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## Reconstructing Paleolithic cave art: The example of Marsoulas cave (France)

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## ABSTRACT

3D technologies are now widely applied in the study of decorated caves and rockshelters because they provide unique volumetric representations of the art. In the cave of Marsoulas (Haute-Garonne, France), which has engravings and paintings which date to approximately 17,000 BP, 3D modeling and other image processing techniques have been combined into an analytical system of documentation that addresses the unique challenges and questions that this site presents to researchers. 3D modeling is used as a new tool for producing easily understandable graphic renderings of the cave walls (essential for interpretation), while also creating a publicly accessible reconstruction of the cave art and its environment.

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## 1. Introduction

3D techniques have been applied to the study of decorated caves and rockshelters with great success. Not only does this present an opportunity to represent parietal art in its full volumetric dimensions, but it readily allow for these reconstructions to be accessible to a wider audience. Most often, these 3D technologies are used in the final phase of analysis, to synthesize the body of data collected and to construct a holistic view of the site.<sup>1</sup> Even so, in France, the cost of these operations and of making them publicly available online limits these virtual visits to major national sites.

However, the application of 3D techniques presents many possibilities for all phases of research (among many examples: Pinçon, 2004; Pinçon et al., 2010; Azéma et al., 2012, 2014; Bourrillon and White, 2015; Feruglio et al., 2015; Fritz et al., 2010a; Delannoy et al., 2012). Since 2003, we have employed these tools in the interpretation and documentation of engravings and paintings from the cave of Marsoulas, which date to approximately 17,000 calBP (Fritz and Tosello, 2004, 2007). The constant evolution of 3D modeling techniques has allowed for considerable advancement in data acquisition in the cave environments as well as their reconstruction both for researchers and the greater public.

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<sup>1</sup> In France, we cite as examples the sculpted rock shelters of Chaire-à-Calvin (<http://www.sculpture.prehistoire.culture.fr/fr/la-chaire-calvin.html#visite>) and Roc-aux-Sorciers (<http://www.sculpture.prehistoire.culture.fr/fr/le-roc-aux-sorciers.html#visite>), and the painted caves of Lascaux (<http://www.lascaux.culture.fr/>) and Font-de-Gaume (<http://font-de-gaume.monuments-nationaux.fr>).

## 1.1. A fragile cave with a complex past

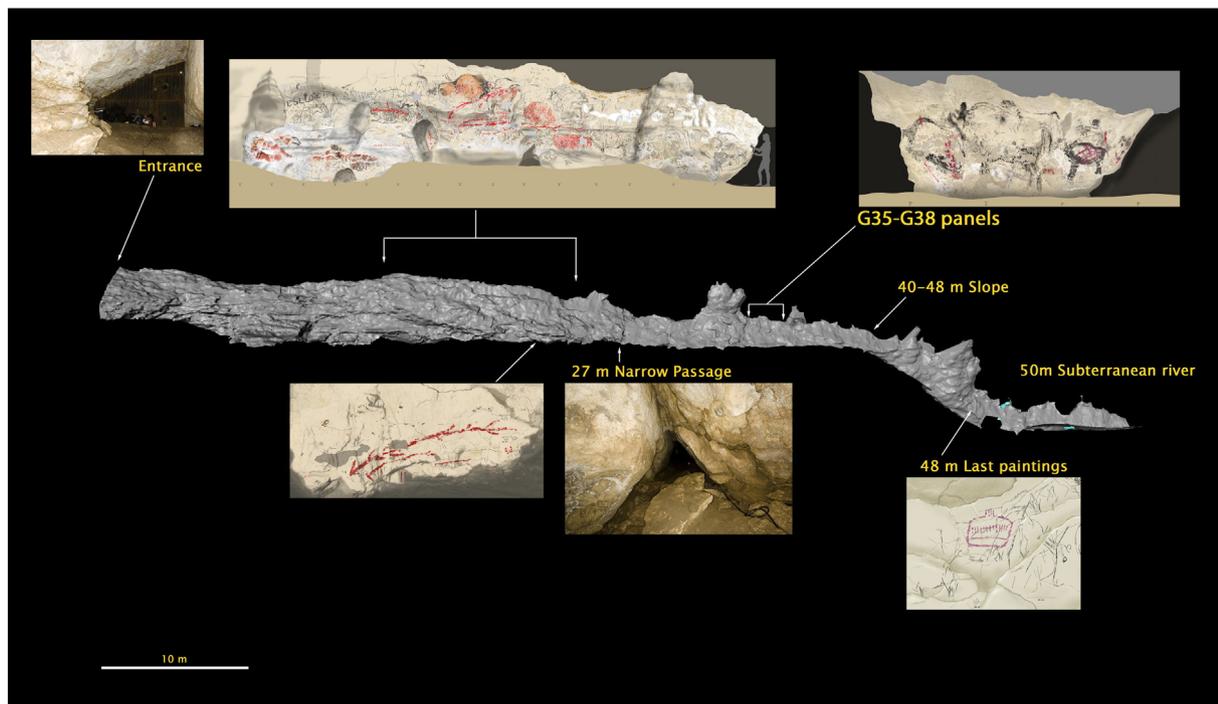
Marsoulas is a straight narrow gallery of moderate size, about 100 m long, and can be navigated easily to about 27 m from the entrance at which point the walls narrow drastically and the ceiling lowers, forcing the visitor to proceed by crawling. At 40 m from the entrance, the floor curves downward at an abrupt angle, while the roof maintains its height, for about a dozen meters. At 44 m in, one can more stand upright again on a steep surface until an underground stream is reached at 50 m. In cross-section, the cave has an asymmetrical triangular profile (3 m wide and 4 m tall in the largest sections). The right wall is slanted, inclining to form the roof and eventually meeting the vertical left wall. Parietal art has been documented along the entire length of the chamber (Fig. 1).

Marsoulas has a long research history. An excavation trench from 1883 to 1884 is still visible today at the base of the left wall, 13 to 18 m from the entrance (Cau-Durban, 1885). In addition to substantial archaeological material, the primary significance of this excavation remains the exposure of engravings and paintings that were obscured by infill until that point (Fig. 2).

In 1897, F. Regnault discovered the paintings that form the principal panel (Regnault, 1897). Throughout the 19th and 20th centuries, numerous researchers have studied the cave (e.g. Cau-Durban, 1885; Cartailhac and Breuil, 1905; Bégouën and Russell, 1933; Méroc et al., 1948; Leroi-Gourhan, 1971; Breuil, 1952; Plénier, 1971; Vialou, 1986; Foucher, 1991; Lacombe, 1996). Despite the previous work, a considerable area of the site remained unexamined, which led us to embark on a renewed study in 1998. Both the material culture items and the parietal art suggest the primary occupation phase occurred in the beginning of

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**Fig. 1.** Marsoulas cave. Complete 3D profile of the cave from the entrance to the end. In the present paper, the panels G35–G38 are presented as examples of the methodological protocol (doc. G.Tosello/C.Fritz).

the Pyrenean Magdalenian, around 17,000 calBP (Fritz and Tosello, 2005).

Early notoriety, significant and enduring scientific interest, and ease of access have had heavy impact on the conservation of the cave by attracting several generations of visitors who, through ignorance or vandalism, have damaged the walls in all areas within easy reach. The site was closed to the public in 1996. Even though research remains authorized, rules of conservation impose restrictions on maximum working time in the cave. This limits the impact that human presence can have on the subterranean climate, whose maintenance and stability are crucial to the conservation of the parietal art. With limited time to spend in the cave each year, we began to look for a way to continue portions of the documentation process from the laboratory.

### 1.2. An original style of cave art

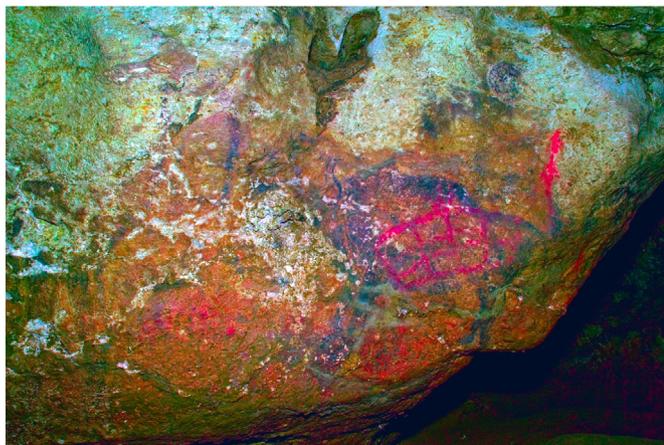
At the end of 2015, the inventory of themes represented at Marsoulas (based on the analyzed panels, which comprised 60% of the cavity) included more than 340 animal and human figures, geometric motifs, and diverse markings. Overall Marsoulas is thought to comprise 500 motifs based on our survey to date. Among the repertoire we note several large bison and horses painted in red and black and accentuated with engravings; one of the bison is covered in red dots, and another in black dots. Geometric motifs are grouped on the left wall and include: tectiform (Figs. 3 and 4), rectangles, clusters of lines, dots and dashes, inverse “T” shapes, grids, large “harpoon” forms, and shorter groups of oblique marks. The art of Marsoulas is of profound stylistic originality



**Fig. 2.** From the entrance to the back of the cave, the gallery is straight in plan and triangular in section. The trench from early excavations is visible at left (image C. Fritz).



**Fig. 3.** Panel of paintings and engravings on the left wall, between 37 and 38 m from the entrance. In addition to the black bison on the right, once can discern vestiges of red pigment belonging to geometric signs (see also Figs. 8–12) (image C. Fritz). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



**Fig. 4.** DStretch treatment of the preceding photo renders visible an additional red tectiform sign on the body of the black bison. This type of sign is very rare in the region of the Pyrenees (see also Figs. 8–12) (image C. Fritz). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

with few equivalents in the region from the same period (Fritz and Tosello, 2005, 2010).

The complex topography and relief of the cave ceiling has provided opportunity for prehistoric artists to explore the three-dimensional portrayals of animals and other motifs. On certain panels, the entire composition appears to incorporate the natural shape of the walls' niches and undulating surfaces to complete the form of engraved animals. The dimensions of the figures are highly variable. In spite of the constraints of the space, we find a wide range of scale from large animals (from 1.2 to 2.2 m) that are hardly identifiable because they surpass the visual field to figures in miniature nestled in the folds of the rock (Fig. 5).

### 1.3. A method of study in constant evolution

Because of the fine execution and the density of the prehistoric engravings, as well as the graffiti that has obscured certain panels, the parietal art of Marsoulas must be deciphered before it can really be readily interpreted (Fig. 6a, b, c). Therefore, the core of the current research

program is the analysis and the graphic survey of the decorated surfaces. For conservation reasons, physical contact with the walls is strictly forbidden during these operations. For over a decade research has been centered on traditional photographic reproduction of the decorated panels, which has served as the basis for the observation and recording of data in the cave. Once digitized, the detailed renderings created in the field are placed against a background that imitates the rock wall with the aid of infographic processing (see below).

Through this combination of techniques, we create a synthetic reconstruction of the panels. This technique of hand-drawn renderings on two-dimensional photographs is a long and complex process. Additionally, the frequent use of relief by the original artists and the positions of the panels in the space of the gallery have led us to devote a great deal of time and effort to the graphic reconstitution of the cave wall surfaces as well as the figures themselves (Fritz and Tosello, 2007).

For the reasons outlined above, we have undertaken a preliminary evaluation of 3D modeling methods and its contribution to renderings of parietal art (Fritz et al., 2010a; Fritz et al., 2010b). From 2003 to 2007, the interior of the cave was recorded with a laser scanner by a team of expert surveyors at varying levels of point-density (one point per square cm in non-decorated areas and one point every 2 mm for decorated areas). From the orthophotographs generated in the textured 3D model, we produced the renderings of the decorations by the conventional methods, first inside the cave and then at the computer. This “mixed” (2-D and 3D) method presented a marked methodological improvement, but it could not be produced on a large scale due to costs and multiple, complex phases of data exchange. In addition to laser scanning, enhancements, such as those provided by DStretch software (Harman, 2005), helped in the reconstitution and interpretation of damaged panels in both 2D and 3D (Fig. 4).

The recent and rapid evolution of 3D methods, software programs, and tools for digital image-capture have allowed us to progress even further in our search for an efficient method for the study of art at Marsoulas that could be implemented without the aid of dedicated outside specialists.

## 2. Methodology

Archaeologists, especially those working with paintings in caves, are constantly trying to improve the methods by which they record or



**Fig. 5.** One of the primary difficulties of interpretation stems from the abundance of surfaces covered with fine, overlapping engravings like the miniature bison head shown here (scale = 5 cm) (image C. Fritz et G. Tosello).



**Fig. 6.** a. Panel on the left wall between 14 and 16 m from the cave entrance, damaged extensively by modern graffiti (image C. Fritz). b. Complete rendering of the panel shown in Fig. 6a; underneath the modern graffiti prehistoric markings are visible, and can be identified based on their darker patina (image C. Fritz and G. Tosello). c. Panel on the left wall shown in Fig. 6b: the virtual elimination of graffiti reveals Magdalenian engravings (image C. Fritz and G. Tosello).

capture images for posterity. To this end, we have developed a new recording technique that enhances the archaeologist's ability to accurately document rock art in both two dimensions (2D) and three dimensions

(3D). The technique we present uses Structure from Motion (SfM) photogrammetry to capture the shape of the cave wall as well as its detailed photographic texture (De Reu et al., 2013, De Reu et al., 2014, and Kjellman, 2012). This provides the archaeologists, who are intimately familiar with the site, a platform for accurately tracing and recreating the ancient marks from the cave wall. This workflow consists of three major stages (data collection, data processing, and image tracing) and each step presents its own set of challenges. Data collection begins with a team of two people in the cave, both of whom are archaeologists. In the case of our team, one person is also a trained artist while the other an experienced photographer. The team works together to examine the portion of the wall being documented to identify and discuss specific images. Choosing the best imaging techniques to employ is decided on a case-by-case basis. In often very cramped and precarious locations, the team uses artificial lighting, normally LED panels, to illuminate the wall (Fig. 7). The direction and position of the lighting can reveal different images; by systematically changing the lighting we often expose numerous works of art on a single surface. Great care is taken to photograph the rock art from the best viewing angle, while also arranging the lighting to illuminate fine details. These steps help ensure data is captured in a way to create faithful renderings. This closely coordinated approach is critical, since the artwork of Marsoulas is often ephemeral and very hard to see. The challenge for the photographer is to balance the low lighting conditions, issues of depth of field (because of space constraints), and the lack of camera stability while attempting to take sharp, high-resolution photographs that accurately represent the rock art. The task for the artist is to insure that the photographer sees and captures the complex and overlapping images. Working together, the team of two takes hundreds and sometimes thousands of photographs of just a few square meters of cave wall in a day.

SfM software is used for the initial stages of data processing. The software used is Agisoft Photoscan Pro (Photoscan). This and other similar software are becoming very popular in a variety of archaeological applications including site mapping and artifact documentation (e.g., Verhoeven, 2009 and Kjellman, 2012). The first step of this technique involves the creation of basic 3D models of the cave walls. The 3D form of the wall is generated from multiple overlapping digital photographs collected in the cave and processed with Photoscan (Graves et al., 2013; Graves and Willis, 2011; Willis et al., 2014). This step creates models that have the same accuracy as most laser scans but have the advantage of being inexpensive to create, easy to collect (no bulky equipment), non-invasive, and fast. Additionally, unlike laser scanning, the



**Fig. 7.** The decorated panels at Marsoulas are often difficult to access, near the current floor. Lack of space for achieving adequate focal length further complicates the tasks of the researchers and the photographer (image C. Fritz).

high-resolution photographic images can be draped back onto the 3D model. The SfM mapping is an iterative process. Once the 3D models are generated, areas with insufficient detail or poor quality are identified. These problems can be caused by blurry photographs, depth-of-field issues, poor lighting, or improper overlap of photographs. Remediating these problems is as simple as revisiting the problem areas and taking more photographs to refine the model. Any additional problematic areas are manually masked, in the software, so as to exclude them from processing. Once all the images have been inspected, the data is reprocessed in Photoscan to produce a high-resolution model of the cave wall. The sharpest photographs are used to create a detailed texture map of the wall as well (Fig. 8). By combining the texture map with the 3D model, an extremely detailed virtual depiction of the cave's surface is created. Furthermore, by using different photographs with diverse types of illumination, multiple texture maps can be created for the same portion of 3D wall. This allows for rock art that may only be apparent from certain angles to be mapped separately on the same 3D surface. Once the 3D model is built, an orthographic 2D image is exported as a in TIFF file.

At this point, the process then moves back into the cave and relies more heavily on the artist. The 2D image of the rock art is loaded on to a tablet running Adobe Photoshop. The specially prepared 2D Photoshop images may have multiple layers with the rock art illuminated from different angles that can be turned off and on to assist the artist as he works. The artist, while looking at the actual cave wall, then traces the prehistoric images onto the 2D version of the same areas in Photoshop (Fig. 9). Once the artist is satisfied that the tracings are complete, the Photoshop file is returned to the laboratory for additional 3D processing and projected onto the digital 3D model of the cave wall (Fig. 10). Projecting the tracings back onto the model also allows for the rock art to be viewed from several angles (Figs. 11 and 12). This makes it possible to see how the natural form of the rock was used as an artistic device and incorporated in the original composition. In the example illustrated in Fig. 11, the head of the bison and the animal face (Fig. 12) are examples where the paintings relate closely to the natural shape of the underlying rock. This relationship is easy to demonstrate with the combination of tracings and 3D data.

### 3. Discussion

There are multiple reasons why these particular techniques are innovative and useful for documenting rock art. It is innovative because it allows for the best focused and well-lit portions of thousands of photographs to be seamlessly stitched together over a complex three-dimensional surfaces. The resulting images can then be brought into software, like Photoshop, that take best advantage of the documenting artist's skills and allows them to work in the comfort of the laboratory or while using a tablet inside the cave. The



Fig. 8. 3D model of the cave wall with the natural texture and relief (image Fritz/Willis/Tosello).

ability to project the 2D tracings back onto the complex 3D surface of the model is the most important part of this technique. Previously, this was only possible by tracing over thousands of photographs individually and assembling those into a final rendering. These techniques make that tedious, redundant, and non-intuitive approach obsolete. Furthermore, it allows researchers to work on portions of the cave in manageable “chunks” that can later be seamlessly combined independent of the order they were originally documented in. The process is a physically more versatile tool adapted to the difficult-to-reach places where rock art is often found. When one compares taking a camera and LED lighting panel into a cramped cave versus an expensive and bulky laser scanner in the same situation, the advantages of the former are obvious. The comparatively low cost and relative ease-of-use also make this approach attractive to many archaeologists. Perhaps the most valuable aspect of this technique is that it allows complex and hard-to-see imagery to be documented at a very high level of detail, in both 2D and 3D. This is important because it provides outside researchers the opportunity to examine the paintings and engravings in renderings that reconstruct as faithfully as possible the natural setting in which the original artists made them. Given the necessary limitations on physical access to painted caves, this provides a certain amount of confirmation and reproducibility to what has been conventionally considered the subjective and unverifiable modern “artist's representation” of the imagery. This technology helps show how the modern artist arrived at their reconstruction, step by step.

Beyond pure documentation, the creation of 3D models and associated renderings builds a virtual recreation of the cave, almost as a byproduct of the primary scientific aims. When this approach is used, the entire cave and all of its art body exists in virtual form. As an outreach tool, the 3D model can be shared directly with the public via a number of avenues, from simple web browsers to the more sophisticated virtual reality headsets that are now available. This allows people who may never have access to the real cave, either due to physical disabilities, cultural restrictions, and/or preservation concerns, the chance to “visit” some of the great ancestral images. Furthermore, as a preservation tool, the virtual representation of the cave provides a means to monitor the physical condition of the site over time. Digital photographs from today's 3D model can be merged with images collected in the future, or even with historic images, to comprehend both geological and anthropogenic changes at the site (Willis, 2011).

Our goal is to provide different recreations of the cave<sup>2</sup> and eventually offer a series of 3D environments for other researchers and the public at large to explore. The first recreation of the cave will be an accurate model of what the cave looks like today. This will help demonstrate the current physical state of the cave with modern damage and graffiti apparent. The next version will be stylized, with our renderings superimposed on the cave walls. This will make the rock art, which can be difficult to see even with a trained eye, clearly visible to the viewer. The third virtual form of the cave will represent the cave as it may have looked like immediately after it was freshly engraved and painted. The final version of the cave will be more speculative, with the prehistoric shape of the cave restored, removing many thousands of years' worth of sediment that has raised the floor of the cave to its current level. This will be based on data from excavations and geophysical survey of the actual cave. This visualization may help us to better understand the placement of certain elements of the parietal art as it relates to the now-buried portions of the site.

<sup>2</sup> A partial 3D representation of the gallery of Marsoulas excerpted from the documentary film *La Grotte Oubliée* by M. Azéma (cf Fritz et Tosello, 2010) can be seen online at: <http://www.creap.fr>.



Fig. 9. Tracing projected onto a modeled 3D surface (image Fritz/Willis/Tosello).

#### 4. Conclusion

This technique is a new and important tool in rock art recording because it goes beyond the distorted 2D representation of the panels created in the past and precisely acknowledges the shape of the wall the art was placed upon. Furthermore, it allows documentation to continue from outside the confines of the cave, limiting the amount of potential impacts to the cave, and maximizing the quality of the reproductions. The research implications and potential are significant, but equally important is the accurate record that is created. The use of this technique is helping to preserve an accurate record of a resource that undoubtedly will not last forever.

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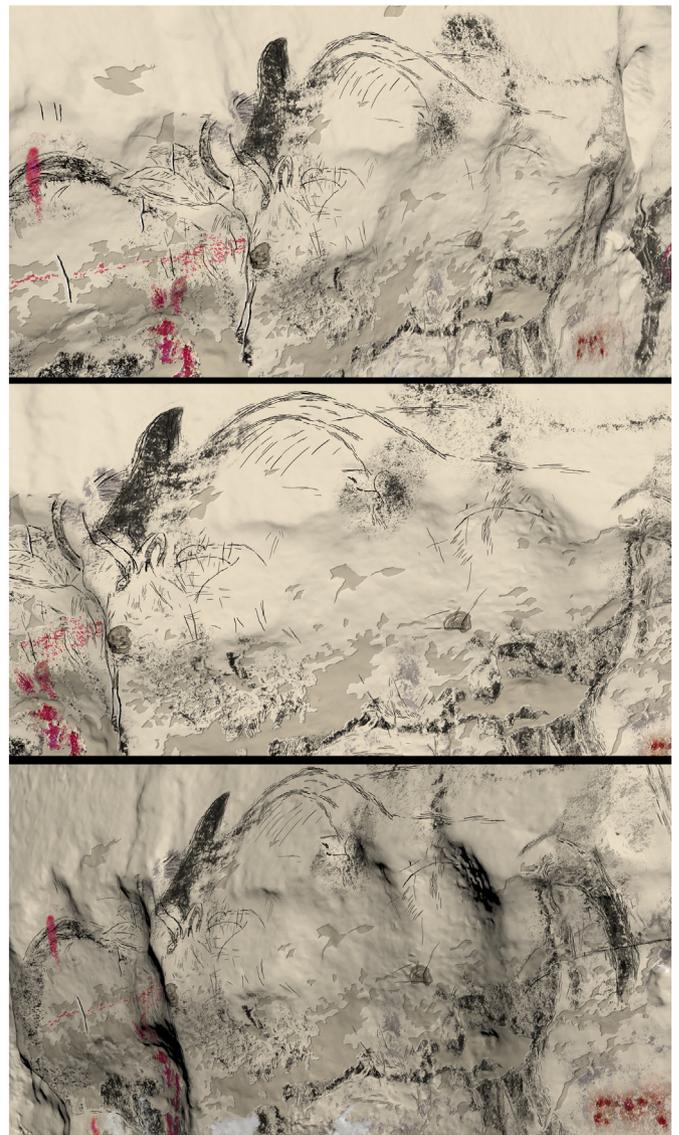


Fig. 11. Three renderings of the same bison from different angles. Note that the natural form of the rock surface that forms the bison's brow is more visible in the bottom image, due to a specific configuration of the lighting (image Fritz/Willis/Tosello).

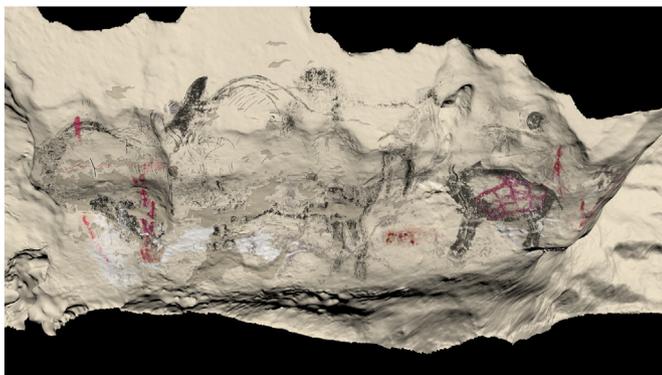
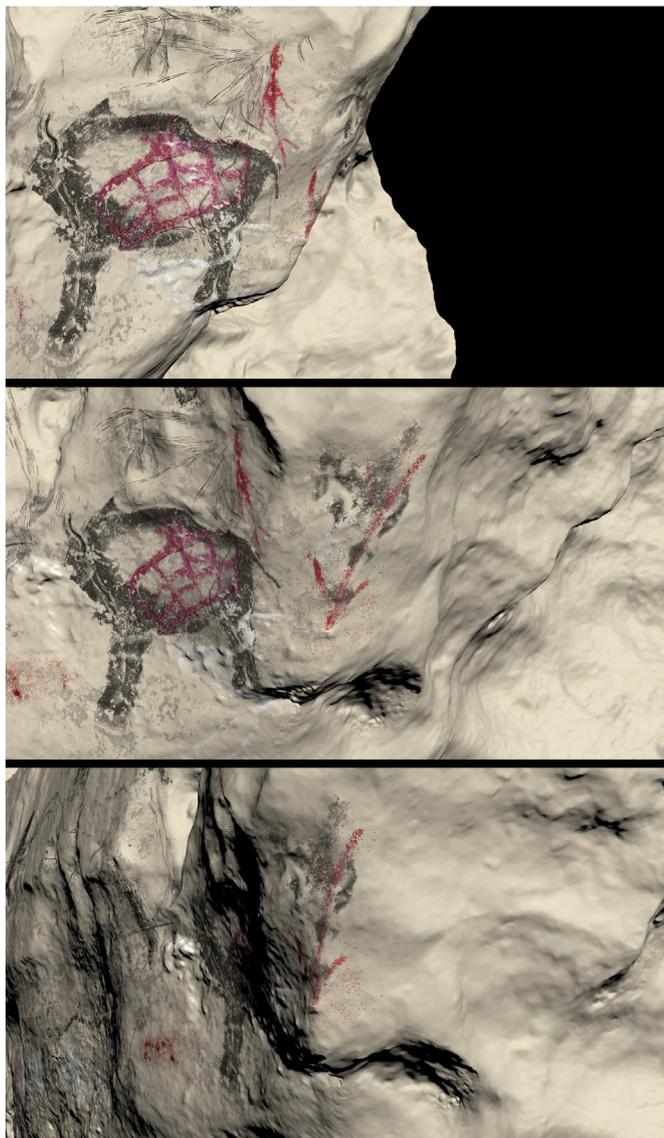


Fig. 10. Rendering of the complete panel with tracings projected onto the modeled 3D surface of model (doc. Fritz/Willis/Tosello).



**Fig. 12.** These renderings show how the edge of a protrusion on the cave wall was used for the profile of an animal face and a red vertical sign (image Fritz/Willis/Tosello). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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