

3D-DOCUMENTATION AND ANALYSIS OF ROCK CARVINGS

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INTRODUCTION

The situation is critical; rock carvings in South Scandinavia are in real danger of disappearing (Löfvendahl 2000, Sharpe et. al. 2008). There is an urgent need to use recording methods, which can cope with the large number of sites.

In order to comprehend the problem, it is necessary with some background information about the rock carvings in this area. The carvings are usually divided into a northern tradition with motifs related to hunting (9000-2000 BC), and a southern tradition created in Bronze- Late Iron Age (1800 BC – 400 AD) with motifs related to agriculture and battle scenes (Mandt & Lødøen 2005: 4). In Denmark 2,000 rock carving sites are known; in Norway there are 5,000, and in Sweden there are as many as 21,000 sites (Glob 1969). Just in the Swedish area Bohuslän, there are 1,500 sites (Ling 2008: 1). Bohuslän and its neighboring area, Østfold, in Norway should be considered one rock carving area, and archaeologist John Coles estimate that this area includes 75,000 motifs (Coles 2005: 17). These numbers give an impression of the challenge cultural institutions face today.

The threats to rock carvings are many

and diverse. Biological factors are some of them. The growth of algae and lichens slowly destroy the carvings. Industrial forests of pine trees also concur with erosion, as pine needles combined with water become an acid formation, which has a corrosive effect on the rock surface (Löfvendahl 2000, Vänska 2000, Mistreu 2006, Ernfriedsson). The growth of moss or trees is also harmful; it keeps the rock surface moist and roots lead water into the rock, and the roots can create cracks in the rock. The weather is another erosion factor. Sudden changes in temperature have a profound impact. Heavy summer rain after the sun has heated up the rock surface determines a sudden change of temperature, which can result in exfoliation. Exfoliation should be understood as thin flakes of the rock surface breaking off. In wintertime, the moisture in the rock freezes, and makes the rock expand, which can result in exfoliation or cause the rock to crack. Many cracks can make the rock break. Thus quantity and fragility are the factors that cultural heritage institutions need to take into account, and the documentations must include so much information and details so they can be useful in the future, when we do not have the carvings themselves anymore. In this paper, the following recording methods

will be evaluated on:

Equipment and storage facilities

- **Applicability:** Is the method dependent on certain circumstances i.e. weather, or condition of the rock surface?
- **Manageability:** How easy is recording and processing of data?
- **Information level:** Does the outcome have information about topography, depth of carvings, and the color of the rock? How is the objectivity level?

TRADITIONAL DOCUMENTATION AND 2D REPRESENTATION

Before describing the traditional 2D recording methods, a brief outline of the historiography of recording techniques applied to rock carvings in South Scandinavia will be presented. It is a development of recordings aiming at analyzing the carvings through a cultural historical understanding, into a work affected by the fact that the future of carvings is fragile. The historiography can roughly be divided into three phases. The earliest documentation is from 1627, and since this time, the technique despite few examples was drawn freehand. The recordings reflected an antiquarian thought; the contexts of objects were not important, nor how the objects were produced. It was neither important to touch the carvings nor to investigate the rock surface, so the documentations lacked carvings and crucial information about the rock surface. With time this recording technique became better, the carvings were sketched into a quadratic system, so their interrelationships were presented more realistically. In the second phase, during the 20th century, a scientific attitude developed.

Documentation became holistic concerning information of the rock, i.e. the slope, topography, and the length/width of carvings were measured. The last phase cannot really be separated from the previous, but the importance of documentation also integrates scientific reasons like degradation (Rabitz 2013: 7-12). Today the research also involves consideration about which methods to use, so the recording techniques will not risk being harmful to the rock surface.

The technique of tracing consists of marking the carvings with chalk or painting them with non-permanent chalk paint. Subsequently, a plastic foil (180 x 90 cm, 0,1 cm. thick) is attached upon the rock surface, and the contours of the carvings are traced or stippled with a pen (figure 1). Lamps can be used to augment contrast and recognize more details. Some depth information can be hinted by the stipple, cracks are represented by lines or broken lines, exfoliated areas of the rock surface are indicated by small circles stippled inside (figure 2).

With the rubbing method, sheets of paper (100 x 70 cm, 90-110 grams) are attached upon the rock surface, and the whole surface is rubbed with carbon paper wrapped around a cloth (figure 4). In order to fix the pigment, the paper is subsequently rubbed with grass, rich in chlorophyll which fixes the pigment. The processing of both methods consists of scanning the paper or plastic foil into the computer, so they can be saved as one image.

Both methods have a disadvantage concerning the portability of the equipment, particularly for remote sites. Further the methods are very time-consuming, and need huge storage space for the numerous sheets of paper and



Figure 1. Tracing on plastic foil. Photo: Mette Rabitz.

plastic which are required to document a whole rock carving panel. Another disadvantage is that the processing of both methods consists of scanning the paper or plastic into a computer, requiring large scanners which are expensive. Further the sheets of paper or plastic need to be stitched to become one digital image, and the finished image perhaps need some corrections of colour. Concerning applicability, both methods are dependent on the weather. It is a disadvantage that they cannot be applied to wet or moist surfaces as the plastic or paper is fixed with tape, which cannot stick to a moist surface, although the plastic foil can instead be attached with rocks lying upon it. However, wind can still loosen the plastic or the paper. A disadvantage for the rubbing method implies a much greater contact with the

rock surface than the tracing method, because the whole surface is rubbed. Thus, the method is not applicable upon porous surfaces due to the risk that pieces of the surface may be rubbed off. When it comes to manageability, tracing has the disadvantage that that the symbols used are not standardized. Some documenters draw carvings as silhouettes, and omit to visualize the micro-topography (figure 2). Other documenters trace the carvings as dots and depth with the concentration of dots. Cracks can be traced with either concentration of dots, dash-dotted- or broken lines. An advantage of the rubbing method is that it is standardized; it does not present the carvings or other details using different symbols. Another disadvantage of tracing is that the outcome is dependent on the skills of the documenting person; and an experienced



Figure 2. Tracing of stone slab from the Kivik cist. Photo: Stiftelsen för dokumentation av Bohusläns hällristningar.

observer will see more details than the less experienced, thus weak or eroded carvings can easily be missed. Both methods have disadvantages, when it comes to the amount of information; topography, colours of the rock, and how severely the rock surface is attacked by growth of vegetation. Both tracing and rubbing, produce bi-dimensional representations (figure 3), despite the fact that the carvings are three-dimensional features. Topographic information of the rock and the carvings are crucial information. The topography (figure 5) could have prompted where carvings were placed. Ship motifs or cupmarks can be placed in or at the edge of natural depressions where the rock slopes, or where water naturally flows; human bodies with phalluses can be placed on slopes with slight depressions,

so that only the phallus is overrun by water. The depth of carvings is important when studying rock carvings, as some lines are carved deeper than others. Tracing can record topography, using broken lines, but it is a disadvantage when documentation needs annotations or a notebook to explain symbols (figure 2). The rubbing technique also has the disadvantage that it lacks topographic information. An advantage for rubbing is that it can present shallow or eroded motifs, but it cannot record carvings in quartzite. This is a disadvantage, since cupmarks do occur in quartzite areas in granite rock. cupmarks carved in quartzite are difficult to see compared with those carved in granite, as the contours and the bottom of the motifs are rough and far from smooth. Concerning objectivity, tracing is considered

problematic, as it has a subjective approach to the recording of data. The person documenting only draws what he/she can observe with eyes and sense with fingers, and also decides on behalf of the viewer, what is carved, and what is not. In contrast, the rubbing method has a far more objective approach; single details are not picked out, the whole surface is copied.

It can be concluded that in the historiography of recording techniques, the earliest phase aimed to analyze the carvings through a cultural historical understanding, without any focus on preservation of the prehistoric material. The present phase of documentation still have outcomes most suitable for analytical cultural historical reasons, even though the present research is also focusing on studying degradation and protection against this.

IMAGE-BASED RECONSTRUCTION, A 3D RECORDING METHOD

3D photogrammetry is an image-based method to create 3D reconstructions of objects, and the author used the software PhotoModeler Scanner from EOS. The equipment for recording requires a standard consumer camera with a minimum resolution of 10 megapixels. The calibration of the camera is easily done. The recording of data is to photograph the object all the way around. It is crucial that the digital images are clear with an even balance of light and shadow. The recording can be done despite a wet or moist surface, as long as the surroundings will not be mirrored in the moist, which confuse the software. The following will give a brief description of how the data was recorded and processed.

The carvings were photographed with a 21 megapixel, 35 mm SLR camera (Canon 5DMKII), which was calibrated and profiled in the software with a 24 mm lens; giving a diagonal field of view of approximately 90 degrees. Correspondingly, when the images were caught at a distance of 70 cm., it yielded about 1 meter of horizontal coverage in each (camera)frame. The camera was attached to a tripod and pointed straight towards the carving, so that the images were recorded perpendicularly to the surface. The entire tripod with camera attached was then moved around parallel to the surface, covering a new area within each frame, but taking great care to have overlap of minimum 2/3 between each frame. It is crucial that all parts of the surface are visible in at least two of the captured frames, in order to make the image-based reconstruction work. Sometimes the surfaces were so curved, that part of it was obscured if only photographing from one angle; it was necessary to capture a number of frames at an angle so it would reveal blind spots, still making sure that the images had sufficient overlap. This was the case, when recording data in the casestudy Finntorp, correspondingly a 17 mm. lens was used. After loading the images into PhotoModeler Scanner, the first task for the software is to orient the camera positions in relation to each other. The software locates common points in between the images. Due to the calibration of the camera, the software can calculate the original position of the camera in an XYZ coordinate system of each image. When the camera positions have been determined, the software can then triangulate the XYZ coordinates for each point in the images, resulting in a dense point cloud, representing a reconstructed 3D model of the surface.

Due to the fact that all points in the 3D model was calculated from the original images, the software can now warp the original images back onto the 3D surface model. The 3D model can be saved both in PhotoModeler Scanners own file format or exported to almost all major 3D file formats or saved as a PDF. The 3D model can be observed in texture- shaded- or dotted view. For rock carvings these views are useful when studying details. With texture view, the 3D model can be observed in colours derived from the digital images. In shaded view carvings can be detected, also faint carvings due to the software's ability to exaggerate the depth and make ephemeral details stand out. The dotted view allows close up observation and study of pecking marks. It is possible to measure directly from the 3D model, if a scale, ruler, or target points from the software are present at the images.

Image-based 3D reconstruction has many advantages. The equipment is portable and time-consumption low. The recording and processing will take one or few hours, and the outcome will need minimum storage space, and only needs to be stored at a computer. Concerning applicability, the method is dependent on calm winds, if there are plants or bushes around the object, they will move in the wind, which is a problem. When using 3D photogrammetry, details cannot change in between the images. However, one advantage is that the recording can be done despite a wet or moist surface. Further, the recording can be non-tactile, but if it is necessary to study close-up details of micro-topography, target points are needed when taking the pictures. Some experience in taking good pictures is crucial for using the technique. An advantage is the ability to make weak details stand out; and observe

the object from many different angles. The information level is high; due to the fact that 3D photogrammetry adds depth to the object (figure 3), depth, it will record the topography of the rock, and the depth of carvings. Since image-based 3D reconstruction is based upon digital images, it is possible to visualize the colour of the rock, and eventually also observe the impact of algae and lichens. Concerning objectivity, image-based reconstruction does not pick out details to the exclusion of others, and has an objective approach to the documentation of rock carvings. It presents the result to the viewer, without affecting the viewer to focus on specific details. Some rock carvings have been documented with laser and white light scanning. The results are good, but both methods present some limitations; recording and processing of data can be very time-consuming; the equipment needs huge amounts of electricity, and can be heavy and thus far from portable, the post-processing requires computers of considerable processing power and the equipment needs continuous service and calibration (Bertilsson & Magnusson 2000, Johansson & Magnusson 2004, Chandler et. al. 2007, Duffy 2010).

The traditional 2D methods have limitations, when it comes to the portability of the equipment. Sometimes it will be necessary to have portable equipment, if the sites are situated in remote distance from transportation routes. 3D photogrammetry would prove more useful, due to the fact that the photo-equipment is portable. The recording and the processing of data is time-consuming when using the traditional recording techniques, compared with using image-based 3D reconstruction which is quick. One advantage of 3D photogrammetry is that the outcome requires minimum

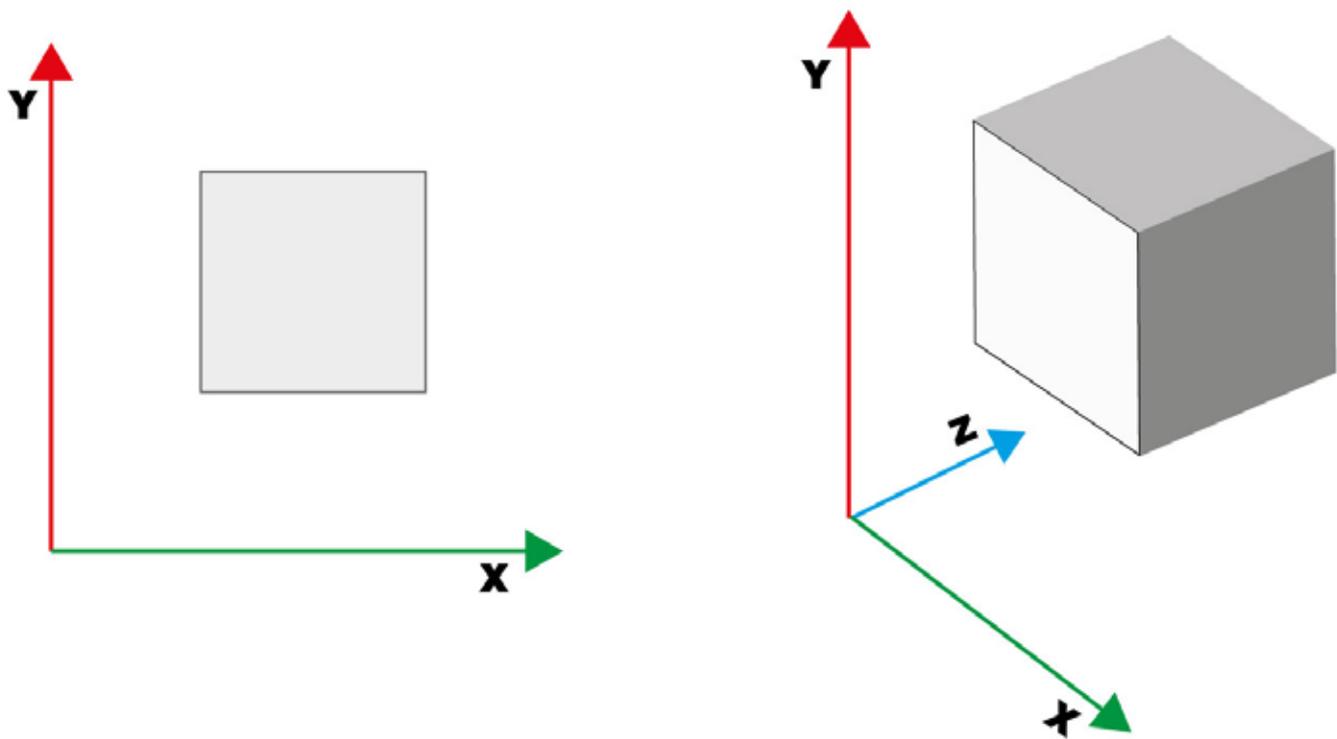


Figure 3. 2D versus 3D. To the left: example on 2D with x- and and Y-axis, to the right: 3D with x-, y-, and z-axis. Model: Mette Rabitz.

storage facility, compared with the storage space that the traditional methods need. Concerning the applicability, all methods can be challenging to apply on rough or eroded carvings. A disadvantage of the traditional methods is that they cannot be applied on very uneven or rough surfaces. In contrast 3D photogrammetry has the advantage that it is applicable despite the surface being wet, moist, rough or uneven. The rubbing technique has the disadvantage that it is very tactile, while 3D photogrammetry can be non-tactile. Considering manageability, an advantage of the traditional methods is that they are easier manageable by everyone. However, considering the quality of the outcome, some knowledge about rock carvings is necessary. An advantage of 3D photogrammetry is that the documenting person does not need

to have much knowledge about rock carvings. Concerning the information level, the traditional recording methods lack the ability to present the colours of the rock and depth information, although a rubbing can have some indicators of depth differences in between the carvings. But in a scientific perspective, the results would have been more useful, if the realistic depth of the carvings were presented; thus it would be possible to study technical questions. Using image-based 3D reconstruction did not only prove useful concerning topography and depth of carvings, the outcome can also give technical information which can develop the science of rock art. Such information is crucial, when studying how the humans used the cravings. Due to the fact that image-based 3D reconstruction is based upon digital images, the outcome

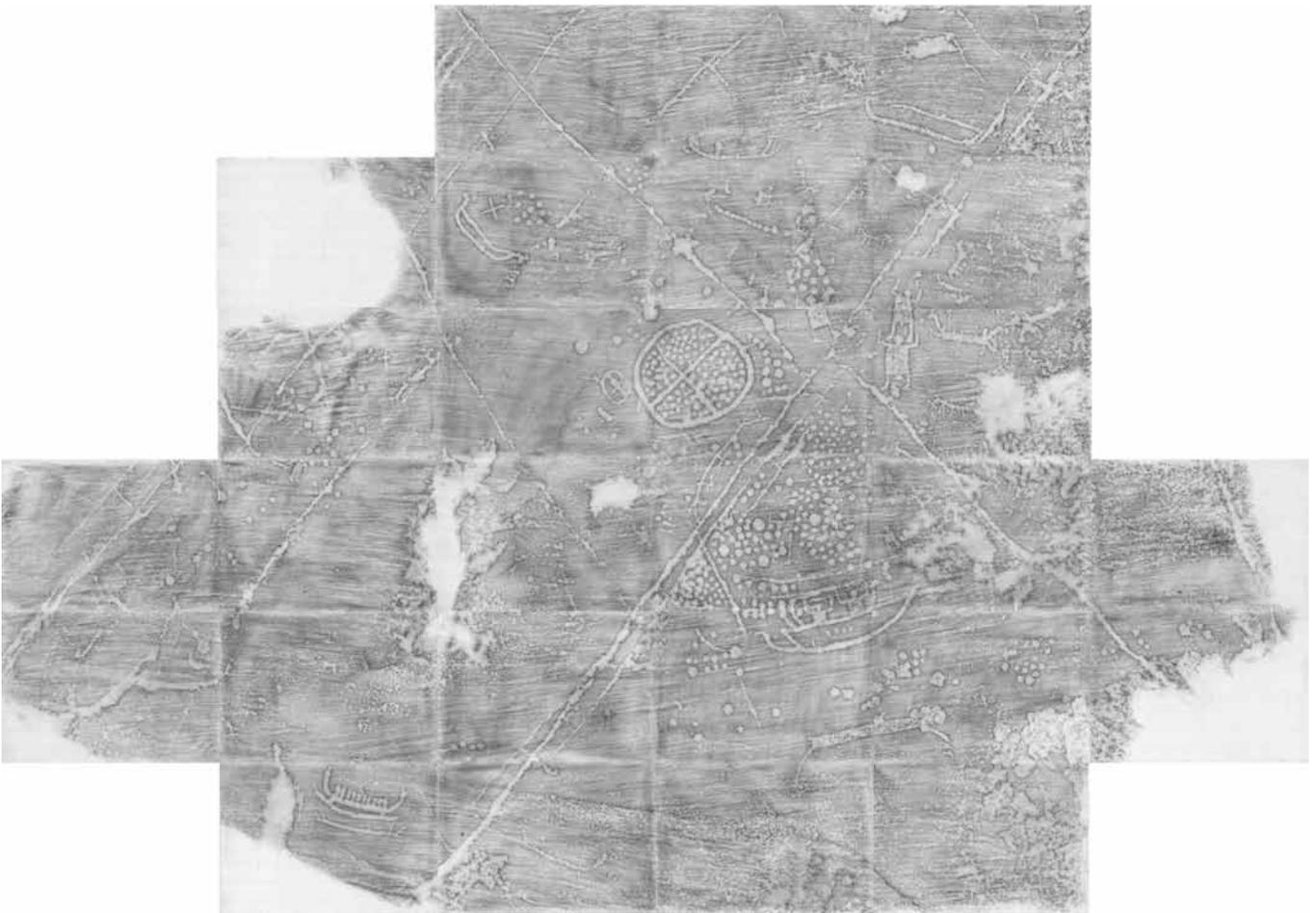


Figure 4. Rubbing of the Finntorp-panel, Sweden. Photo: Tanums Hällristningsmuseum.

can be viewed with colours. Thus the technique produces useful information for the studies of degradation and reasons for degradation, which is crucial when considering which carvings are in more need than others concerning protection. Furthermore it is problematic that the use of symbols is not standardized, thus the viewer needs explanation of what the symbols mean. The tracing method is therefore considered as inappropriate for the documentation of rock carvings. Due to the rubbing technique's higher level of objectivity, it is evaluated as a useful method for surveying rock surfaces. As already stressed, the carvings are fragile, so rubbing is inappropriate on rough weathered surfaces. Image-based 3D reconstruction is considered as the method with the highest level of objectivity. The outcome is realistic,

and the viewer will get a neutral representation, which is not affected by the documenting person.

DOCUMENTING ROCK CARVINGS: SOME CASE STUDIES

In the following, the rubbing technique and 3D photogrammetry will be applied to rock carvings, in order to investigate how they apply to three different cases. The Finntorp panel from Tanum UNESCO World Heritage area in Sweden (figure 4-5) is an interesting case for its location of carvings in the topographic context. Two ships are carved in a creek-like depression, and appear in the bottom right corner of the rubbing. There are also three small depressions

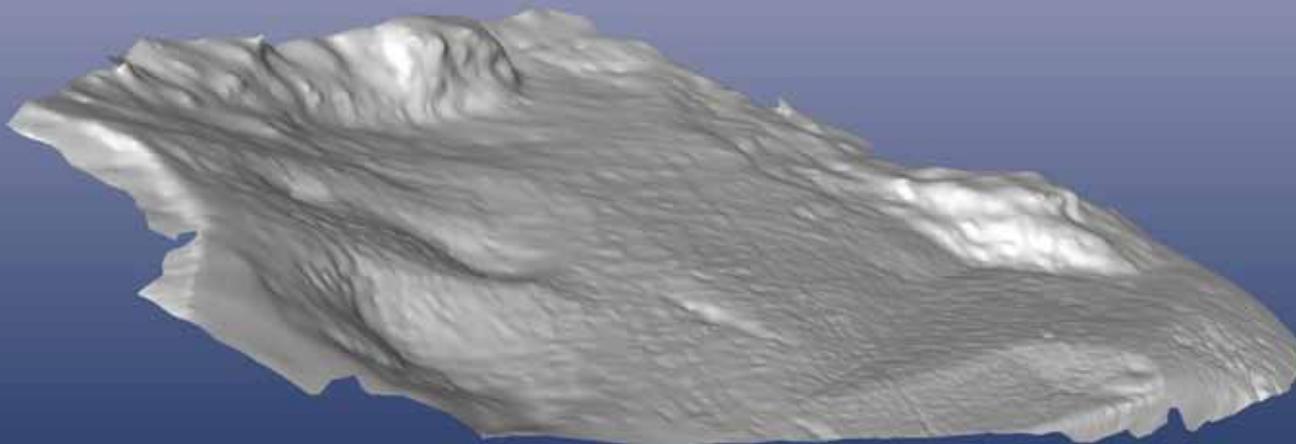
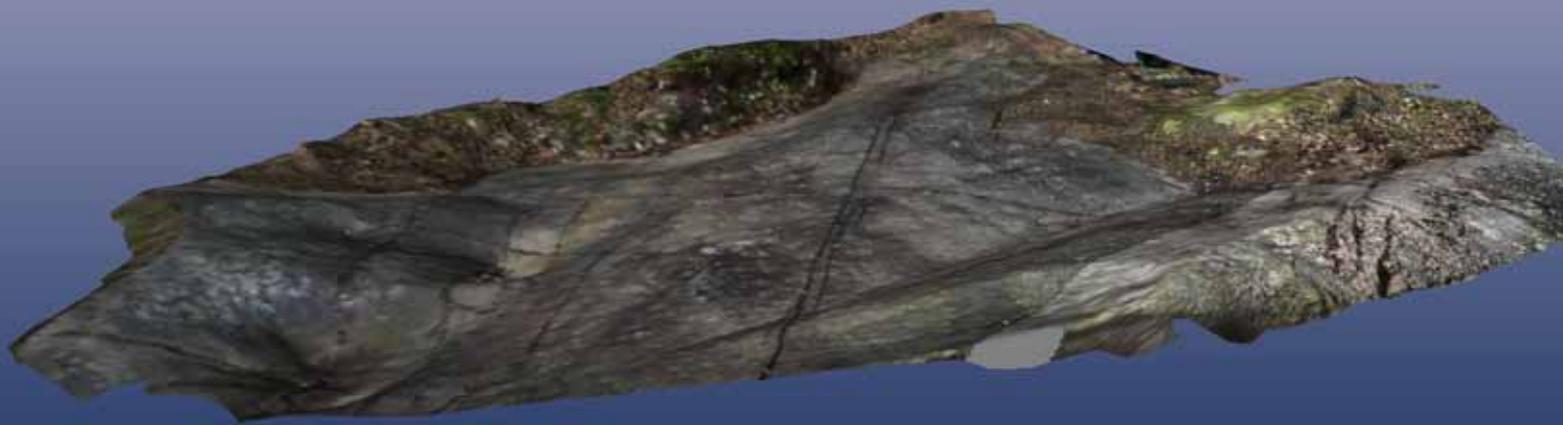


Figure 5. 3D model of the Finntorp panel. Top: model with texture; bottom: model in shaded view. Photo: Mette Rabitz.

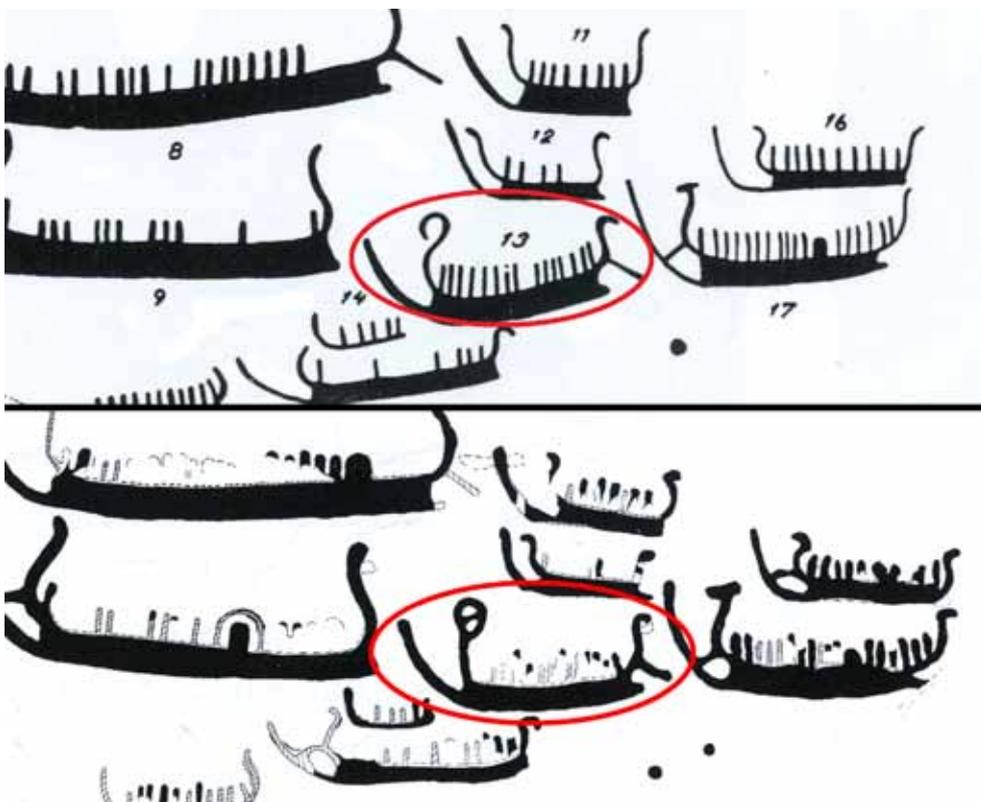


Figure 6. Tracings of Post-Hornes. Top: section of the tracing from 1963, after Martstrander 1963. Bottom: section of the tracing from 1997, after Vogt 2012.

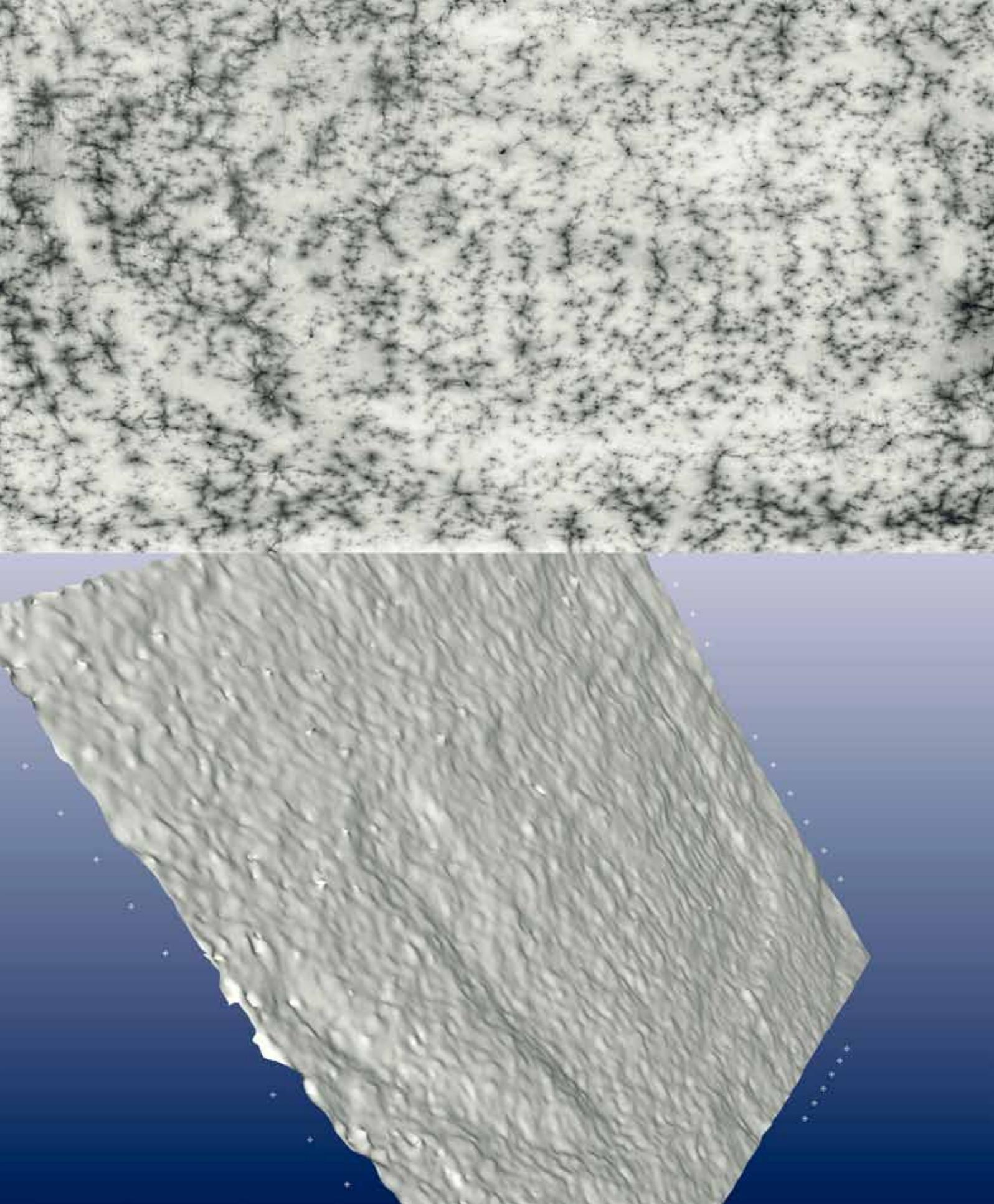


Figure 7. Documentation of the section from Post-Hornes, Norway. Top: rubbing of a ship. Bottom: 3D model of the same ship in shaded view with exaggerated z-axis. Photos: Mette Rabitz



Figure 8. Close up of the stem in dotted view. Photo: Mette Rabitz

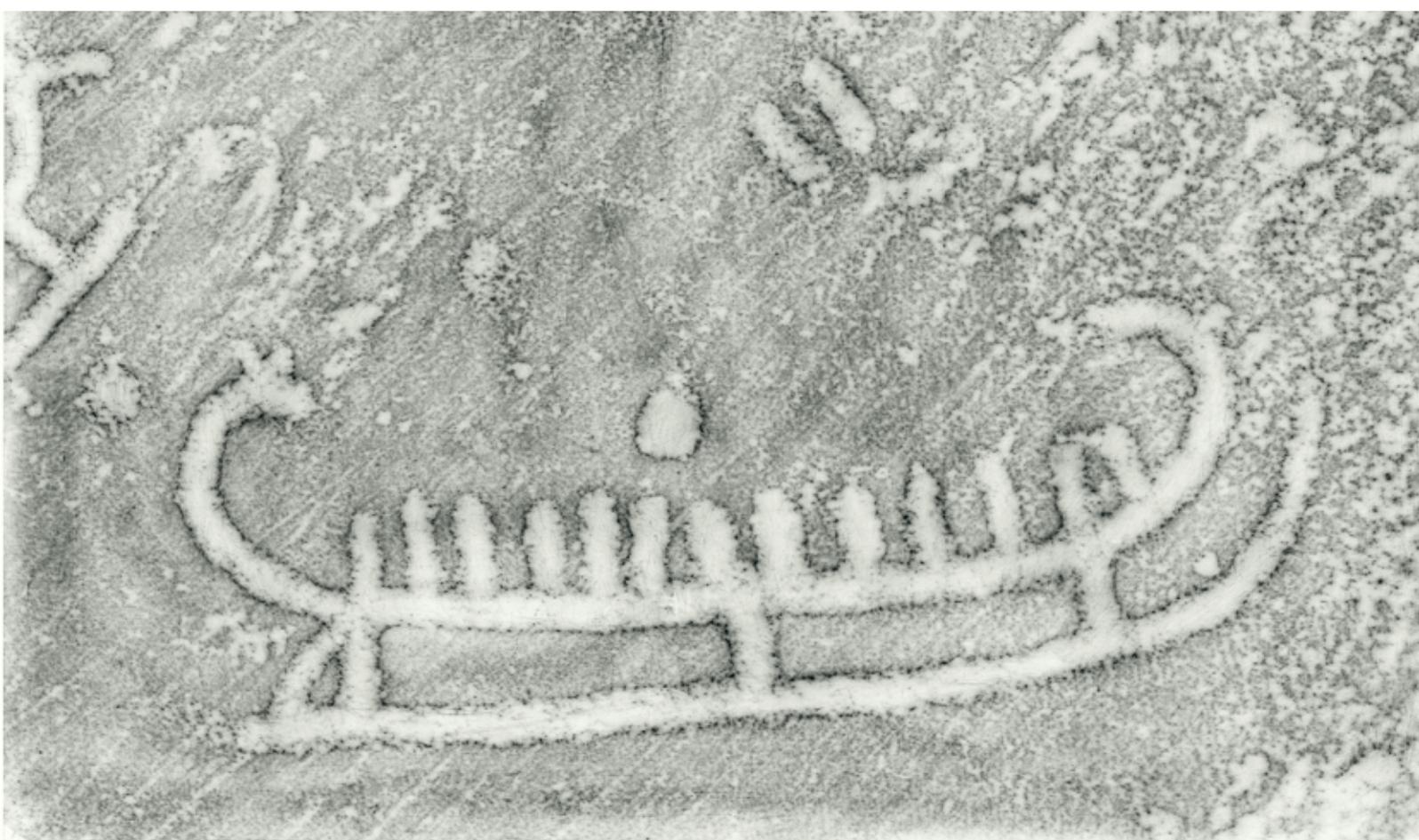


Figure 9. Rubbing of the ship from Brastad 5, Sweden. Photo: Mette Rabitz

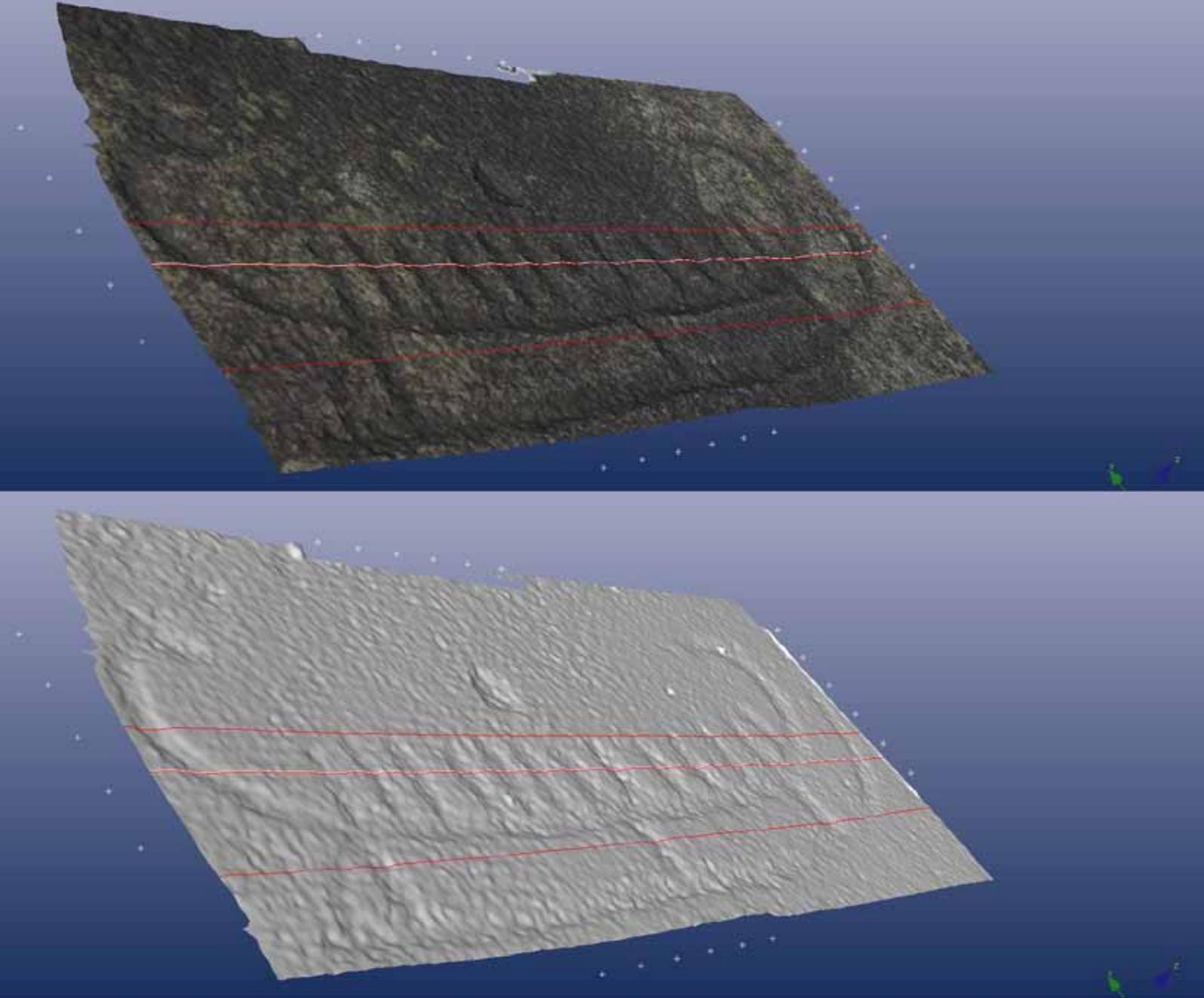


Figure 10. 3D model of the ship motive from Brastad 5. Top: 3D model with texture and contour lines; bottom: 3D model in shaded view. Photo: Mette Rabitz

containing cupmarks, although this topographic information is not visualized on the rubbing (figure 4). In contrast the topographic information was obtained using 3D photogrammetry (figure 5), enabling the viewer to experience the topography, but unfortunately not the carvings. The author realized that the carvings should have been painted before recording data, thus they would have been visible at the 3D reconstruction.

In the southwest part of Norway, in the area of Østfold, there is a panel called

Post-Hornes. The carvings are eroded, and the surface is rough, because many stone particles have fallen off and due to exfoliations. Before the author's documentation, the panel had only been recorded with tracing in 1943 and 1997. Some details are incongruent between the two tracings (figure 6), and have been debated by scholars. For example, the prow of one of the ships has been object of debate: The tracing by Marstrander shows that the prow ends in an S-shape (Marstrander 1963: pl.2), while Vogt's tracing (Vogt 2012: 387) shows a circle

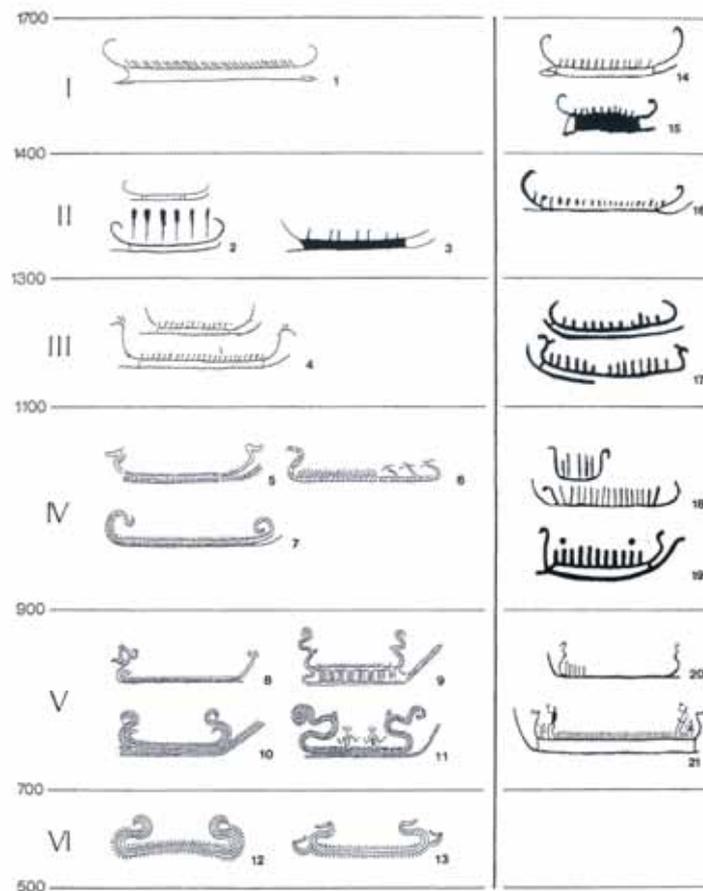


Figure 11. Flemming Kaul's chronology of ship types. After Kaul 1998: 88

with a linear mark going through it. It was therefore necessary to document this particular detail with both rubbing and 3D photogrammetry. The rubbing technique was difficult to perform, due to the rough surface, it was difficult to attach the paper tight and plane, and the sharp stone particles made the paper crack during the documentation process. In the rubbing (top photo on figure 7), the prow appears to look like a wheel cross. The 3D reconstruction was also affected by the rough surface. However, by exaggerating the z-axis, the faint details could be observed. This procedure evidenced that the prow was shaped like a circle with the interior part carved away (figure 7, bottom). A close-up of the 3D model in dotted view confirms a circle-shaped prow, but it also reveals a slightly higher point in the middle of the circle. This feature may explain the misinterpretation by Vogt (figure 8). The rubbing and the 3D reconstruction were

incongruent. But one benefit of using image-based 3D reconstruction was the ability to study the microstructure. It informed what shape the detail actually had, but also gave information of why the detail had been misinterpreted. Another benefit of 3D photogrammetry was the ability to enhance the contour of faded details.

The panel Brastad 5 located in the southern part of Bohuslän (Sweden) presents a ship with an updated prow. The prow is shaped like a horse head with ears. According to Flemming Kaul's (Kaul 1998, 88) ship typology (figure 11), this feature can date the ship to period III of the Nordic Bronze Age (1300-1100 BC). The rubbing (figure 9) and with 3D reconstruction (figure 10) were congruent and recorded the updated ears, but the 3D reconstruction also recorded the growth of algae and lichens.

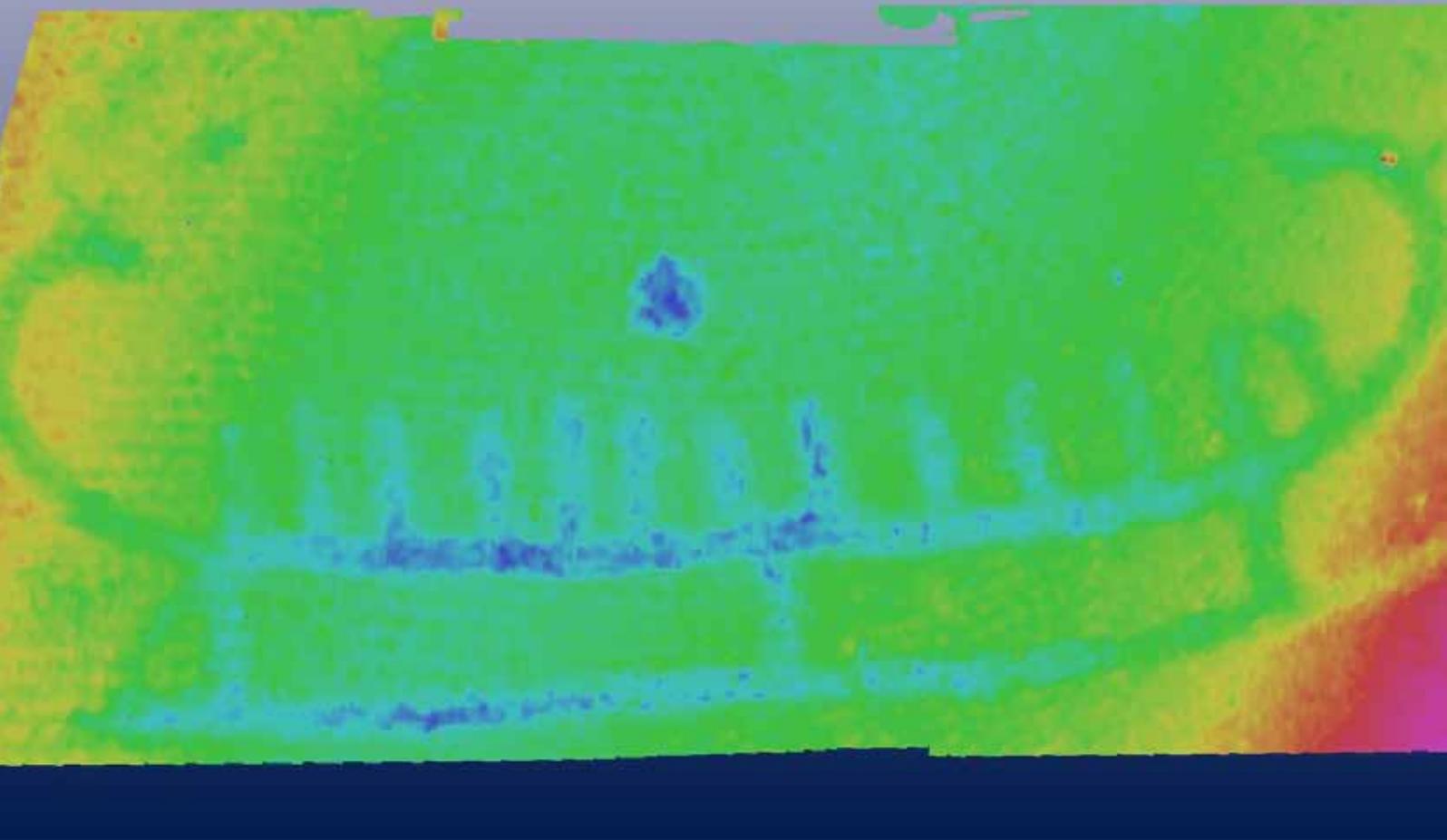


Figure 12. 3D model with colour spectrum: pink is highest, while blue is lowest. Photo: Mette Rabitz.

A tactile investigation revealed that the ears of the horse head were not carved as deeply as the rest of the motif. This may indicate that they were added later, and carved with another technique. A hypothesis is that the ship was originally carved with inward prow, a feature which can be dated to period II of the Nordic Bronze Age 1400-1300 BC (cfr. Kaul 1998: 88). PhotoModeler Scanner has a depth-feature which can visualize depth differences mapped with colours; this procedure confirmed that the ears were not carved as deeply, as the rest of the ship, reinforcing the hypothesis. But it also revealed even more variations in depth, these differences were not detected despite careful tactile investigation and observation during fieldwork, nor did they appear on the rubbing. The 3D reconstruction did not show these

differences either (figure 10), but when it was viewed with the depth-feature, it revealed that the middle part of the ship was deeper carved than the rest of the ship, and the extension of the keel line was less deep than the rest (figure 12). One advantage of image-based 3D reconstruction is the possibility to study differences in carving technique, which gives knowledge about the production process of carvings. A crucial benefit of PhotoModeler Scanner is the ability to reveal more information than expected. As demonstrated in the case studies, the methods apply differently to the documentation and the following will discuss the methods and the advantages/disadvantages.

CONCLUSION

It can be concluded that in order to produce useful documentation for future research, it is important to use a method with a high level of objectivity. In this sense both the rubbing technique and 3D photogrammetry are considered as appropriate methods. Considering the state of the rock carvings and the amount, it is recommended to use 3D photogrammetry; it is a non-intrusive method with a high degree of information, the outcome will be useful to the whole team of researchers studying the degradation of rock carvings, archaeologists, biologists, and geologists. The result is not specifically focused on one group, but all of them, so they can choose how to work with an image-based 3D reconstruction on their own. Further image-based 3D reconstruction would be a good way to cope with the enormous amount of rock carvings, which need to be documented before disappearing. It is believed that image-based 3D reconstruction can preserve material for researchers to work with in the future

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