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3D Models of Some Figurines from the Swabian Aurignacian
New Insights into the Markings

Abstract 3D scanning is an advantageous technique for the documentation and conservation of archaeological remains. In 2017, the State Office for Cultural Heritage of Baden-Württemberg in cooperation with the respective museums produced 3D laser scans and Structure-from-Motion (SFM) photogrammetric images of the Aurignacian figurative artworks from the cave sites of the Swabian Jura (SW-Germany) (Steffen and Steffen 2017). The laser scans provide 3D models of the objects' surface topography. In addition to the shape, the SFM images document the color of the objects in high resolution. Both methods combine the high geometric resolution of the surface with the high-quality color textures. Besides the documentation and the conservation of information about archaeological finds, 3D models are a very useful tool for the study of small and fragile objects. The figurines from the Swabian Aurignacian are among the oldest evidence of figurative art, dating to 43,000 to 34,000 cal BP (Conard and Bolus 2003; 2008; Higham et al. 2012). An extensive study of the markings on the figurines and tools from this assemblage has been recently completed using analysis of the originals and microscopic 2D images (Dutkiewicz 2021). In this paper, I will use the 3D models of some selected figurines from Vogelherd and Hohle Fels Caves to analyze the markings, compare the 2D and 3D images, and point out the advantages and disadvantages of both documentation methods.

Keywords Swabian Aurignacian, Palaeolithic art, Figurines, Markings, 3D and 2D images

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Introduction

The last decade saw an enormous increase in digital methods of 3D documentation, analysis, reconstruction, and exhibition of archaeological remains (e.g. McPherron, Gernat, and Hublin 2009; Ahmed, Carter, and Ferris 2014; Heidenreich and Steffen 2014; Shott 2014; Bourdier, Fuentes, and Pinçon 2015; Younan and Treadaway 2015; Mélard et al. 2016; Fuentes, Lepelé, and Pinçon 2019). These methods are applied to sites, surfaces, features, or artifacts. While traditionally, archaeological objects have been drawn or photographed, methods of 3D-documentation and visualization allow us to experience the appearance of objects that were designed in three dimensions in a more "accurate" way. In 2017 and 2018, the State Office for Cultural Heritage of Baden-Württemberg (Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart) in cooperation with the respective museums, produced 3D laser scans and Structure-from-Motion (SFM) photogrammetric images of the Aurignacian figurative art from the cave sites of the Swabian Jura (Steffen and Steffen 2017). The laser scans provide 3D models of the surface topography of the objects. In addition, the SFM images document the color information in high resolution. The combination of both methods makes it possible to merge the high geometric resolution of the 3D scan with the high-quality color texture from the photogrammetric method (https://sketchfab.com/ladbw/collections/ice-age-art, Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart 2018).

An extensive study of decorated artworks and tools from the Swabian Aurignacian has recently been completed (Dutkiewicz 2021). These objects derive from four cave sites of the Swabian Jura, southwest Germany, close to the city of Ulm. Hohle Fels and Geißenklösterle Caves in the Ach Valley, and Hohlenstein-Stadel and Vogelherd Caves in the Lone Valley are mainly known for figurative artworks: Small to medium-sized figurines of humans and Pleistocene animals, mainly made from mammoth ivory and dating to around 43,000 to 34,000 cal BP (Conard and Bolus 2003; 2008; Higham et al. 2012). One striking feature of these figurines is the deeply incised markings. They appear on almost all of the figurative artworks as well as on certain tools. These are mostly parallel lines, notches, dots, or crosses. There are some good arguments that some of these depict fur patterns or other typical features of the animals, but also abstract markings, are present (Conard 2003; 2009; Conard, Malina, and Münzel 2009; Conard et al. 2015; Wolf 2015; Dutkiewicz and Conard 2016; Dutkiewicz et al. 2018; Dutkiewicz, Wolf, and Conard 2018; Dutkiewicz 2021). One difficulty in analyzing these markings is that they are applied to three-dimensional surfaces, and therefore, documentation in two dimensions, through photographs and drawings, always misses parts of the whole picture. It is necessary to choose the views on the object, and consequently, only a selection of the markings visible; Some markings might appear reduced or not fully recognizable.

In this study, I analyze several figurative artworks from the cave sites of Vogelherd and Hohle Fels using 3D models. The goal is to pinpoint the advantages and disadvantages of 3D models for scientific research after having analyzed the same objects working with the original finds and with 2D methods before. With the newly gained data, I highlight some of the markings and features of these highly detailed figurines and provide a deeper insight into the work of the Aurignacian artists from the region of the Swabian Jura.

Vogelherd

Vogelherd Cave was first excavated by Gustav Riek in 1931, where he found ten ivory figurines and one antler artifact with a relief of a mammoth in the Aurignacian layers V and IV (Riek 1932a; 1932b; 1934). Riek excavated the entire cave and left the backdirt in front of the entrance. From 2005 to 2012, a Tübingen team under the direction of Nicholas Conard re-excavated this backdirt. It seemed to be necessary, as Riek worked for only three months at Vogelherd and did not sieve or water-screen the sediment, so that many finds were expected. This excavation completed the assemblage of artworks and other finds from Vogelherd. Nowadays, more than 60 figurines and fragments of figurines are known from this cave (Conard, Zeidi, and Janas 2016; Conard et al. 2015; Dutkiewicz 2021).

Horse

The figurine of a horse *(Equus ferus*) is one of the most well-known figurines from Vogelherd. It was excavated in 1931 in the lower Aurignacian layer V (Riek 1934). The left side of the figurine is complete, except for the legs, which are preserved about to the half. On the right side, the head and neck, as well as the base of the tail, are preserved. The horse is depicted in a particularly elegant and expressive way. The noticeably lowered head is narrow and shows a slight S-curve when viewed from the front. The nostrils, mouth, eyes, and ears are carved out anatomically correct. The animal has a standing mane as is typical for wild horses and the neck is curved and separated from the withers by a kink. The body is slim and shows distinct muscles. The tail is only partially carved out, the typical long tail hair is absent. The right front leg points slightly forward as if the animal is taking a step; the hind leg points slightly backward.

Along the mane on the ridge of the neck, there is a series of at least 17 short notches. These are largely leveled by polish and difficult to see. Occasionally it was stated that it is a series of crosses (Hahn 1986; Müller-Beck 2001), but the notches are too poorly preserved to be identified as such. A row of 13 crosses runs from about the middle of the back over the rump to the base of the tail. This part is also heavily polished, but still well recognizable. Often, an inverted V-sign is described on the left side breast (Hahn 1986; Marshack 1976; 1989; 1991). Marshack (1976) even speaks of a ritual killing of the animal because of the fresh appearance of the mark. In the photography of this part, the supposed V-mark appears prominently, as it disrupts the blue color of the surface (Fig. 1a and 1b). The color derives from the deposition in the sediment, where minerals fed into the material and resulted in the blue and brown hues of the patina (Reiche et al. 2000; Wolf 2015). However, arguments against the interpretation as intentional marks are to be discussed. First, no features of intentional marking are present; the mark has no clear structure that indicates a deliberate fabrication (Dutkiewicz 2021; Dutkiewicz and Conard 2016; Dutkiewicz, Wolf, and Conard 2018). The two lines are very thin and irregular and do not show repeated cutting and are therefore not to be interpreted as intentional markings. The profile of the cutmark does not show a V-shape, but rather an irregular U-shape, which is typical for natural causes (Steguweit 2003; 2009). This observation is confirmed by the 3D model. Here, the lines of the supposed V-mark are barely visible (Fig. 1c). Therefore, I conclude that

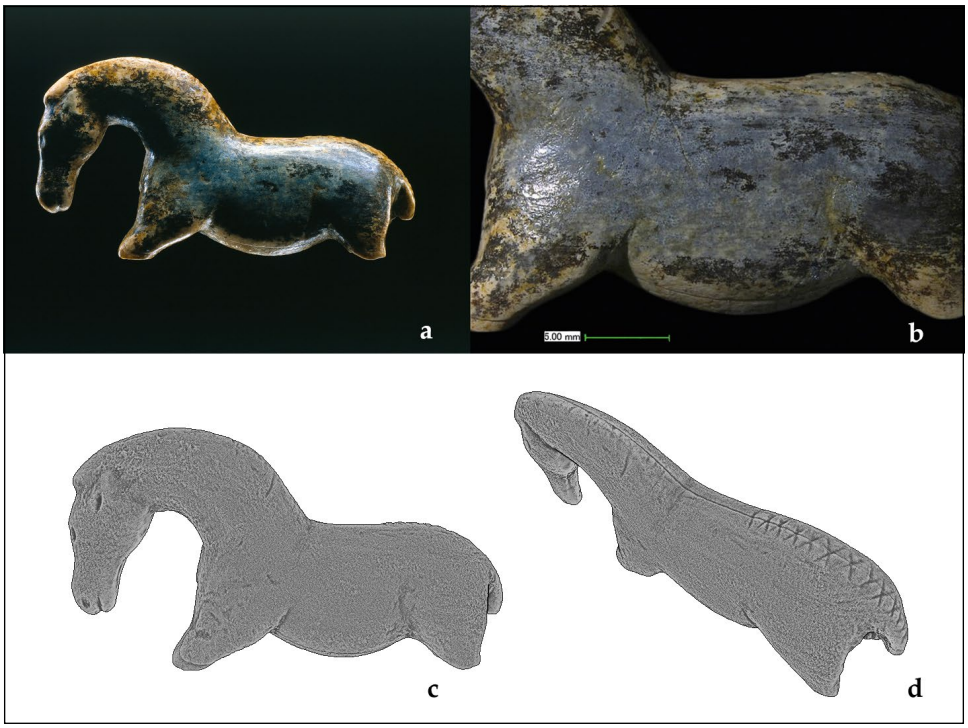

Fig. 1 | a) Vogelherd, horse figurine found 1931, mammoth ivory, length 4.8 cm. (Photo: J. Lipták, Universität Tübingen). b) Detail of the left body side using Keyence VXH-500. (Photo: E. Dutkiewicz, Universität Tübingen). c and d) 3D model of the horse figurine. Radiance Scaling: Grey Descriptor, Enhancement 1.00. (Scanning and processing: M. Steffen and C. Steffen, Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart; picture: E. Dutkiewicz).

this V-mark is not intentional; rather, these are superficial scratches resulting from damage during the use, accident during the fabrication of the figurine, or the result of taphonomic processes. Fig. 1d shows the neck and back part. As described above, the markings on the neck are too heavily worn, presumably from long-term handling, to be recognized as a distinct pattern.

Felid

This figurine of a felid (*Panthera* sp.) was discovered in Vogelherd layer V during the excavations in 1931 (Riek 1934). The right side of the animal is largely preserved, with only the cheek and neck flaked off. The back part of the left side is missing. Three legs are preserved at their bases. Large parts of the surface are heavily weathered; two longitudinal cracks run through the body. The well-preserved parts show careful working and polishing. Although large pieces of the figure are missing, the outline is completely preserved. The felid is depicted with its head stretched far forward. The body is elongated and has a straight backline, only the withers are slightly humped upwards. The legs point straight down and show the animal standing still in its place. Both eyes are facing forward, the preserved ear is laid back. The animal's nose is separated from its mouth by a dip. It is noteworthy that two further incisions follow

Fig. 2 | Above, 3D model of a felid figurine from Vogelherd, found in 1931, mammoth ivory, length 6.8 cm. Lit Sphere Radiance Scaling, Enhancement 0.50, Transition 1.00. (Scanning and processing: M. Steffen and C. Steffen, Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart; picture: E. Dutkiewicz). Below, detail of Panel of the Lions, Grotte Chauvet. (https://archeologie.culture.fr/chauvet/en/mediatheque/lion-panel-6, accessed January 5, 2021, detail).

below, although anatomically only one is necessary to show the mouth (Dutkiewicz 2021). Although the mouth part of this figurine is poorly preserved, the 3D model helps recover the original details. We see a separated nose and upper lip and the lower lip with the chin. The mouth is open, and it appears that the tongue is stretched out, giving the impression that the animal is roaring. This representation is reminiscent of the lions from Grotte Chauvet (France) some of which are depicted with open mouths as well (Fig. 2). As in many other examples, this figurine proves that the Pleistocene animals of the Swabian Aurignacian were depicted in special moments or actions (Dutkiewicz 2021).

Anthropomorphic Figurine

The so-called Anthropomorphic figurine was found in Vogelherd layer IV in 1931 (Riek 1934). The left side of the figure is completely preserved. Riek discusses whether this is a semi-finished product and argues that it may be. As arguments for this, he cites the roughly worked out and not further trimmed head, as well as the coarse and completely unsmoothed leg/knee area. However, the smooth surface and the rows of dots on the body suggest careful finishing. The figure is worked in the longitudinal direction of the ivory piece. Both ends were nicked and then broken off. Although

the fuselage is smoothed, numerous working traces are visible. The head is narrow and set off from the body by a notch. The eye, ear, and mouth are represented schematically by notches. The top of the head is sunken, creating the impression of pointed (animal) ears when viewed from the front. This and the protruding mouth could be indications that a hybrid being, perhaps of lion and man, comparable with the well-known figurines of the Lion Man from Hohlenstein-Stadel and the miniature version from Hohle Fels (Conard, Langguth, and Uerpmann 2003; Ulmer Museum 2013; Kind et al. 2014; Dutkiewicz 2021). The body is long, cylindrical, and, apart from a drawn-in thinning of the back, has no further formations. The figurine has no legs, but a button-like, unworked thickening at its lower end. The interpretation as a human figure is given by the upright, elongated body shape without the front and rear legs of an animal, by the head sitting perpendicular to the body axis and the thinning of the waist in the back.

Fig. 3 | a) Vogelherd. Anthropomorphic figurine found 1931, mammoth ivory, length 6.9 cm. (Photo: J. Lipták, Universität Tübingen). b) 3D model, Radiance Scaling: Grey Descriptor, Enhancement 1.00. (Scanning and processing: M. Steffen and C. Steffen, Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart; picture: E. Dutkiewicz).

In the 3D model, the working trances are clearly visible (Fig. 3). Particularly the difference between the head and body is apparent. The sculpting traces on the neck, head, and bottom of the figurine are rough, while the body appears well elaborated and finished. Notches at the head show roughly cut features like eye and mouth. The fine finish of the body, despite a few cut marks, suggests that the figurine was deliberately worked in a rough manner. This stands in contrast to most of the other figurines from the Swabian Jura that are quite elaborately finished. The front of the figurine bears an oblique V-sign on the upper chest, as it has been described in Dutkiewicz (2021).

Additionally, two dots in the front are visible in the 3D model. They are placed on the chest and might depict nipples. This provides further evidence that the figurine is anthropomorphic. The rows of dots on the right side are visible. Besides the hitherto described rows of 9 in the front, 8 in the middle, and 6 or 7 (3/4+3) dots in the back (Dutkiewicz 2021), the 3D model reveals even finer dots reaching the bottom of the figurine. Altogether there are 10 to 11 dots in the first row, including the uppermost dot that might be a nipple. The middle row might have an additional dot at the bottom as well. Due to the rough carving in the lower part, the definite number remains uncertain. Connecting lines between the dots in the middle row are clearly visible. The three uppermost dots are all separate, in the lower part the upper two followed by the lower three care connected. This might represent some symbolic connection of the individual dots, maybe counting or notation of some interconnected events or the like.

Felid

This figurine of a felid was discovered in 1931 in Vogelherd layer IV (Riek 1934). It broke along the longitudinal axis, and only the left half, with the outline of the torso and the head, is preserved. The fracture surface is convex and covered with fine scratches and polish. Therefore, and for the overall flat appearance of the animal, it was previously assumed that the figurine was designed as a relief. In 2013 a heavily weathered fragment of the head was found (Conard and Zeidi 2014). It belongs to the right side of this figurine, proving that this figurine was also designed as a round sculpture. The outline of the animal is almost entirely preserved, only the legs are rudimentary. The trunk is massive and elongated, but noticeably narrow in depth. The long ears are semi-sculpted and laid back and the mouth is shaped with a deep cut. The eyes consist of approximately vertical, elongated incisions. The slightly lowered head with its chewing muscles is set apart from the short and thick neck that merges into a massive shoulder area. The upper arm muscles are pronounced and appear particularly strong. The backline gently slopes down from the highest point on the ridge towards the buttocks; the thigh and the buttocks appear flat. The most remarkable feature of this animal is the area of the ribs and abdomen, the surface of which bulges inwards with a large pattern. It consists of ten diagonally crossing long lines forming a grid. This is the only case in the Swabian assemblage that the decoration of a concave surface has occured. Additionally, 95 dots are applied over the entire left side of the body. There are two V-patterns in the neck area, one pointing upwards, the other downwards. Another V-pattern is just behind the left ear. Below the mouth, there are two short, parallel notches that run from the mouth to the chin and probably depict the whiskers.

In this example, the characteristic grid pattern on the left side of the body provides a good basis to discuss different documentation and analysis methods. In the photograph (Fig. 4a), the placement and overall appearance of the pattern within the composition of the figurine is best shown. The microscopic photograph allows for a detailed examination of the pattern (Fig. 4b). The starting points of the engraved lines, with their deep and abrupt beginning, may hint at the use of pre-treatment—likely watering—of the ivory durine the carving process, as comparisons with experimentally applied lines suggest (Dutkiewicz 2021). Nevertheless, the detailed microscopic

Fig. 4 | a) Vogelherd. Felid figurine, found in 1931, mammoth ivory, length 8.7 cm. (H. Jensen, Universität Tübingen). b) Detail of the grid-pattern, using Keyence VXH-500. (Photo: E. Dutkiewicz, Universität Tübingen). c) 3D model of the grid pattern. Radiance Scaling: Lit Sphere Radiance Scaling, Enhancement 0.60, Transition 0.70. (Scanning and processing: M. Steffen and C. Steffen, Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart; picture: E. Dutkiewicz).

photograph is difficult to interpret when it comes to the succession of the lines. In this case, the radiance scaling and enhancement of the 3D model, excluding the original color information of the surface, provide a better view (Fig. 4c). First, six lines running from top right to bottom left were applied, crossed by four lines from top left to bottom right. Additionally, the working process becomes clearer, showing repeated carving to achieve the desired depth of the lines. Dots on the right and the upper parts of the grid pattern superimpose the lines, indicating that the latter were applied first.

Relief of a Mammoth

This object was discovered during Riek's excavations in 1931 in layer IV (Riek 1934). It is the only figurative representation from Vogelherd that is made from antler and designed as a relief. The base of a reindeer antler serves as the raw material (Leroy-Prost 2002; Dutkiewicz 2021). The object has an elongated, oval shape. The cancellous bone protrudes clearly on the upper side, while the backside forms a smooth, curved surface. At the pointed end, there is a perforation that broke out. This piece was probably worn attached to a string. The cancellous surface forms an oval field in which the

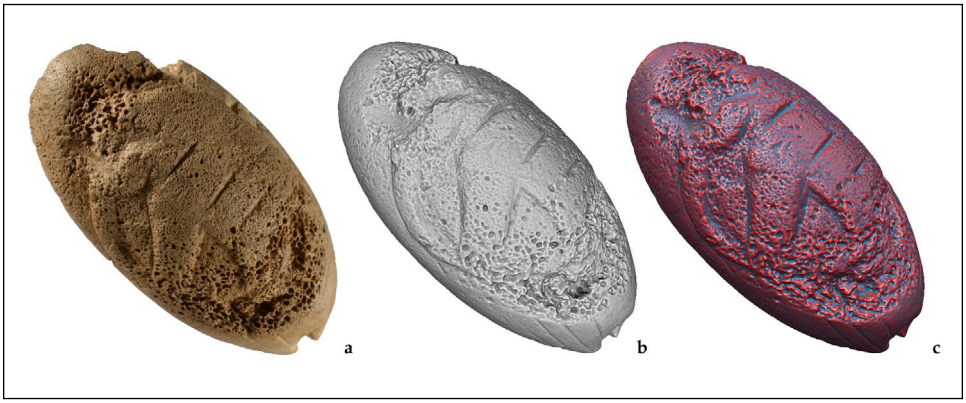

Fig. 5 | a) Vogelherd. Relief of a mammoth, antler, length 6.9 cm. (Photo: H. Jensen, Universität Tübingen). b) 3D model. Radiance Scaling: Lambertian Radiance Scaling 0.30 and c) Lit Sphere Radiance Scaling, Enhancement 1.50, Transition 1.00. (Scanning and processing: M. Steffen and C. Steffen, Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart; pictures: E. Dutkiewicz).

relief of a mammoth (*Mammuthus primigenius*) is located. The trunk, the mouth, the front leg, and the belly line of the animal are visible. The hind leg is only indicated cranially; the surface is too spongy in the caudal direction, so that the outline is not visible here. The backline starts roughly at the top of the head and runs in a strongly curved line to the base of the buttocks. The towering skull and the typical saddle on the neck are missing, the tusks are not represented. These characteristics distinguish this mammoth as a young individual. Originally, ochre residues were visible in some grooves, depressions, and the broken eyelet (Riek 1934), but are no longer preserved.

This is one of the most difficult representations to read. The structure of the cancellous bone blurs the figure, and the concave surface makes it necessary to rotate the object to fully see the animal (Fig. 5a). Here, the 3D models help a lot. Not only is it possible to freely rotate the object without touching it, but the Radiance Scaling also allows for a better view of the representation. As shown in Fig. 5b, the outline of the relief becomes more visible. Additionally, the use of the natural relief of the surface in the figure's design is evident, a technique often described in Palaeolithic rock art, such as in Altamira (Breuil and Obermaier 1935; Beltrán, Saura Ramos, and Bosinski 1998). Fig. 5c highlights details of the irregular surface visible in the 3D model. Previously deemed too blurry to be recognizable, parts like the head now exhibit a meticulously designed and well-chosen appearance. The cheeks of the animal are well incorporated into the surface, as well as the morphology of the head. Particularly striking is the eye, which has not been described in previous analyses but is clearly visible in the 3D model. The position is anatomically correct, the bone around the eye is pronounced, and fits well into the elaborated design of the head.

Felid

This figurine of a felid was found in 2006 during the excavations in front of Vogelherd Cave (Conard, Lingnau, and Malina 2007). About half of it, a large part of the left side, and the uppermost part of the right side are preserved. The fracture extends in the

Fig. 6 | a) Vogelherd, felid figurine found in 2006, length 5,6 cm. (Photo: H. Jensen, Universität Tübingen). b-d) 3D model of the felid figurine. Lit Sphere Radiance Scaling, Enhancement 0.50, Transition 1.00. (Scanning and processing: M. Steffen and C. Steffen, Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart; pictures: E. Dutkiewicz).

longitudinal axis along with the natural ivory. In this figure, a felid with a narrow and elongated body is shown. The withers bulge remarkably upwards and give the impression, that the animal is sneaking up on something. The legs are not preserved. The muscles of the shoulder and buttock areas are carefully modeled; the tail is preserved only at the base. The neck is long and stretches forward with the head lowered. This again speaks to the sneaking attitude of the animal. The forehead, the left ear, and the base of the right ear as well as the left eye are preserved, a tear duct runs from the eye. Despite the fragmentary state of preservation, the fine elaboration of the head is a testament to the masterful carving. Overall, this figure makes a very fine and slim impression. A deeply cut row of crosses runs along the back. Less visible are two vertically arranged rows of dots along the left shoulder. This pattern is also present on the right shoulder, as evidenced by two remaining dots (Dutkiewicz 2021). In the photographs, the row of crosses on the back is well visible (Fig. 6a and c). The rows of dots on the shoulder, however, are less clear due to the black spots of patina on the surface. Here, the 3D model gives a better overview of the composition of the markings by enhancing them using Lit Sphere Radiance Scaling. The pattern consists of two parallel rows of elongated dots, running vertically over the shoulder. The cranial row starts with a V-mark followed by seven preserved dots. The caudal row shows seven preserved dots (Fig. 6b); the two preserved dots on the right side are clearly discernible in the 3D model (Fig. 6d). The details of the head, the ears, the left eye, and the corner of the mouth are also plainly visible in the 3D model, providing an excellent impression of the finely carved features of this figurine.

Hohle Fels

Hohle Fels is a large cave with a long research history. Modern standards excavations at this site began in the late 1970s with the work of Joachim Hahn (Hahn 1989). From the late 1990s until today, Hohle Fels has been excavated annually by the University of Tübingen under the direction of Nicholas Conard. Mobile artworks in the form of ivory figurines have been found in different Aurignacian layers (e.g. Conard and Uerpmann 1999; Conard and Malina 2008; Conard and Janas 2018; Conard et al. 2015). The most spectacular find is the female figurine from the basal Aurignacian layer Vb, discovered in 2008 (Conard 2009; Conard and Malina 2009; Conard and Wolf 2020).

Female Figurine

The female figure made of mammoth ivory is almost completely preserved; only the left arm and shoulder are missing. The figure is worked out asymmetrically, with the right shoulder slightly raised. There is no head; instead, there is an eyelet above the left shoulder. Below the broad shoulders, large breasts protrude forward. Both arms are held close to the body. The carefully designed hands rest below the breasts on the upper abdomen. The oversized vulva is shown with the labia open. The thighs are small, and the legs end below the knees (Conard 2009; Conard and Wolf 2020). The figure bears markings everywhere except for the legs and buttocks. In addition to the cuts that reflect anatomical details, the figure also has numerous additional patterns (Dutkiewicz 2021). On the front, ten long, almost parallel lines running horizontally across the entire abdomen are initially noticeable. There are 12 very thin radial lines on the lower abdomen, radiating out roughly from the navel. On the upper back of the figure, there is a long, curved line that runs along the shoulder girdle. Vertical parallel notches were attached to this line at regular intervals, of which only nine have been preserved. The area of the left shoulder is not preserved, so the sequence could have included one to three more notches. A few lines are loosely scattered over the entire back, with a concentration in the waist area. A pattern of four U-shaped, concentrically arranged long lines extends from the tip of one breast across the flat upper chest to the other breast. In the shoulder area, three long parallel lines appear on each side. On the outside of the right breast, there are two sequences of parallel vertical lines—one with six and one with four. Further, there are four parallel, vertical lines on the outside of the left chest and three on the inside. The right arm also bears several markings. Starting at the shoulder, a sloping line is accompanied by two parallel lines directly below it. There are six parallel lines along the upper arm and four more on the forearm. At the wrist, two rows of dots are present—one with three or four and one with two. It can be assumed that the left arm, which is not preserved, was also decorated with similar markings, since the patterns in this figurine are overall arranged symmetrically.

Although the visibility of most of the markings on the female figurine is good, the 3D models improve them significantly. Due to the fragmented state in which the figurine was found, cracks and scratches disturb the surface in some parts and make it difficult to recognize some patterns, such as very fine lines on the lower abdomen. Additionally, the style of the markings is quite rough, meaning that the cuts are

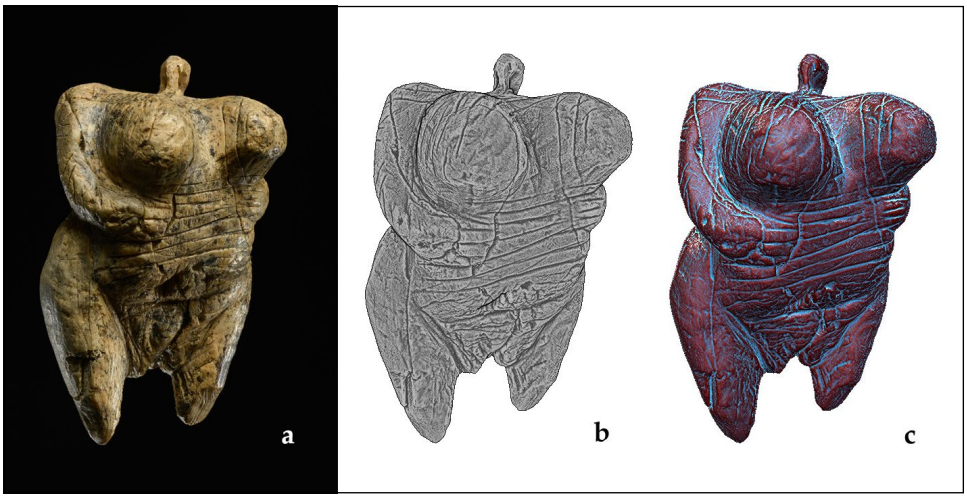

Fig. 7 | a) Hohle Fels. Female figurine, found in 2008, mammoth ivory, height 6 cm. (Photo: J. Lipták, Universität Tübingen). b) 3D model. Radiance Scaling, Grey Descriptor, Enhancement 0.75, and c) Lit Sphere Radiance Scaling, Enhancement 0.75, Transition 0.50. (Scanning and processing: M. Steffen and C. Steffen, Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart; pictures: E. Dutkiewicz).

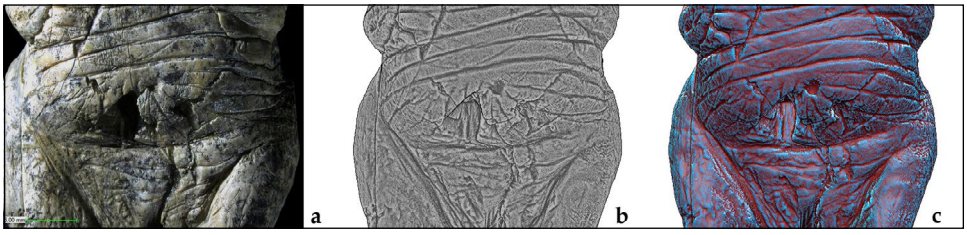

Fig. 8 | a) Detail of the female figurine from Hohle Fels using Keyence VXH-500. (Photo: E. Dutkiewicz, Universität Tübingen); b) 3D model. Radiance Scaling, Grey Descriptor, Enhancement 1.0, and c) Lit Sphere Radiance Scaling, Enhancement 0.75, Transition 0.90. (Scanning and processing: M. Steffen and C. Steffen, Landesamt für Denkmalpflege im Regierungspräsidium Stuttgart; pictures: E. Dutkiewicz).

executed in a not very accurate way, and many side-lines scatter around the marks. The 3D model eliminates the disturbing information, making the overall composition of the markings better visible. In Figure 7b and c, for example, the composition of the markings is clearer than in the photograph. Nevertheless, some of the cracks are difficult to distinguish from the markings. Therefore, the comparison and adjustment with the original figurine remain very important to interpret the information correctly. This is evident when looking at the dots on the left wrist, for example. While the dots were fairly visible to the naked eye and in photographs—though not as clear as other markings—the 3D model does not provide enough detail to recognize this part clearly. This is because the markings are applied on a rough surface and are not very deep. However, in Figure 8 the lower abdomen and parts of the vulva highlight the difference in the photograph and 3D model very well. In the photograph, it is difficult to differentiate between markings and cracks in this damaged area, whereas in the 3D model

the entire composition is clearer and easier to identify. The radially applied fine lines are well visible. Additionally, the rough-cut marks in the pubic area, which differ from the deep and precise cuts on the abdomen due to the coarse cutting technique, are clearly recognizable. I interpret this as a different use/purpose of the markings. While the lines on the abdomen have a fixed, stable character and very likely relate to body decoration or even pregnancy-related calendrical notations, the vulva bears rough cuts that seem more indicative of an action applied to this area, possibly a kind of "opening" of the vulva in connection with symbolic birth-giving (Dutkiewicz 2021; 2023; Dutkiewicz, Wolf, Velliky, and Conard 2024). The variations in the engravings across different zones of the figurine are clearly discernible in the 3D models.

Discussion

3D models of the figurines from the Swabian Aurignacian have added very useful information about the markings to the data already obtained through analysis of the originals, photographic documentation, and drawing of the objects (Dutkiewicz 2021). Many previously unclear or questionable parts have now become more visible, allowing for a better understanding of the overall composition of the markings. Working with the originals is indispensable, but restricted to a certain time frame, as handling them poses a danger to the objects and access is limited. Additionally, some of the objects are very small and fragile, and therefore cannot be touched or analyzed extensively. Furthermore, the originals show influences of taphonomy, such as weathering, patina, scratches, or the like, and recognizing all those factors and differentiating them from intentional anthropogenic manipulation is not always possible when studying the objects for a limited amount of time. There is always a risk of misinterpretation or overlooking certain aspects. To document the features, photographs are very useful. The difficulty is that certain views and sections must be selected, with a high chance of missing other important parts. Although this method is fast and not labor-intensive, during the process one tends to select already recognized features, while potentially overlooking unidentified parts. Although producing many pictures helps a lot, these are still fixed, and recognizing overlooked parts is limited to the selected view, light, and quality of the photograph. Another issue is the three-dimensionality of the figurines; much of the overall impression is lost when viewed in two-dimensional pictures. Drawings help to erase the misleading information from cracks, patina, or broken parts, but are also restricted to certain views and, of course, subject to individual interpretation (and talent) of the person who is drawing.

Many of the addressed problems find solutions in the use of 3D models. First, they allow constant access and the possibility of rotating, zooming in, and enhancing parts of the objects, without the need to access the originals. It is possible to check unclear parts very quickly. Views from different angles, changing light intensity or light incidence help to recognize details of the three-dimensional figures much better than a two-dimensional picture. Plus, disturbing information like color, patina, and scratches, and cracks can be erased or limited, giving a much better impression of the original design, and reconstructions of missing parts can also complete the image. The recognizability of markings, as well as features of the topography of the objects, are significantly improved. Furthermore, programs allow measurements of distances, surfaces, profile views, etc.

However, depending on the technique and the processing, the resolution of microscopic details might be insufficient. For example, details of the engraving technique are often not recognizable, and shallow depths are sometimes not recorded. As shown in the example of the dots on the wrist of the Hohle Fels female figurine, the model does not clarify the composition as much as desired. However, in other cases, like the V-sign on the horse, the 3D model supports the interpretation that these are scratches and not marks. Although the 3D model is very helpful in many cases, the analysis of the original object, photographs, and drawings remain necessary and should go hand in hand to get the best results. Another important point is, that although 3D models appear very realistic, and the astonishing details and different views give the impression of being close to reality, one must keep in mind, that digitization is not objective, and an enormous amount of editing must take place during the production of the 3D model–"they are just a hypothesis of an artifact or space" (Younan and Treadaway 2015, 241). And while the scanning itself might be a quick process, the processing of the data is tedious and labor-intensive. The storage and future accessibility of the data (computers, programs, etc.) must be considered as well.

Summary

The 3D models of the figurines from the Aurignacian cave sites of Vogelherd and Hohle Fels allow some interesting insights into details of markings and surface features. Comparing them with the analysis of the originals and photographs, some hitherto unclear parts were clarified. In the horse figurine, a supposed V-sign on the shoulder was identified as a scratch and excluded from the intentional markings the 3D model supports this interpretation. One of the felid figurines found by Gustav Riek in 1931 has some remarkable characteristics in the design of the mouth that was difficult to interpret. The 3D model shows that the animal is presumably represented with an open mouth. The Anthropomorphic figurine that has been interpreted by Riek as a probably semi-finished product, appears well designed in the 3D model. Some additional, hitherto unknown markings were recognized in this study. Details on the felid figurine, which used to be considered as a relief before a part of the back side was found in 2013, show that, by using different techniques of documentation, different aspects of the grid pattern on the side of the body become evident. While the photographs using a digital microscope show details like the starting points of the lines, which suggest pre-treatment of the ivory through watering, the 3D model points to compositional aspects like the succession of the lines, that is not as clear in the photographs. Astonishing insights were gained from the 3D models of the mammoth relief from Vogelherd. The convex and spongy surface of the cancellous part of the antler piece, on which the mammoth is engraved, makes it difficult to fully recognize the animal. Some parts are even obscured due to the blurry surface. However, the 3D model helps reveal the overall composition and highlights exceptionally well-designed details of the head. An eye, previously overlooked because it "hides" in the spongiosa, is now clearly visible. Like in Palaeolithic rock art, the artist included the natural surface to carve the animal. The 3D model of the felid figurine discovered in 2006 shows the potential to spot markings that may be heavily blurred through the color of patina. Finally, the example of the Hohle Fels female figurine demonstrates that 3D models can

enhance fine markings in challenging areas, such as the lines on the lower abdomen. However, in the wrist area, the markings are less distinct than expected, and the dots, which are clearly visible in photographs, are less defined in the model.

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