at Chauvet Cave

Many rock art sites contain objects dropped (including manuports) or made by people, but how these artefacts relate to the site's physical evolution and the history of human engagements is rarely studied. From the onset, it has been clear that at Chauvet Cave many objects such as animal bones and blocks of rock had been prominently positioned and sometimes arranged in complex ways by people at very specific locations within the cave. These installations—for us today one of the most obvious and spectacular of which is a bear skull placed on top of a metre-long block that rises from the ground (Clottes 2001; Geneste et al. 2017)—indicate a purposeful remodelling of the interior of the cave to suit how it was socially engaged at the time. Rock walls and underground spaces are integral to the social construction of a site because these are all important features within which people engage. But what is the social signification of such aménagements, and how do they relate to the artworks on the nearby walls? Here, we focus on structures created when people moved blocks of rock around because it is these that first came to our attention and that originally caused us to adopt an archaeomorphological approach (Delannoy et al. 2012, 2013).

A dozen installations have been catalogued, although the cave has not yet been entirely archaeomorphologically surveyed. While some of these could be clearly seen to have been built by people (Geneste 2001), others were not so clear-cut, in some cases requiring detailed study to determine whether people were implicated in their make-up and where the blocks had originally come from. Drawing up large-scale archaeomorphological maps of these enigmatic structures, where each component could be clearly shown, was critical to deciphering how each rock came to now lie and thereby to determine whether a given structure was indeed partly or entirely of human origin. The following example shows how this was done for the structure known as 'the Cactus'.

The ten rocks that form the Cactus lie toward the terminal end of the chamber called the Cactus Gallery, just below a small passage leading to the Red Panels Gallery and near some large, red-outline paintings of cave bears and felines. The Cactus forms a fairly well-defined circle of rocks around a group of calcite concretions that includes the distinctive 'Cactus stalagmite', after which the gallery was named (Figure 8). Could this rock circle have formed through ceiling collapse, as some observers maintained? Or does it owe its neat symmetry to human action? Archaeomorphological mapping allowed researchers to determine where in the ceiling each block had fallen from and thereby decide if it lay in its natural position or if it had been moved after it fell. Examining the layering of blocks on the ground showed the order in which they were laid (Delannoy et al. 2012, 2013) (Figure 10).

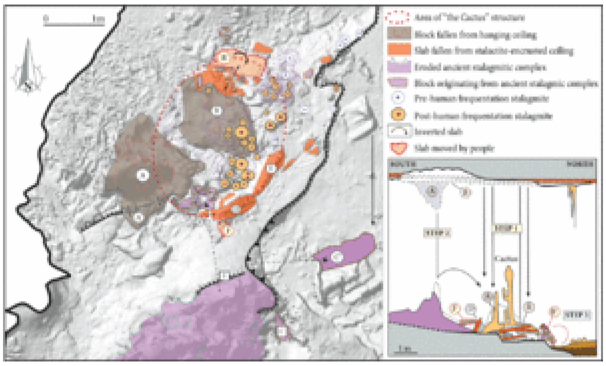

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Figure 10 Archaeomorphological map of the Cactus Gallery, and cross-section showing the sequence of events that led to the creation of the structure now known as “the Cactus”.

Image courtesy of Jean-Jacques Delannoy.

Petrographic analyses of the blocks showed that most of them had originally been part of the ceiling. The reddish, decimetre-thick slabs were part of an old, stalactite-encrusted ceiling, while the large blocks on the edge of the structure were separately produced when a hanging ceiling also collapsed. Detachment scars from where the blocks had fallen can still be seen on the ceiling above. The superimposed blocks are the result of at least two events. First, a section of the old stalactite-encrusted ceiling collapsed and shattered into metre- to decimetre-sized slabs when it hit the floor (e.g., elements D and E of the structure in Figure 10). Sometime later, the hanging ceiling (elements A and B) also collapsed, hitting a stalagmite below (‘1’ in Figure 10) and smashing it into several large pieces (blocks C and C′). The impact also broke this newly collapsed hanging ceiling into large pieces (A and A′; B and B′), which landed on slabs from the section of the stalagmitic ceiling that had earlier collapsed (D and E), breaking them into smaller pieces (D–D′) and tilting those pieces upwards. We do not know how much time passed between these two events: it may have been anywhere between seconds and thousands of years. However, stone artefacts found in hollows in block A show that it was already in place during the period of human presence.

This initial analysis showed that the block circle was mostly the result of natural events caused by karst processes culminating in gravitational collapse. Further examination showed that at least two of the blocks (B′ and F) had been moved after they had been deposited by the above processes. Slab B′ lies diagonally across the top of a preexisting stalagmite. That stalagmite is undamaged, so it could not have been hit by the slab as it fell from the ceiling. Hence, slab B′ must have been moved from its initial position and carefully placed on top of the then actively growing stalagmite, which then stopped growing. We can conclude that slab B′ was intentionally moved by people, perhaps to complete the rock circle, for there is no other way that it could have gotten there. Similarly, block F was moved on top of slab D and then wedged in position with a small stone. These modifications give the entire circle of rocks a cultural dimension as an installation. A flint chisel, limestone flakes, and some ochre pieces deliberately placed in hollows in the structure’s main block (A) provide further archaeological evidence for the overall installation’s significance in the gallery’s Upper Palaeolithic landscape (at a time when it had not yet been transformed by the later, late glacial and Holocene speleothems that subsequently grew on the installation). Like that gallery’s artworks, the Cactus is an anthropogenic structure that indicates that the art did not operate on its own; other parts of the cave were also transformed at the time the paintings were made, and they, too, would have been prominent features and foci of performative attention in the Upper Palaeolithic subterranean landscape. Understanding the art, including its social engagements, needs to consider the creation and use of these contemporary installations.

Analysing relationships between stacked, aligned, and otherwise unusually positioned blocks has also revealed several installations relating to the making of pathways through the cave (stepping stones) and to the trapping of water (aligned blocks caulked with clay) (Figure 11) (Delannoy et al. 2012, 2017*b*). These show that people intended to return to the cave after their construction; the cave, the galleries, the installations, and the art were created not just for the passing moment but for longer-term engagements. Whatever meanings they held for Upper Palaeolithic peoples, and however they were used, these installations found across much of the cave are the results of considerable labour investments, both to extract the raw materials and to move and rearrange the blocks (some of which weigh 60–70 kilograms and could thus only have been moved by several people working together). Archaeomorphological study of the blocks, walls, and ceilings has shown where in the cave the blocks came from and how the installations were put together.

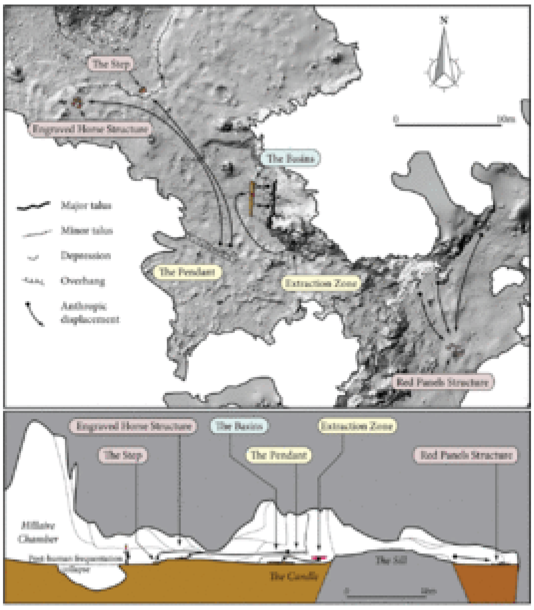

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Figure 11 The various installations, all anthropic, identified through archaeomorphological mapping in the mid-sections of Chauvet Cave.

Image courtesy of Jean-Jacques Delannoy.

Several of the largest block structures are close to panels of artwork (e.g., in the Cactus and Red Panels Galleries, Hillaire and Skull Chambers), suggesting likely links between them. Other Upper Palaeolithic caves in western Europe also have such associations between rock formations and rock art, indicating a likely fruitful avenue for future study. Examples include Cueva de la Garma in Spain (Arias, Laval, Menu, Sainz, & Ontañon et al. 2011; Ontañon 2003), Tuc d'Audoubert in France (Bégouën et al. 2009), and Trois Frères also in France (e.g., Bégouën, Clottes, Ferruglio, & Pastoors 2014). The presence of substantial, morphologically analogous installations in caves devoid of rock art, or their production well before there are any signs of the making of art (e.g., at Bruniquel by Neanderthals; see Jaubert et al. 2016; Rouzaud, Soulier, & Lignereux 1996), suggests that explanations need to be case-specific. Nevertheless, what they all have in common is that the installations marked spaces of performance in ways that the rock art alone cannot explain. These manifestations of human agency provide a new perspective on how Upper Palaeolithic peoples engaged with their underground landscapes. Archaeomorphological studies at Chauvet Cave show how new light can be shed on the intentional, premeditated actions of people deep in the past.

Nawarla Gabarnmang

Nawarla Gabarnmang is a large rock shelter on the Arnhem Land plateau in northern Australia. It has a long history of human use, extending from shortly before 47,200–51,700 cal. BP to the early nineteenth century (David et al. 2017*a*; Gunn 2016). The site is of major archaeological importance both for the wealth of artefacts it contains, including fragments of some of the oldest ground-edge stone axes in the world (David et al. 2013; Geneste, David, Plisson, Delannoy, & Petchey 2012), and for its exceptionally rich and detailed rock art panels. Some 1,392 images have been catalogued from the shelter's ceilings, most of which are superimposed by many layers of painting that together cover thousands of years of artistic activity. Radiocarbon determinations for a drawn or painted rock found during excavations and that had fallen from the ceiling indicate that the earliest art was made some unknown time before 26,739–27,657 cal. BP (the age when the excavated decorated rock fragment fell from the ceiling), whereas the most recent paintings were made in the nineteenth or early twentieth century (Gunn 2016). Remarkable also is Nawarla Gabarnmang's size and structure—a huge cavity (32 metres long, 23 metres wide, 2 metres high) in hard quartzitic bedrock, open at both ends and with a ceiling supported by around 50 bedrock pillars (Figure 12).

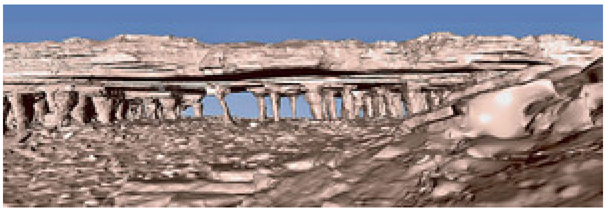

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Figure 12 3-D model of Nawarla Gabarnmang as seen from the northern entrance of the site, and clearly showing the wide-open spaces between pillars.

Image courtesy of Jean-Jacques Delannoy.

How did Nawarla Gabarnmang's unusual architecture arise? How did such a large cavity form in the hard quartzite, a rock that is not at all conducive to the formation of large underground cavities? These are not just geomorphological questions, as identifying the processes responsible for Nawarla Gabarnmang's architecture is also an essential step in understanding the site's archaeological (i.e., human) history and deciphering relationships between its artworks and the exceptional setting in which they were made. To answer these questions, we turned to archaeomorphology.

Archaeomorphological Mapping: Nawarla Gabarnmang as an Architectural Landscape

The rock at Nawarla Gabarnmang was formed by the compaction of coastal sands deposited almost 1.7 billion years ago (Carson, Haines, Brakel, Pietsch, & Ferenczi 1999). The rock matrix is poorly soluble and highly resistant to erosion. The cavity could not, therefore, have formed by the sorts of dissolution processes responsible for creating most other underground cavities. Geological voids, formed over several hundred million years by a slow dissolution process known as ‘ghost-rock weathering’ or ‘phantomization’ (Delannoy et al. 2017*a*; Quinif 2010), do occur in Arnhem Land quartzites. However, these voids are usually small and tend to be arranged in regular grid shapes that ‘map on’ to fracture lines and bedding planes. At Nawarla Gabarnmang, as in other parts of the Arnhem Land plateau, dissolution largely follows these more ‘soluble’ lines of weakness in the rock, in due course causing linear cavities.

Such cavities are also found in the rock on either side of Nawarla Gabarnmang, suggesting that ghost-rock weathering initiated the cavitation process, but ghost-rock weathering alone cannot explain the significantly more open spaces that span multiple ghost rock cavities, causing massive, continuous voids. Moreover, the plan-view layout of these larger spaces is largely independent of the fracture network. In addition, the flat ceiling surfaces generally follow bedding planes and step upwards towards the site’s northern and southern entrances, suggesting that they formed by successive roof collapses rather than by dissolution. If the rock shelter is the result of ceiling collapse in voids originally produced by ghost-rock weathering, how large and what shape were the voids before sections of the ceiling collapsed? And where is the rock that must have fallen from the ceiling? It was to address such questions that archaeomorphological mapping was here undertaken (David, Taçon, Delannoy, & Geneste 2017*b*; Delannoy et al. 2012, 2013).

We began by drawing a map that showed the position of every object greater than 5 centimetres long on the rock shelter floor, incorporating details that could shed light on how those objects got there (e.g., on rocks: evidence of exfoliation, flaking, heat fracturing, grinding) (Figures 13, 14). The various kinds of morphogenic details evident on objects were listed in a detailed legend. Analysing the map was useful as it enabled us to consider this large site in its entirety in a single view, something not readily possible from within the site because of its large size and features hidden from view by the standing pillars. A number of critical observations were thus made:

1. The charcoal-rich, sandy-silt floor is flat.
2. On the floor, there is a dearth of slabs of rock fallen from the ceiling, even though the morphology of the extant ceiling clearly indicates that many layers of hard quartzite had fallen.

3. Many slabs of rock lying horizontally on (or embedded in) the floor show signs of anthropogenic modification (e.g., grinding, rounding of edges, traces of pigment, flaking). Some of these slabs are positioned side by side, like paving stones; others are found in other positions that could not have been achieved by gravitational collapse.

4. Scree deposits outside the overhang's northern and southern entrances are composed of consistently shaped and sized slabs of rock, typically a few tens of centimetres long and wide, each a single layer thick. These rock deposits are very different from scree slope deposits formed by the gravitational collapse of overhangs.

5. Regularly sized slabs of rock were found stacked around the edges of the overhang in areas where the ceiling is highest. Usually, those rock stacks were made up of slabs coming from single ceiling rock layers and cannot therefore have formed through gravitational collapse.

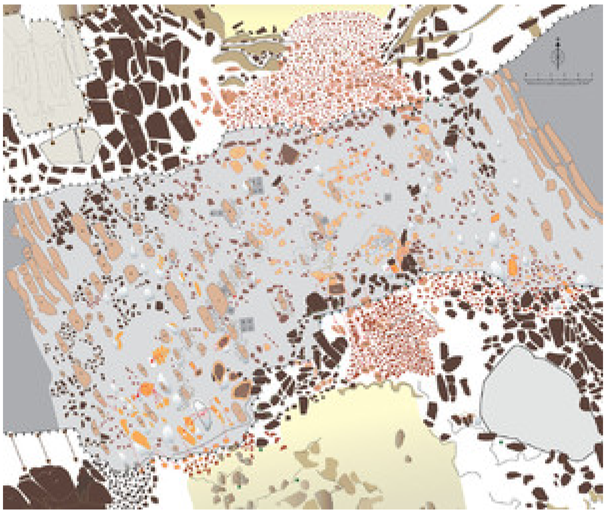

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Figure 13 Archaeomorphological map of Nawarla Gabarnmang's floor.

Image courtesy of Jean-Jacques Delannoy.

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Figure 14 Features recorded during the archaeomorphological mapping of Nawarla Gabarnmang's floor.

Chart courtesy of Jean-Jacques Delannoy.

These observations were corroborated by information provided by the archaeological excavations (e.g., David et al. 2017a). Collapsed blocks were found buried at a range of depths, but their total volume was much less than the volume of rock that had fallen from the ceiling. This difference raised two questions: Did the blocks found in the excavations come from the ceiling or from the supporting pillars? And where is all the rock that fell from the ceiling?

Differences in grain size, mineral composition, degree of compaction, and other such details give each of the site's quartzite layers their own particular petrographic signature. Comparing the petrographic 'fingerprint' of each block on and in the floor against that of the extant pillars and ceiling layers enabled identification of their original sources (Delannoy et al. 2017*a*) (Figure 15). Applying this same procedure to the blocks in the scree piles outside the overhang showed that they did not come from the rock shelter's adjacent lateral porches, but rather from further quartzite layers that once formed the ceiling.

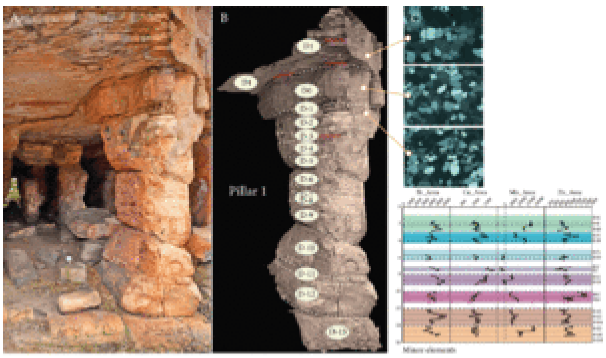

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Figure 15 Pillar 1 at Nawarla Gabarnmang, showing its distinct rock strata. These strata are shared across the site's pillars, enabling identification of the original source location of individual detached blocks and slabs that now lie on the floor or buried in its sediments.

Images courtesy of Jean-Jacques Delannoy.

The petrographic data showed that missing ceiling layers are absent from the rock shelter floor. This absence cannot be due to erosional or weathering processes, as evidence from eighteen excavations across the site indicates continuous deposition of fine sandy-silt beginning around 50,000 years ago until the past few decades. Although this sandy-silt contains minor quantities of sand produced by the weathering of quartzites (analysis of particle sizes and the shape, coating, and marks on individual sand grains allowed us to distinguish aeolian sands from in situ decomposed quartzites), there is no evidence of any erosion process powerful enough to remove the large volumes of fallen ceiling rock now missing from the ground.

The ceiling was then mapped at the same scale as the floor map in order to compare ceiling morphologies with those of the fallen blocks under the overhang and in the scree slopes nearby (Delannoy et al. 2017*a*). This work involved producing a three-dimensional (3-D) laser model in which every object could be mapped at spatial resolutions (subcentimetre-scale precision) not possible on hand-drawn maps.

Mapping the ceiling (Figure 16) showed that:

1. The large painted panels were made on ceiling surfaces exposed by the collapse of previous ceiling layers. The art could thus only postdate those ceiling collapses.
2. The inverted staircase form of the ceiling was produced by different sections of the ceiling collapsing at different times. Therefore, the oldest sections of the ceiling are the oldest ceiling surfaces capable of bearing paintings.
3. The position of now-absent pillars could be determined by scars on the ceiling. Around 100 such scars have been identified, indicating approximately 100 missing pillars. This finding allowed researchers to reconstruct the site's past morphology by digitally reintroducing the missing pillars into the underground landscape (Figure 16).

Click to view larger

Figure 16 A: Map of the present ceiling of Nawarla Gabarnmang. B: The ceiling with the missing pillars identified through remnant fragments of their uppermost rock strata still attached, and as deduced by the intersection of fissure lines (below the ceiling representing spaces between pillars).

Images courtesy of Jean-Jacques Delannoy.

The reconstructed grid-like pattern of pillars (and voids) under the overhang aligns with that on either side of the rock shelter. So how did the wide-open spaces under the overhang, signalling the disappearance of pillars whose remnant tops could still be seen on the ceiling, come about? They could not have been caused by geological forces alone.

The discrepancy between the large volume of rock absent from the pillars and ceiling and the small amount of debris lying on and in the floor under the overhang raises an important question relating to the processes at work: what happened to the rock from the collapsed ceilings and pillars? In some rock types (limestone and other soluble rocks), such discrepancies are often attributable to the disappearance through dissolution of the fallen rock. However, such an explanation does not work here as the quartz-rich rock is poorly soluble, and yet the floor sediments lack the large quantities of rock that fell. There remains only one possible explanation: people. This is entirely consistent with the evidence on the remnant blocks both inside the rock shelter and as scree deposits outside its two entrances, where individual blocks are of a regular size and often show flaking scars indicating that they had been broken and removed by people.

The Southwestern Sector of the Site

Three factors make the southwestern corner of the site of particular interest to the preceding question:

1. It is relatively open towards the southern entrance, but quickly closes up with dense pillars further inside the overhang. This part of the site forms an interface between the main (open) body of the archaeological site as it appears today and its more densely pillar (closed) aspect prior to the arrival of people (Figure 12).
2. Unlike other parts of the site, it contains much debris produced by pillar and ceiling collapse.
3. One painting (Motif A27) on the ceiling, on Art Panel A3, overlies a mudwasp nest whose organic components were radiocarbon dated to 10,154 ± 40 BP (11,624–12,024 cal. BP, with a median age of 11,883 cal. BP at 95.4% probability) (see Gunn 2016 for details). This painting must therefore be younger than *c.* 11,500–12,000 years. Patterns of superimposition indicate that most of the paintings on Art Panel A3 must be younger again than Motif A27.

Archaeomorphological mapping (Figure 17) of this sector of the site revealed further details. We asked: Where did the blocks now lying on the floor come from? Their petrographic signatures indicate that many of the blocks came from pillars; others had fallen from the ceiling. However, the ceiling blocks did not come from the ceiling layers that had collapsed most recently. Nor are they now located directly below those parts of the ceiling from which they had fallen. Rather, most of these ceiling blocks lie close to pillars. Only the largest blocks have not been moved. These larger blocks are covered with flaking impact marks, suggesting that attempts were made to break them into smaller pieces or to round off their sharp corners. All this evidence clearly points to the work of human hands.

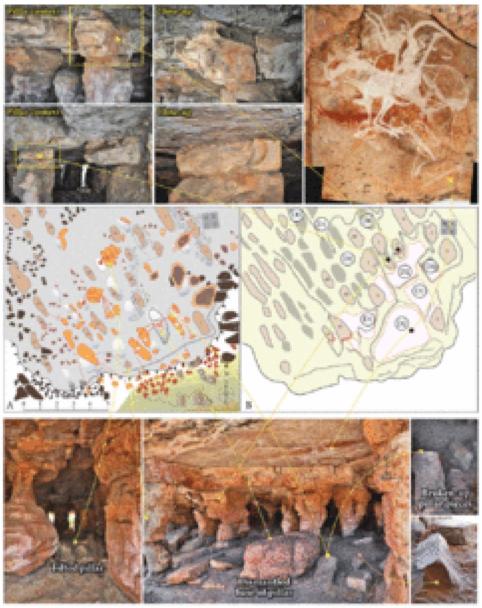

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Figure 17 Archaeomorphological maps of the floor and ceiling of the southwestern sector of Nawarla Gabarnmang, showing missing pillars and ceiling strata and the anthropic breakage and evacuation of blocks towards outer parts of the site.

Images courtesy of Jean-Jacques Delannoy.

Some of the blocks that had fallen from the ceiling now lie on rocks protruding from the ground (for details, see Delannoy et al. 2017*a*). This is the case for Block A, which fell from ceiling rock layer D0 and now lies directly on a protuberance of rock layer D-13 that was once the base of a now-absent pillar. This superposition of a D0 block immediately on an in situ D-13 protruding rock signals that all the rock layers (D-3, D-2, D-1) that fell before D0 are missing, although some remnant sections remain attached to the ceiling. If only natural processes had been involved, these fallen rock layers would have been sandwiched between the bedrock (base of the pillar layer D-13) and Block A (from ceiling layer D0). That they are not also shows that the pillar was no longer standing when Block A fell. A similar pattern occurs in several other areas of the southwestern corner of the site, indicating that there, too, pillars were removed before blocks fell from the ceiling. But was this a case of people removing blocks that had fallen simply through forces of gravity or had the now-collapsed pillars and fallen ceiling layers been dismantled by people?

In order to answer this question, research now focused on pillars that were only partially removed from their originating positions, those that had remnant 70- to 90-centimetre-high pedestals protruding from the ground. These pedestals are surrounded by blocks with similar dimensions to the widths of missing pillars (Figure 18). Petrographic analyses showed that these blocks belonged to the rock layers that had made up the pillars. Because the quartzite is so resistant to chemical weathering and breaks so cleanly, fragments that were once joined could be reassembled relatively easily. Most of these fragments exhibit percussion impact marks at their extremities, suggesting that they had been flaked into smaller pieces, presumably so they could be removed to the edges of the overhang. This would also explain the piles of regularly sized rocks on the northern and southern screes, at the edges of the site. The collapsed pillar blocks thus showed clear signs of having been broken up into smaller pieces and manually removed from their original positions under the overhang.

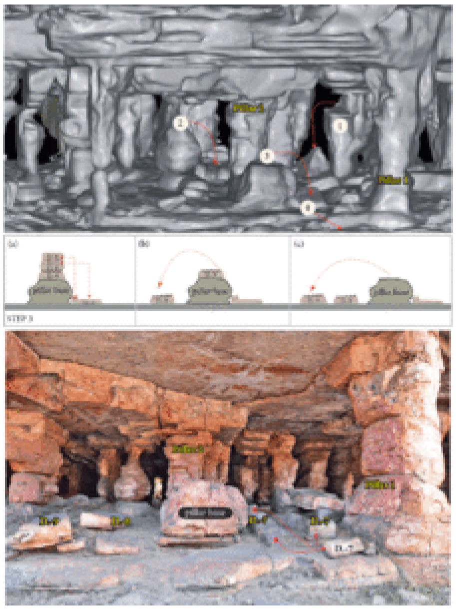

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Figure 18 Different stages of anthropic dismantlement of pillars in the southwestern sector of Nawarla Gabarnmang.

Image courtesy of Jean-Jacques Delannoy.

But are there any signs that the pillars were toppled by people in the first place? The 'smoking gun' appears in the form of still-standing pillars whose uppermost layers only were removed, sometimes by vertical sectioning, sometimes by horizontal flaking (Figure 17). They show the process involved: the pillars were toppled by first removing the uppermost rock layers in contact with the ceiling. Only then could the rest of the pillar be tipped over or dismantled layer by layer.

All in all, the opening up of the rock shelter space in the southwestern corner of the site appears to have been interrupted because, unlike elsewhere in the site, here the floor is strewn with only partially removed blocks, and the process of removing still-standing pillars deeper under the shelter seems to have been left unfinished.

By identifying the morphogenic processes responsible for the current position of every visible component of the pillars, ceiling, and floor blocks and determining the vertical and horizontal relations between components, the southwestern sector of Nawarla Gabarnmang produced a coherent model for the rock shelter's morphogenesis. Most of the changes to the site's configuration are the result of intentional human actions, indicating an architectural space that through time became richly decorated with rock art, but understanding the art needs to go hand in hand with understanding the evolution of the site as a continuously transforming 3-D space and canvas.

At Nawarla Gabarnmang, that transformation began with the removal of the uppermost layers of pillars, after which the pillars themselves could be toppled and subsequently dismantled layer by layer. Once they lay on the ground, the larger individual blocks and the remnant stubs were fragmented into small sections by flaking, and the rock was evacuated to the edges of the site. Removing the pillars led to the collapse of many of the now unsupported ceiling panels, and again, the resulting debris was further fragmented into manageable slabs by flaking and evacuation to the scree slopes outside (Delannoy et al. 2017*a*). It is not known whether the ceiling layers were prised down to facilitate their collapse or whether they fell purely because their pillar supports were now missing. But each time a new layer fell from the ceiling, a clean surface was created for painting. Albeit the dense painted frescoes now evident on the ceiling, with their dozens of superimpositions, suggest that it was not necessarily fresh surfaces that artists always looked for.

Because paintings could not have been made before the ceiling surfaces were exposed, a chronology for the creation of the art can be drawn up, at least for the ceiling panels, by stratigraphically dating ceiling collapses as well as individual paintings (for details of the art's chronology, see Gunn 2016).

Conclusion

Archaeomorphological mapping allows researchers to track through time the changing configuration of sites, including rock surfaces and the morphogenic forces at work, and thereby the changing spatial contexts of the art on its surfaces. Here, we apply it to rock art sites, but it could be employed to address many other aspects of human engagements-in-place and the dynamics of sites with conservation in mind, for example. Archaeomorphology subtly shifts our attention away from the site as a 'natural' canvas upon which people could inscribe their presence and activities through artworks to social engagements that involved the active construction of place. The art does not simply 'sit' on the rock but is rather part of a broader process of social emplacement that requires us to consider sites as architectural and active performative spaces.

Both at Chauvet Cave and Nawarla Gabarnmang, culturally unrelated sites on opposite sides of the world, details of the social creation of place can be seen by how people engaged with the material fabric of the site. The art was not just the final step, but rather actively articulated with how people reshaped the site and created installations, each transformation altering patterns of movement with each site and pointing to the art as a performative space rather than as inscriptions fixed for all times.

Acknowledgements

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References

Arias, P., Laval, E., Menu, M., Sainz, C. G., & Ontañon, R. (2011). Les colorants dans l'art pariétal et mobilier paléolithique de La Garma (Cantabrie, Espagne). *L'Anthropologie, 115*(3), 425–445.

Bégouën, R., Clottes, J., Ferruglio, V., & Pastoors, A. (Eds.). (2014). *La Caverne des Trois-Frères: Anthologie d'un exceptionnel sanctuaire préhistorique*. Paris: Somogy.

Bégouën, R., Fritz, C., Tosselo, G., Clottes, J., Pastoors, A., & Faist, F. (2009). *Le Sanctuaire Secret des Bisons: Il y a 14 000 Ans, dans la Caverne du Tuc d'Audoubert*. Paris: Somogy.

Binford, L. R. (2001). *Constructing frames of reference: An analytical method for archaeological theory building using ethnographic and environmental data sets*. Berkeley: University of California Press.

Burns, J. A. (2005). What about behavior? Methodological implications for rockshelter excavation and spatial analysis. *North American Archaeologist*, *26*(3), 267–282.

Butzer, K. W. (1982). *Archaeology as human ecology: Method and theory for a contextual approach*. Cambridge: Cambridge University Press.

Butzer, K. W. (2008). Challenges for a cross-disciplinary geoarchaeology: The intersection between environmental history and geomorphology. *Geomorphology, 101*, 402–411.

Carson, L. J., Haines, P. W., Brakel, A., Pietsch, B. A., & Ferenczi, P. A. (1999). *Milingimbi SD53-2, 1, 250 000 geological map series explanatory notes*. Darwin: Northern Territory Geological Survey, Government Printer of the Northern Territory.

Clottes, J. (Ed.). (2001). *La Grotte Chauvet: L'art des Origines*. Paris: Seuil.

David, B. (2017). *Cave art*. London: Thames & Hudson.

David, B., Barker, B., Petchey, F., Delannoy, J. -J., Geneste, J. -M., Rowe, C., … Whear, R. L. (2013). A 28,000 year old excavated painted rock from Nawarla Gabarnmang, northern Australia. *Journal of Archaeological Science, 40*(5), 2493–2501.

David, B., Delannoy, J. -J., Gunn, R., Chalmin, E., Castets, G., Petchey, F., … Pietrzak, U. (2017*a*). Dating painted Panel E1 at Nawarla Gabarnmang, southern Arnhem Land plateau. In B. David, P. S. C. Taçon, J. -J. Delannoy, & J. -M. Geneste (Eds.), *The* *archaeology of rock art in Western Arnhem Land, Australia*. Terra Australis 48. Canberra: ANU Press.

David, B., Taçon, P. S. C., Delannoy, J. -J., & Geneste, J. -M. (Eds.) (2017*b*). *The archaeology of rock art in Western Arnhem Land, Australia*. Terra Australis 48. Canberra: ANU Press.

Delannoy, J. -J., David, B., Geneste, J. -M., Gunn, R., & Katherine, M. (2017*a*). Evidence for the origins and transformation of sheltered spaces at Nawarla Gabarnmang: Engineers of the Arnhem Land plateau. In B. David, P. S. C. Taçon, J. -J. Delannoy & J. -M. Geneste (Eds.), *The archaeology of rock art in Western Arnhem Land, Australia*. Terra Australis 48. Canberra: ANU Press.

Delannoy, J. -J., David, B., Geneste, J. -M., Katherine, M., Barker, B., Whear, R. L., & Gunn, R. (2013). The social construction of caves and rockshelters: Chauvet Cave (France) and Nawarla Gabarnmang (Australia). *Antiquity, 87*, 12–29.

Delannoy, J. -J., Debard, E., Ferrier, C., Kervazo, B., & Perrette, Y. (2001). La cartographie morphologique souterraine: Apports aux reconstitutions paléogéographiques et paléoenvironnementales—Application à la grotte (Ardèche, France). *Quaternaire, 12*(4), 235–248.

Delannoy, J. -J., Geneste, J. -M., Jaillet, S., Boche, E., & Sadier, B. (2012). Les aménagements et les structures anthropiques de la grotte Chauvet-Pont d’Arc: Apport d’une approche intégrative géomorpho-archéologique. In Delannoy, J. -J., Jaillet, S., & Sadier, B. (Eds.), *Karsts, paysages et préhistoire: Journées 2012 de l’Association Française de Karstologie dans le Sud-Ardèche* (pp. 43–62). Le Bourget-du-Lac: Laboratoire EDYTEM.

Delannoy, J. -J. Jaillet, S., Monney, J., & Sadier, B. (2017*b*). La grotte au temps des fréquentations paléolithiques. In J. -J. Delannoy & J. -M. Geneste (Eds.), *Atlas de la Grotte Chauvet*. Paris: Documentation Française de l’Archéologie.

Delannoy, J. -J., Perrette, Y., Debard, E., Ferrier, C., Kervazo, B., Perroux, A. S., … Quinif, Y. (2004). Intérêt de l’approche morphogénique pour la compréhension globale d’une grotte à haute valeur patrimoniale: La Grotte Chauvet (Ardèche-France). *Karstologia, 44*(2), 25–42.

Delannoy, J. -J., Sadier, B., Jaillet, S., Ployon, E., & Geneste, J. -M. (2010). Reconstitution de l’entrée préhistorique de la grotte Chauvet-Pont d’Arc (Ardèche, France), Les apports de l’analyse géomorphologique et de la modélisation 3D. *Karstologia*, *56*, 17–34.

Ferrier, C., Debard, E., Kervazo, B., Brodard, A., Guibert, P., Baffier, D., … Maksud, F. (2014). Les parois chauffées de la grotte Chauvet-Pont d’Arc (Ardèche, France), Caractérisation et chronologie. *Paléo*, *25*, 59–78.

Geneste, J. -M. (2001). La fréquentation et les activités humaines. In J. Clottes (Ed.), *La Grotte Chauvet: L'Art des Origines* (pp. 44–50). Paris: Seuil.

Geneste, J. -M. (2005). L'archéologie des vestiges matériels dans la Grotte Chauvet-Pont d'Arc. In J. -M. Geneste (Ed.), *La Grotte Chauvet à Vallon-Pont- d'Arc: Actes de la Séance de la Société Préhistorique Française, 11 et 12 Octobre 2003, Lyon, Sous la Direction de Jean-Michel Geneste, Jean-Pierre Fagnart et Jean-Jacques Delannoy*. *Bulletin de la Société Préhistorique Française*, *102*(1), 135–144.

Geneste, J. -M., David, B., Plisson, H., Delannoy, J. -J., & Petchey, F. (2012). The origins of ground-edge axes: New findings from Nawarla Gabarnmang, Arnhem Land (Australia) and global implications for the evolution of fully modern humans. *Cambridge Archaeological Journal*, *22*(1), 1–17.

Geneste, J. -M., Delannoy, J. -J., Boche, E., Le Guillou, Y., Jaillet, S., Monney, J., & Sadier, B. (2017). Aménagements anthropiques. In J. -J. Delannoy & J. -M. Geneste (Eds.), *Atlas de la grotte Chauvet*. Paris: Documentation Française de l'Archéologie.

Genty, D. (2017). Spéléothèmes: Datations des événements spéléogéniques et reconstitutions des climats passes. In J. -J. Delannoy & J. -M. Geneste (Eds.), *Atlas de la Grotte Chauvet*. Paris: Documentation Française de l'Archéologie.

Genty, D., Blamart, D., & Ghaleb, B. (2005). Apport des stalagmites pour l'étude de la grotte Chauvet: Datations absolues U/Th (TIMS) et reconstitution paléoclimatique par les isotopes stables de la calcite. In J. -M. Geneste (Ed.), *La Grotte Chauvet à Vallon-Pont-d'Arc: Actes de la Séance de la Société Préhistorique Française, 11 et 12 Octobre 2003, Lyon, Sous la Direction de Jean-Michel Geneste, Jean-Pierre Fagnart et Jean-Jacques Delannoy. Bulletin de la Société Préhistorique Française*, *102*(1), 45–62.

Gunn, R. (2016). *Art of the ancestors: Spatial and temporal patterning in the rock art of Nawarla Gabarnmang, a major Jawoyn cultural site on the Arnhem Land plateau*. Unpublished PhD thesis. Monash University, Clayton.

Heydari, S. (2007). The impact of geology and geomorphology on cave and rockshelter archaeological site formation, preservation, and distribution in the Zagros mountains of Iran. *Geoarchaeology*, *22*(6), 653–669.

Ingold, T. (2000). *The perception of the environment: Essays on livelihood, dwelling and skill*. London: Routledge.

Jaillet, S., Delannoy, J. -J., & Sadier, B. (2017). Caractéristiques morphogéniques de la grotte Chauvet. In J. -J. Delannoy & J. -M. Geneste (Eds.), *Atlas de la Grotte Chauvet*. Paris: Documentation Française de l'Archéologie.

Jaubert, J., Verheyden, S., Genty, D., Soulier, M., Cheng, H., Blamart, D., … Santos, F. (2016). Early Neanderthal constructions deep in Bruniquel Cave in southwestern France. *Nature*, *534*, 111–114. doi: 10.1038/nature18291.

Joly, F. (1977). Point de vue sur la geomorphology. *Annales de Géographie*, *86*(477), 522–541.

Jones, R. (Ed.). (1985). *Archaeological research in Kakadu National Park*. Special Publication 13. Canberra: Australian National Parks and Wildlife.

Lekson, S. H. (Ed.). (2006). *The archaeology of Chaco Canyon: An eleventh-century Pueblo regional center*. Sante Fe: School for Advanced Research Press.

Leroi-Gourhan, A. (1965). *Préhistoire de l'art occidental*. Paris: Lucien Mazenod.

Leser, H., Stäblein, G., Göbel, P., & Werner, R. (1975). *Geomorphologishe Kartierung: Richtlinien zur Herstellung geomorphologischer Karten 1, 25 000*. Berlin: Institut für Physische Geographie der Freien Universität.

Lorblanchet, M. (2010). *Art Pariétal: Grottes Ornées du Quercy*. Rodez, FR: Rouergue.

McFadyen, L. (2008). Building and architecture as landscape practice. In B. David & J. Thomas (Eds.), *Handbook of landscape archaeology* (pp. 307–314). Walnut Creek, CA: Left Coast Press.

Ontañon, R. (2003). Sols et structures d'habitat du Paléolithique supérieur, nouvelles données depuis les Cantabres: La Galerie Inférieure de La Garma (Cantabrie, Espagne). *L'Anthropologie*, *107*(3), 333–363.

Quiles, A., Valladas, H., Bocherens, H., Delqué-Koli, E., KaltnecKer, E., van der Plicht, J., … Geneste, J. -M. (2016). A high-precision chronological model for the decorated Upper Paleolithic cave of Chauvet-Pont d'Arc, Ardèche, France. *Proceedings of the National Academy of Sciences, 113*(17), 4670–4675.

Quinif, Y. (2010). *Fantômes de Roche and Fantômisation: Essai sur un Nouveau Paradigme de Karstogénèse*. *Karstologia Mémoires* 18.

Rouzaud, F., Soulier, M., & Lignereux, Y. (1996). La grotte de Bruniquel. *Spelunca, 60*, 27–34.

Sadier, B., Delannoy, J. -J., Benedetti, L., Bourlès, D., Jaillet, S., Geneste, J. -M., … Arnold, M. (2012). Further constraints on the Chauvet cave artwork elaboration. *Proceedings of the National Academy of Sciences of the United States of America, 109*(21), 8002–8006.

Schiffer, M. B. (1976). *Behavioral Archaeology*. New York: Academic Press.

Theunissen, R., Balme, J., & Beck, W. (1998). Headroom and human trampling: Cave ceiling-height determines the spatial patterning of stone artefacts at Petzkes Cave, northern New South Wales. *Antiquity*, *72*, 80–89.

Thomas, J. (2008). Archaeology, landscape, and dwelling. In B. David & J. Thomas (Eds.), *Handbook of landscape archaeology* (pp. 300–306). Walnut Creek, CA: Left Coast Press.

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