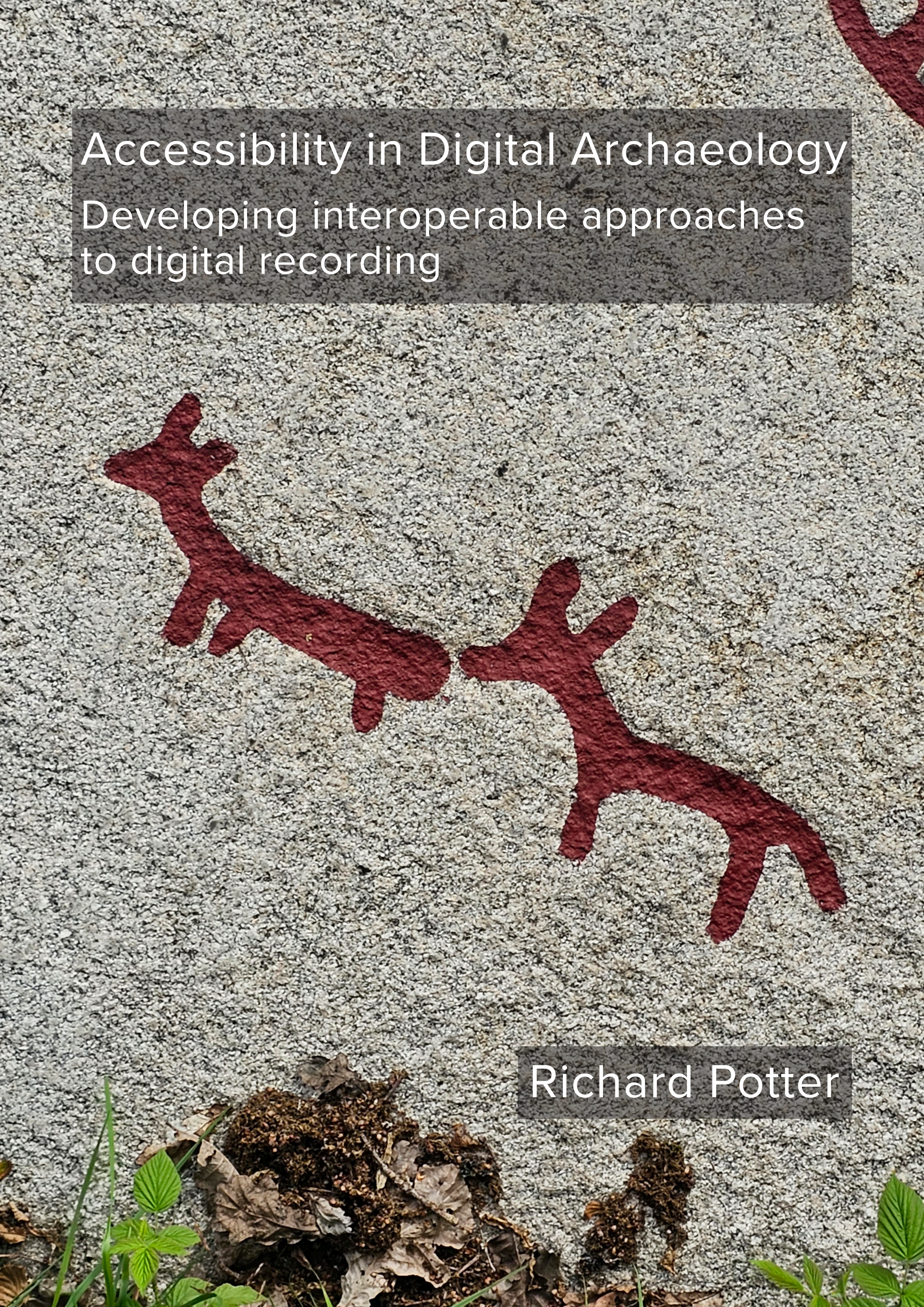
Accessibility in Digital Archaeology

Developing interoperable approaches to digital recording

Richard Potter



Accessibility in Digital Archaeology

Developing interoperable approaches to digital recording

Richard Potter

Submitted in award of a PhD from Bournemouth University

July 2023

Author's declaration:

This is a phd by publication and therefore some of the presented works have joint authorship. Individuals contributions can be found in Figure 1 and are extrapolated upon when the articles are introduced within the chapters.

Abstract:

This thesis examines rock art documentation methods within the field of archaeology, starting with traditional analogue methods and moving through to digital documentation methods. It then introduces analytical processes which allow us to get more from the 3D models created by digital documentation.

A key theme in the thesis is that of democratisation and accessibility. By focusing on these concepts through the lens of Scandinavian rock art, the author suggests several improvements that could be made to the overall workflow of documenting and analysing carved panels.

Digital recording methods have been suggested to be more democratic than traditional methods, and this is explored within the discussion of this thesis, as well as how this can be improved in the long term.

Rock art is found all over world in various forms, and is an endangered heritage both due to climate change and vandalism. It is important that it is documented before it is lost, and also as a resource for evaluating change over time. Visualising rock art is an important strategy for both displaying and evaluating carvings, and also for the discovery of new carvings. One of the intentions of this thesis is to democratise the documentation, visualisation and analysis of these carvings.

The thesis comprises of twelve published articles and a supporting narrative which cover a wide range of digital recording methods and visualisation techniques as well as more theoretical aspects of Bronze Age Scandinavian rock art. It also includes articles about democratic methods, and democratisation in general.

This thesis presents a large body of work which incorporates both methodological and theoretical works that have contributed to our understanding of Scandinavian Bronze Age rock art studies, and which can be applied to multiple topics.

Acknowledgements:

I would like to thank my colleague Derek Pitman for his calm and reassuring advising, and also to Bournemouth University for giving me the opportunity to pursue my PhD. I am also obligated to thank my temporary assistant to the second supervisor, Christian Horn for also being present. I would of course like to thank Joana Valdez-Tullet and Barry Molloy for their positive and thorough examination, constructive and helpful feedback, and for making the viva an enjoyable experience. I would also like to thank Elvira Bolat, for making sure the viva was a relaxed and positive experience. Furthermore I would also like to extend a huge thanks to Henrik Janson and Lise-Lotte Walter from the University of Gothenburg for allowing me to dedicate time toward this undertaking.

I also wish to thank Naomi Bailey and Charlene Parrish for their help and kind support guiding me through the process behind the scenes. I am indebted to Ellen Meijer and Ashely Green for their sound advice and patience when asked the thousands of questions I had. I also want to acknowledge the help that Kristofer Axelsson, from MLT, gave me in obtaining the Creaform guidelines and his many introductions to various laser scanners over the years.

I extend my gratitude to the SHFA for providing materials and support. In addition, I am thankful for the help, advice, and discussions of various colleagues including, but not limited to, Johan Ling, Fotini Tsouka, Fiona Coward, Mark Gillings, Tony Axelsson, Bettina Schulz Paulsson, Frederik Dahlberg, Robin Rönnlund, Lawrence Shaw, Harry Manley, Sarah Elliot, Ulf Bertilsson, Catarina Bertilsson, Julian Moyano Di Carlo, Jonathan Westin, and Matteo Tomasini. I would also like to thank anonymous reviewers on the publications included in this thesis for their robust and critical reviews. To anyone I have forgotten, sorry, but also thanks!

A huge thanks also goes to my partner, Emma, for being awesome.

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Chapter one: Introduction

1.1. Introduction

This thesis is submitted in support of an application for the award of a PhD by publication. This submission presents a portfolio of twelve papers which focus on digital documentation and visualisation of rock art in the UNESCO world heritage area “Rock Carvings in Tanum” and wider discussions of digital archaeology/heritage. While this is a retrospective thesis, the portfolio is accompanied by a narrative which provides additional context for the research within the published papers. This narrative focuses on an underlying theme, which is the democratisation of digital documentation methods used in the analysis of Scandinavian Rock Art. Collectively, the portfolio and narrative text form a thesis of work that begins with an overview of the methods used to document and visualise rock art and other carved surfaces, before focusing on digital methodologies, and culminating in a discussion through the lens of democratisation, accessibility, and openness within the subject.

This thesis aims to present the methodological evolution of Scandinavian rock art research, and place it in a context of how it can be democratised and made more accessible to researchers and the general public alike. It examines the current documentation methods and determines to what extent digital methodologies have made rock art documentation more democratic, and what this means for researchers and the general public. It does not aim to offer an answer to how, and to what level, democratisation can be achieved within the general field of archaeology, but to act as a catalyst to spark discussion within the field of digital documentation using Scandinavian rock art as a case study.

This thesis also aims to tie together my academic contribution to the field of rock art documentation and contextualise it within the sphere of digital archaeological documentation and visualisation.

By first introducing the main topic of research, Scandinavian rock art, and then introducing the traditional methods of recording, the reasons for digital documentation and visualisation are explored. Through this I critically evaluate my contribution to the field and present a synthesis of how my work has positively contributed to digital analysis in the sphere of rock art, carved surfaces, and field archaeology, as well as to the overall understanding of Scandinavian rock art. This is demonstrated through a selection of my published work thus far, which is more than equivalent to the research within a traditional PhD.

1.2. Publication summary

The main overarching theme of the publications and projects that I have worked with has been the digital documentation of engraved remains -primarily Scandinavian rock art, but also engravings and epigraphy from both Italy and Greece. Within this work I have tried to use accessible and transparent methods and workflows, presenting my work in a way which is easy to follow, and which can be reproduced and utilised by other researchers. The 3D documentation that took place in the submitted articles enabled a deeper analysis of the subject matter, and has frequently been used as a jumping board for experimentation with software and advanced visualisation methodologies. Though my overall involvement in some of the earlier articles is comparatively low in relation to the later articles, the research outcome was significantly enhanced by my contribution.

I have primarily worked with SfM documentation and the subsequent visualisation of Scandinavian rock art, but have also worked with a variety of other methodologies which are introduced in the submitted articles, including drone surveying visualised with DStretch, laser scanning, RTI work, Artificial Intelligence (AI), and Agent

Based Modelling (ABM). While article twelve is not related to rock art, it utilizes many of the same methods, and demonstrates their interoperability, as well as how the democratisation concepts can be applied unilaterally to other types of digital documentation. I introduce and discuss the democratisation of these methods and how they can be used to both expand the workflow of archaeologists, as well as document and preserve endangered cultural heritage.

1.3. Outline of the submission

This thesis presents the main theme of the material (Scandinavian Bronze Age rock art), places the methodological aspects of the documentation of the material in a historical context, and discusses both traditional and digital methods of documentation along with the rationale behind documenting and the need for democratising the documentation and visualisation methods.

All of the submitted articles have at least two authors as rock art is usually documented and evaluated by at least two researchers working in tandem within our work group, especially in terms of analysis (Meijer and Dodd 2018, p. 291; Toreld and Andersson 2015, p. 15). A detailed breakdown, displayed as a percentage of my participation in each of the publications, is given in figure 1 below.

Article	Project Design	Documentation	Processing	Analysis	Write up		Publication Year
1	10	60	75	75	25		14
2	10	50	75	60	20		18
3	40	90	100	50	50		17
4	30	80	100	50	30		18
5	40	90	80	45	40		19
6	50	100	90	50	40		19
7	30	90	80	50	40		20
8	80	100	80	45	40		22
9	80	100	100	100	90		23
10	90	90	95	80	90		22
11	100	N/A	N/A	90	90		23
12	90	80	80	80	80		23

Figure 1: *My participation in the creation and completion of the submitted articles (listed below). In the main table, red represents a lower involvement, with green showing a higher level of involvement in a specific aspect of the publication. The values represent a percentage of my participation in each publication.*

This table demonstrates that my involvement in publishing material has progressed from primarily being related to methodological and documentation roles to taking the lead in project development and subsequent publication. The articles are presented as a narrative of my career, demonstrating both my academic contribution and development as a researcher. They are equivalent to that of seven single-authored papers: more than equivalent to a traditional PhD in terms of academic contribution.

The thesis will primarily be a summary of the evolution of rock art documentation, how it has progressed over time, as well as where it is going, it will be presented in a way that ties into my research thus far, and demonstrates how I have contributed to the advancement of my field. Articles follow each chapter which relate to the topics described and are presented as an overview of the paper and a description of my contribution to the production of the research. The thesis concludes with projects which are currently in progress and those which I intend to pursue following the successful acceptance of this thesis and the award of a PhD.

Chapter 2 briefly introduces the Scandinavian Bronze Age and the main theme material of Scandinavian Bronze Age rock art. The rock art depicts anthropomorphological figures, boats, animals, and a host of other types of motifs, and gives an strong insight into the society that created it. The motifs are both figurative and abstract, and range from crude to detailed representations. While some of the motifs can be dated, primarily through ship and material object depictions, the majority of it can not be safely dated.

Chapter 3 introduces traditional, non-digital, documentation methods including rubbing, plaster casting, tracing and night photography. Although the presented portfolio mainly focuses on digital documentation methods, it is important to understand how the traditional methods work, and what the expected outputs are. Within this chapter, some of the problems that are created by using traditional methods, including physical damage to the surfaces and the inherent human bias that is introduced to the output, are presented.

Chapter 4 then offers a longer description of digital methods, including Reflectance Transformation Imaging, Structure from Motion, and laser scanning. For each method a description of how the process is undertaken is given, as well as some of the reasons to use the methods and the problems that arise through their use. As well as to create a record of the surface being documented, the output can also be used to create visualisations that help scientific analysis, discovery, and enhance the presentation and dissemination of the material to other researchers and the general public. The chapter concludes with a description of some of the more common digital analysis methods that have been used in this way. Throughout this chapter relevant publications are interspersed as an aid to understand how the methods are used for research.

Chapter 5 introduces the concepts of democratisation and accessibility and forms a discussion around how rock art can be made more accessible, both from a perspective of researchers, and an interested public. The discussion includes the necessity for the openness of both documentation and visualisation methodologies by describing how to obtain results from them, as well as an explanation of how they work, and what the expected inputs and outputs are. Data openness is also covered, both in terms of how and why this should be achieved, as well as the problems that are currently facing archaeologists regarding long term storage and open dissemination.

Chapter 6 summarises the thesis and the article contributions and introduces future work which is in progress or will soon be started including a multi-scalar investigation into waterflow in a region in the Bohuslän area, and the development of a reverse-image search application for rock art.

1.4. Author background

I am currently employed at University of Gothenburg as a Research Engineer working at the Department of Historical Studies. I have also been a visiting fellow at the University of Bournemouth since 2019. My role is centred in archaeological research, and is time heavy as I am part of a number of highly funded large projects.

Following my 2:1 bachelor's degree at Southampton University in 2006, I worked in commercial archaeology at Cambrian Archaeology and Wessex Archaeology for 18 months. During this time I became interested in the digital side of the subject, and pursued working in the IT section of Wessex Archaeology where I was encouraged to learn surveying, web design, PHP, ArcGIS, and 3D. In 2008 I moved to Gothenburg and started my own company (ArchaeoDesign) doing 3D work -primarily selling 3D archaeological models and reconstructions online. In 2010 I started a Master's in Interaction Design at University of Gothenburg/Chalmers University, until I took some optional courses at Department of Historical Studies at the University of Gothenburg. It was there that I was offered a job working in the Early Modern Town Project with Professor Per Cornell, which led to me putting my Master's on hold, preferring to maintain my position at the department. A full-time position was eventually created for me, and I have since worked in various roles at the department: starting as a Research Assistant, moving to Editor, and then progressing to Research Engineer in 2018. Within this position I have gained skills including illustration, design, web design, typesetting, and proofreading. As well as holding several administrative roles, I also work in variety of projects both internationally (Greece, Italy, France) and within Sweden. These projects have required a wide range of activities including photography, digital documentation using techniques like Structure from Motion (SfM) and Reflectance Transformation Imaging (RTI), 3D virtual reconstructions, drone work (SfM, Thermography, LiDAR), geophysics (GPR, Magnetometry, Resistivity), and ArcGIS. I have also co-created and taught courses in digital archaeology both at student level (Bachelor's and Master's), and to professional and amateur archaeologists. Within my time working at the University of Gothenburg, I have also worked with the Svenskt HällristningsForskningsArkiv (hereafter referred to as the SHFA). The SHFA is an innovative research infrastructure attached to the University of Gothenburg who over the past 20 years have created an archive of rock art both in Scandinavia and parts of Europe. My work with the SHFA has primarily been related to the development of documentation and visualisation methodology, working with documenting rock art and processing it in preparation for publication within the archive. The majority of the articles submitted in combination with this thesis were created in collaboration with the SHFA and the projects that are attached to it.

I was instrumental in obtaining funding from Epic Megagrants, which helped us to create our department's lab (ArkLab), and have also received funding for several smaller projects. To date I have received over 1,000,000 SEK from external funds. During the last decade I have published several articles with varying levels of involvement (initially focusing on methodological aspects, but later with me taking an academic lead -see figure 1). My ambition is to build on a PhD with more funded research and to continue to develop my academic career within the field of Scandinavian rock art.

1.5. List of publications

1. Andreeff, Alexander, **Richard Potter.** 2014. "Imaging picture stones: Comparative studies of rendering techniques" *Med hjärta och hjärna: En vänbok till professor Elisabeth Arwill-Nordbladh*. eds Henrik Alexandersson, Alexander Andreeff, Annika Bünz. GOTARC Series A: Vol 5.

2. Bertilsson, Ulf, Johan Ling, Catarina Bertilsson, **Rich Potter**, and Christian Horn. 2017. "The Kivik tomb - Bredarör enters into the digital arena - documented with OLS, SfM and RTI." In *New perspectives on the Bronze Age: Proceedings of the 13th Nordic Bronze Age Symposium held in Gothenburg 9th to 13th June 2015*, edited by Sophie Bergerbrant, and Anna Wessman. Oxford: Archaeopress.

3. Horn, Christian, and **Rich Potter**. 2018. "Transforming the Rocks – Time and Rock Art in Bohuslän, Sweden: Time and Rock Art in Bohuslän, Sweden." *European Journal of Archaeology,* 21 03: 361–84. DOI:10.1017/eaa.2017.38.

4. Horn, Christian, Johan Ling, Ulf Bertilsson, and **Rich Potter**. 2018. "By all means necessary: 2.5D and 3D recording of surfaces in the study of southern Scandinavian rock art." *Open Archaeology*, 4 1: 81–96. (Open Access)

5. Horn, Christian, Derek Pitman, and **Rich Potter**. 2019. "An evaluation of the visualisation and interpretive potential of applying GIS data processing techniques to 3D rock art data." *Journal of Archaeological Science*: *Reports,* 27: 101971. DOI:10.1016/j.jasrep.2019.101971. (Open Access)

6. Horn, Christian, and **Rich Potter**. 2019. "A new documentation of "Runohällen" (Gerum, Tanum)." *Fornvännen*. (Open Access)

7. Horn, Christian, and **Rich Potter**. 2020. "Set in Stone? Transformation and Memory in Scandinavian Rock Art" in *Places of Memory: Spatialised Practices*

of Remembrance from Prehistory to Today, edited by Christian Horn, Gustav Wollentz, Gianpiero Di Maida, and Annette Haug. Oxford: Archaeopress. 97-107

8. Horn, Christian, **Rich Potter,** Mark Peternell. 2022. “Water flows and water accumulations on bedrock as a structuring element of rock art”. *Journal of Archaeological Method and Theory*. https://doi.org/10.1007/s10816-022-09578-2 (Open Access)

9. Potter, Rich, Robin Rönnlund, Jenny Wallensten. 2023. An evaluation of Substance Painter and Mari as visualisation methods using the Piraeus Lion and its runic inscriptions as a case study. *Heritage Science* 11, 226 https://doi.org/10.1186/s40494-023-01071-7 (Open Access)

10. Potter, **Rich,** Christian Horn, Ellen Meijer. 2022 “Bringing it all together: a multi-method evaluation of Tanum 247:1”, *Danish Journal of Archaeology*. VOL 11, 1-12. https://doi.org/10.7146/dja.v11i.131913 (Open Access)

11. Potter, Rich, Derek Pitman, Lawrence Shaw, Christian Horn. In preparation. Everyone has to start somewhere: Democratisation of digital documentation and visualisation in 3D.

12. Potter, Rich, Derek Pitman, Harry Manley, Robin Rönnlund. 2023. Cost-effective, rapid decorrelation stretching and responsive UAS mapping as a method of detecting archaeological sites and features. *Heritage Science* 11, 89. https://doi.org/10.1186/s40494-023-00931-6 (Open Access)

Chapter two: A little context please...

This chapter introduces the main theme of the thesis, the rock art of the Scandinavian Bronze Age. It also provides an overview of why the documentation and preservation of rock art sites is important. While not an exhaustive overview of the Bronze Age or its rock art, it offers a context through which the submissions and subsequent chapters can be placed.

2.1. An introduction to the Scandinavian Bronze Age

The Scandinavian Bronze Age, which dates from approximately 1700 to 500 BCE, was a period of high mobility, trade, and warfare which is characterized by its move from copper production to the more complex creation of bronze alloys. The production of bronze items was made possible by the opening of trade routes, which allowed raw materials such as tin from Cornwall and copper from several areas throughout Europe to be transported to Sweden (Ling et al. 2014, 2019; Melheim et al. 2018; Radivojević et al. 2019). This advancement meant that better quality items, for example long-bladed weapons, could be created.

It is argued that Early Bronze Age society was initially a top-down system run by wealthy elites who controlled trade and production (Austvoll 2021). Although others suggest that the later Bronze Age moved to a more egalitarian society (Brück and Fontijn 2013), the commonly agreed upon theory is that the decline in house sizes, metal wealth in burials and their construction were related to pressure from over-exploitation of limited resources (Holst et al. 2013). As a whole, the Bronze Age can be seen as having been hierarchically organized, although some localized hierarchies might have been flatter than others (Horn et al. In press). This multi-faceted crisis, potentially driven by climactic change (Molloy 2023), seems to have developed into an ideological shift in both housing types -from large central longhouses to scattered farmsteads (Artursson et al. 2012), and burial types -from large monuments to cremations under the influence of the Central European Urnfield Culture (Bergerbrant et al. 2017; Holst 2013), and led to large scale interpersonal combat (Horn and Kristiansen 2018; Molloy and Horn 2020; Jantzen et al. 2011; Price et al. 2019).

During the Bronze Age, there was a tradition of creating rock art in Scandinavia (and other regions including for example Valcamonica in Italy (Nash 2011)). There are multiple interpretations of the purpose and meaning of the rock art (see below for discussion), but in Scandinavia it appears to be heavily linked to the maritime environment and seafaring activities, and its production increased with the influx of metal (Horn et al. 2022c, p. 9). It is also strongly connected to burials with examples like Kivik and Sagaholm linking the two together (Goldhahn 2013, p. 229; Goldhahn and Ling 2013, p. 279).

The Scandinavian Bronze Age clearly displays numerous links to the importance of seafaring and water, through its reliance on boats for trade (Horn et al. In press; Ling et al. 2018), the proximity of many known settlements to water (Andersson 2005; Eriksen and Austvoll 2020; Ling 2014), the use of water and maritime themes in the creation of rock art (Horn et al. 2022d; Ling 2014), and the burial/ritual aspects that appear to include maritime themes (Horn et al. In press).

Although there are a large amount of bronze finds, primarily from hoards, rock art is one of the most abundant sources of information about Scandinavian Bronze Age thought processes that we currently have access to (Rédei et al. 2019, p. 543). As such it is an important source through which we can make interpretations about Bronze Age societies in connection with other finds and sources.

2.2. Overview of Scandinavian rock art

The main area of focus of this thesis, and of my work to date, is the UNESCO world heritage area "Rock Carvings in Tanum", which is located in and around Tanum, Northern Bohuslän, Sweden (see Figure 3). Tanum was designated a world heritage site in 1994, and has the largest concentration of carvings in Sweden (Horn et al. 2018, p. 81). Of the more than 30000 sites known in Europe, (Goldhahn and Ling 2013, p. 270), more than 1500 of them are concentrated in Bohuslän alone (Horn et al. 2022c, p. 1). The rock art is often painted red at sites that are open to the public in an effort to make them easier for the public to see. There is no evidence that the carvings were originally painted in any way in the Bronze Age.

Figure 2: *Rock art from Aspeberget in Tanum, Sweden.*

The majority of the rock art carvings in the Tanum area were created on bedrock panels that would have emerged from the sea during the Bronze Age as a result of land uplift and shoreline displacement (Goldhahn and Ling 2013, p. 280; Horn et al. 2022c, pp. 8–9; Ling 2014; Milstreu 2017, p. 40; Rédei et al. 2019, p. 544). There is also rock art found in burial contexts (Goldhahn 2013, p. 223; Goldhahn and Ling 2013, p. 279). The primary focus of this thesis and my portfolio, however,

Figure 3: *Map showing the location of the Tanum world heritage area.*

is on open air rock art. The rock art panels are formed from Bohus Granite, a type of granite specific to the Bohuslän area (and Östfold, where it is identical, but named differently) which is mechanically hard and contains areas that were polished by ice movement (Horn et al. 2022d, pp. 3–5). The carvings were created by pecking, grinding, or scraping at the surface with a tool (Horn et al. 2019, p. 2; Nordbladh 1981, G15; Seidl 2016, pp. 85–86). The direction of the carvings is considered to have significance (Hesse 2013, pp. 2324–2325; Rédei et al. 2019, p. 549), but in general the carvings are orientated with the topographically lowest part of the panel as the bottom (i.e. down) and with carvings facing left to right (Nordbladh 1981, G6). It is assumed that this was probably the most comfortable way to produce and view the art (Hesse 2013, p. 2325).

There are two commonly regarded subsets of Scandinavian rock art, the northern and southern tradition (Horn and Potter 2018, p. 361, Skoglund and Ling 2017). The northern tradition is considered to have been associated with hunters-gatherers while the southern tradition is more related to farmers, often due to its placement in the landscape (Bertilsson et al. 2021, p. 20; Stebergløkken 2017, p. 36). The southern tradition is more associated with boats, while the northern tradition features more animals. However, both traditions may contain either motif type as there is no tangible boundary between the two given that there was likely some interaction/ overlap between the groups through trade (Melheim and Ling 2017; Stebergløkken 2017, p. 36). There is some contention about whether the divide is too simplistic, or whether they relate to different time periods or groups (Lødøen 2017; Stebergløkken 2017). The situation is complicated further by the criticism of stylistic dating of the northern tradition rock art as is at odds with the shoreline dating, and local variations and personal styles must be taken into account (Lindgaard 2013; Stebergløkken 2017).

Some of the rock art, specifically cupmarks and a selection of boats, are considered to be from the Neolithic period (Melheim and Ling 2017), but the majority of the rock art is considered to have been created between 1700 - 500BCE (Chacon et al. 2020, p. 80; Goldhahn and Ling 2013, p. 270; Horn et al. 2022c, p. 1). Precise dating is very difficult for individual elements (Gibbon 2017, p. 6) but can be accomplished as some elements of the rock art are created in the form of real world items that have been dated (Bertilsson 2017, p. 64, p. 69; Horn and Potter 2018, pp. 373–374). It is also difficult to date elements as they were frequently updated or altered at unknown time intervals (Hauptman Wahlgren 2002; Horn et al. 2022c, p. 9; Milstreu 2017, pp. 37–38). The chronology of boats is very well established, however, due to the inclusion of carvings on objects in burial environments that were possible to date (Horn et al. 2022c, p. 3; Ling 2014; Kaul 1998, 2005).

The motifs in the Tanum area include boats, cupmarks, anthropomorphic figures, fishing nets, terrestrial animals, birds, carts / chariots, footsoles, musical instruments, weapons, abstract symbols e.g. sun wheels, wavy lines, indeterminate shapes, etc.

(Horn et al. 2018, p. 81; 2019, p. 2; Horn and Potter 2018, p. 361; Rédei et al. 2019, p. 543). Motifs are sometimes overtly created in the form of scenarios, which can include hunting, intercourse, combat, and sailing (Chacon et al. 2020, p. 80). The panels are rarely considered to be complete scenes, but rather comprised of additions over the years (Fahlander 2021, p. 304). The proportions of some of the figures can often be exaggerated, for example calves, and some figures seem to be purposefully incomplete (Bertilsson et al. 2021, p. 23; Fahlander 2018, pp. 78–81). It is not clear if this is just a stylistic choice, or if there was some representation associated with these features (Fahlander 2021, p. 303).

While it is not within the scope of this thesis to give a detailed overview of each type of motif, the most common or interesting motifs (based on levels of detail and potential for analysis) are described below with references given to further reading.

- Cupmarks – small round depressions in the rock surface, the most abundant and ubiquitous of all motif types, can be separate or included as part of another motif. Often represents heads on anthropomorphs (Horn 2015).
- Boats – Boats are the second most common motif on the rock art in Scandinavia. They come in many forms, often featuring crewstrokes (single upright lines that represent sailors) or more detailed scenes which can include acrobats, musicians, warriors, etc. (Ling 2014; Ling et al. 2020)
- Weapons – There are a number of different types of weapons included in carvings, often associated with anthropomorphic figures who are depicted with weapons in their hands or on their body. Swords, for example, are mostly depicted sheathed. These weapons can include spears, axes, swords and bows and arrows. The larger examples are often updated. (Bertilsson 2017; Goldhahn 2014; Horn and Potter 2018; Skoglund et al. 2022)
- Fishing Nets – webbed carvings representing fishing nets that are sometimes anthropomorphised and may be representative of the dangers of seafaring (Oosterwijk 2020)

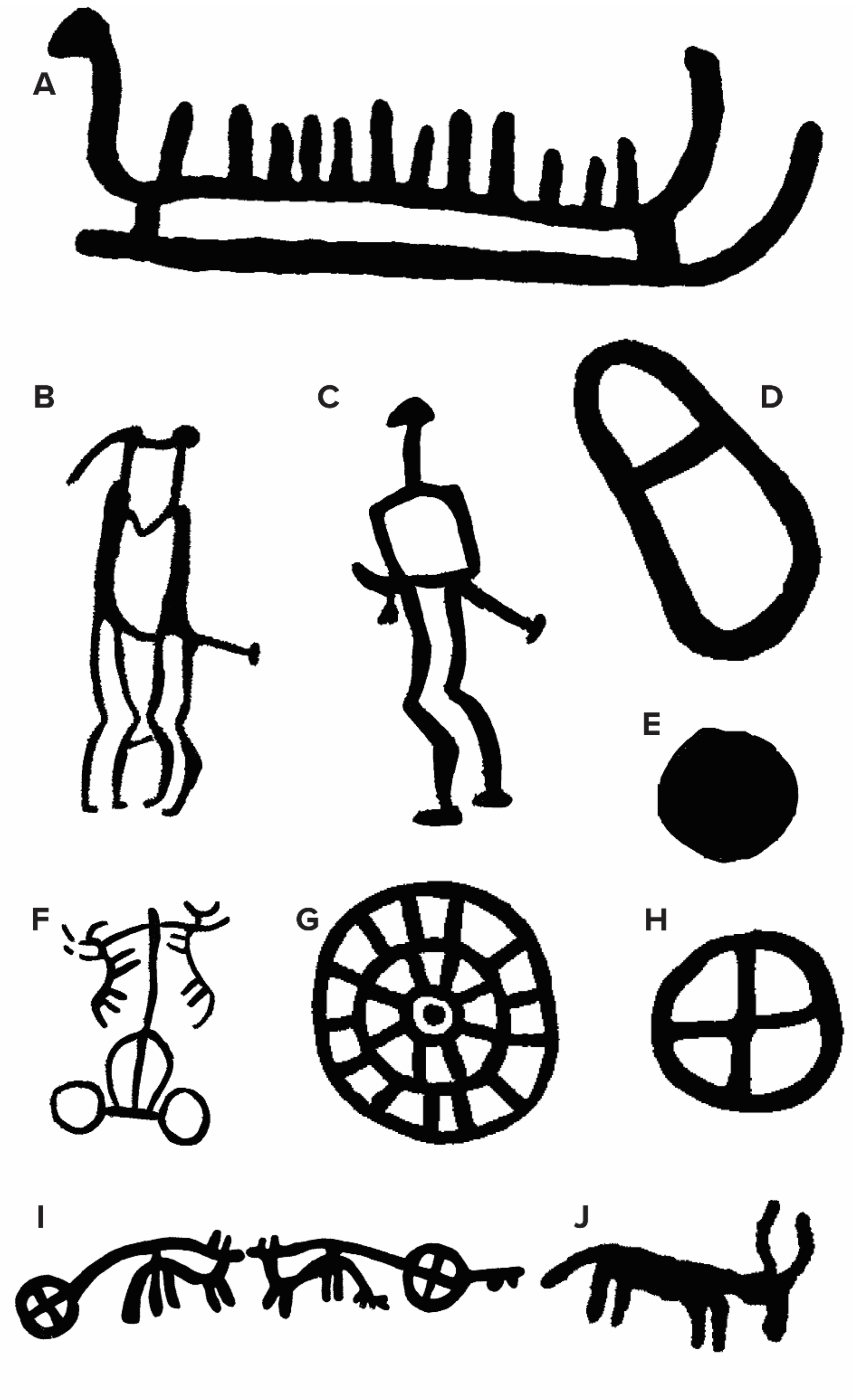


Figure 4: *General overview of some of the more common motifs found in Scandinavian rock art, note that there is huge variation between individual motifs of the same style and no scale is implied. A) Boat B) "Marriage couple" C) Anthropomorph D) Foot sole E) Cup mark F) Chariot G) Wheel H) Sun Wheel I) Animals pulling ards J) Animal.*

- Anthropomorphs – a very common type of motif, frequently presented as a warrior figure with a sword and phallus and occasionally other equipment. Scenes which include fighting are commonly represented as the anticipation of the first blow, rather than actual killing scenes, though there are exceptions (Horn 2022a; Skoglund et al. 2022, p. 183). Some of the anthropomorphic figures are shown as being merged into animal form (for example the figures with wings on Bottna 88:1)[1] or shown in ceremonial gear (Goldhahn and Fuglestvedt 2012, p. 247). While the usual interpretation of the figures is that they are male, there are a number of representations which have been identified as being female (Goldhahn and Fuglestvedt 2012), though there is some discussion about how females are represented on panels (Hays-Gilpin 2004; Horn 2017).
- Hand signs – these fairly accurate representations of hands (which are usually paired with some representation of four strokes) have been suggested to be related to the number 29, or one month of the synodic calendar based on the numeric counting system of the urnfield culture (Dam Hansen 2020).
- Feet / Footsoles – there are a large number of sites which contain footsoles or feet, which appear to be sized anatomically correctly and can help determine potential ages of those whose feet were being used as a reference. It is also possible that the feet were used as viewpoints or to create a route for viewing the carvings. (Goldhahn 2013; Sognnes 2011)
- Musical Instruments – primarily lurs, which are considered to be associated to ceremonies related to burials. Often seen in conjunction with anthropomorphs on ships (Skogstrand 2020; Sognnes 2017)
- Animals – There are a variety of different types of animals presented on the rock art, from birds, to fish, to snakes, to land animals, some of which are pulling what is considered to be farming machinery (Ranta et al. 2020; Skoglund 2018).
- Wagons / Chariots – 2D representations of chariots are frequently presented on Scandinavian rock art with the wheels shown as being flat next to the body of the chariot. There is a particularly large cluster at Frännarp (RAÄ Gryt 1:1) in south east Sweden (Coles 2002).

1. Overview of Bottna 88:1 - https://shfa.dh.gu.se/site/130118 (accessed 12/08/23)

- For a general overview of Scandinavian rock art (Goldhahn and Ling 2013; Horn et al. 2022c).

The number of carved ships and the location of the rock art show a clear link between the panels, the maritime environment, and other waterways (Chacon et al. 2020, p. 80; Nimura et al. 2020). The carvings are frequently placed by or in very close vicinity to the water's edge or bodies of water (Goldhahn and Ling 2013, p. 280; Hauptman Wahlgren 1998; Ling 2014). This is reinforced by a recent study in which it was determined that there appears to have been some thought behind the placement of motifs in terms of water flowing over the rock art surfaces, as will be discussed in more detail later (Horn et al. 2022d). There also seems to be a significant relationship between the positioning of the rock art in the landscape, the sea, and other features including burials, perhaps related to the liminal nature of the sea (Goldhahn and Ling 2013; Horn 2022b; Oosterwijk 2020). This relationship is personified by the positioning of the panels both through their proximity to water, the frequent representations of maritime scenes on the carvings themselves, and that they seem to have been designed to interact with water flowing over their surface (Ling 2014, Horn et al. 2022d). It is clear that rock art should be seen as a canvas which is situated within a wider landscape, rather than just as a standalone feature. Recent multi-scalar approaches have shown that there is often a correlation between the landscape and its placement (Barnett et al. forthcoming, Gjerde 2010, Nash 2011). In addition to the role of the micro-topography of the rock surface (Horn, et al. 2022d), all these aspects may support the narrative structure of rock art (Rédei et al. 2020). A viewshed analysis of the rock art locations has also shown that the sites overlook fjords and bays, but avoid looking out to the open sea (Horn 2022b).

Motifs from rock art panels also appear on other forms of media, such as bronze razors (Bradley 2006; Kaul 2005). Like the rock carvings, these are considered to have cosmological interpretations, which, based on the symbology and the direction of the carvings, portray the mythological perpetual journey of the sun (Bradley 2006; Kaul 2004, 2005; Vianello 2008, p. 32).

It is likely that the carvings did not serve one specific purpose or have a single meaning. It is also likely that their meaning changed over time (Dam Hansen 2020, p. 59). They may even have been designed to be ambiguous despite being figurative, due to the similarity of the carved elements that they are constructed from (Horn et al. 2022c), and as such they are inherently open to interpretation by viewers with different backgrounds (Rédei et al. 2020). The rock art motifs were frequently updated and re-carved, seemingly to amend older carvings so that they represented current weapons and material objects (Bertilsson 2017, p. 64, 2018, p. 76; Bertilsson et al. 2021, p. 24; Hauptman Wahlgren 2002; Horn and Potter 2018; Milstreu 2017, pp. 37–38, p. 44). The carvings on panels were not made all at once, but were instead carved over a long period of time, with carvers returning to the same spots to add additional motifs as required, reflecting an ongoing tradition (Dodd and Milstreu 2019, p. 53; Fahlander 2021, p. 304; Horn et al. 2018, p. 94; Horn and Potter 2018, p. 361; Milstreu 2017, pp. 45–46; Sognnes 2017, p. 35). It is also likely since the re-carving motifs would lighten up the carving compared to the uncarved surface, that they were periodically re-carved to make them more visible again (Goldhahn 2014, pp. 117–119; Hauptman Wahlgren 2002; Nordbladh 1981, G6; Moe Henriksen 2021, pp. 54–55; Skoglund et al. 2022, p. 181).

Rock art can be very difficult to record (Gibbon 2017, p. 8), and is even harder to interpret as there are often a number of different possible interpretations which can change over time, or depend on the context of the motif, or even just on which researcher is working with it (Tilley 2021). Since there is no written record of the meaning of the carvings, it is unlikely that any full understanding of the motifs will ever be reached. However, as discussed in Gibbon's article regarding rock art research, the best method for creating interpretations we currently have is by correlating ideas and data from other researchers with your own, and determining if there are any common themes, as well as through the inclusion of ethnographic studies (Gibbon 2017; Ling et al. 2020).

Chapter three: Traditional documentation methods

Before discussing digital methods, it is critical to examine and get an understanding of the traditional/analogue methods that preceded them. Although much of the current rock art documentation being published primarily uses digital methods of recording rock art, there is a certain sensorial appeal to seeing and working with the more "physical" traditional methods. Additionally, non-digital methods such as rubbing have a continued importance as a rapid and accessible documentation method and as a control for digital recordings, and as such their value should not be understated, as will be discussed later (Potter et al. 2022). It is important to note, however, that while many traditional approaches still have value, some have been shown to be destructive to the surface of the panels and should no longer be used.

The two methodologies for recording rock art: non-digital, and digital (Brady et al. 2017, p. 2), will henceforth be referred to as traditional and digital respectively in this thesis. In this section an overview of the traditional methods will be given, as they are important to understand when evaluating the digital methods that are now more commonly used. Several of the traditional methods can be considered to be illustrative rather than a true documentation since they are not accurate or scaled representations of the material. Illustrative recording includes methods like sketching, since the results are difficult to recreate exactly the same way twice, and an interpretation is already engrained into the final piece. Other methods like rubbing can be considered to be a true documentation since they record what is present on the surface directly, with less interpretation from the documenter. Photography is difficult to categorise as it both records what is present, but is also highly dependent on what the photographer wishes to record, with the possibility to manipulate, focus on, or omit elements of the surface. Since the output of traditional methods tends to be instantly recognisable and understandable, some digital methods seek to create visually similar outputs while using less invasive methods, and also producing more objective and interactive results.

Although there is much discussion about the risk of damage being caused by the traditional methods to the rock surfaces (Brady et al. 2017, p. 15; El-Hakim et al. 2004, p. 345; Monna et al. 2018, pp. 125–126), there is still much information to be gained from some of them, and in general the risk of damage is minimal if they are applied correctly. The already historically created results from these methods must not be disregarded either, as they are still a numerous, coherent, accurate, and extremely useful record of a material which may now have changed due to various external factors such as weathering.

The majority of the documentation methods presented below have been successfully used on material other than rock art. However, since the main focus of my work is Scandinavian rock art, they will be referred to primarily in terms of their use in rock art here.

3.1. Sketching

Sketching is a low impact methodology whereby carvings on rock panels are drawn onto graph paper using tools including grids to place motifs (Brady et al. 2017, p. 13). While relatively low impact, it still relies on objects being placed onto the rock surface, which, although unlikely, may cause some level of damage.

Sketching is highly interpretive, despite the occasional use of measuring grids. It can often lead to inaccurate results in terms of their position, scale, and content, and they will be different every time they are produced (Stuart 1978, pp. 193–194). They should therefore be considered illustrative rather than scientific.

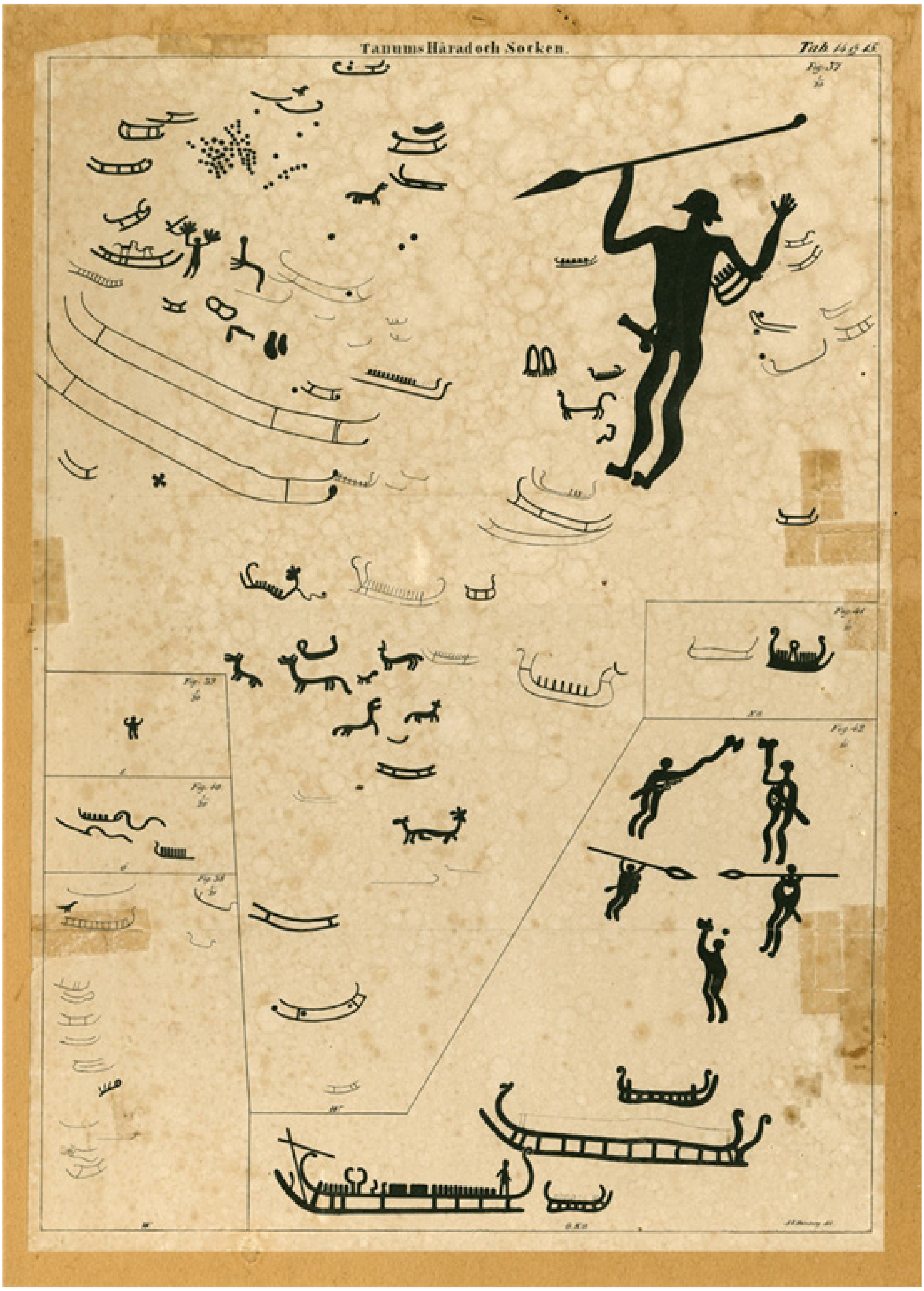


Figure 5: *Indian ink drawing of Tanum 75:1 by Axel Emanuel Holmberg in 1848, reproduced with permission from SHFA.*

3.2. Plaster casts

There are several workflows for the creation of a plaster cast, but in general the process involves building a frame around the area being documented, lining it with a separation agent (like chalk), and pouring a medium (either latex, plaster of Paris, or a paper squeeze) to make a negative impression of the carving (Bertilsson 2018, p. 272; Flinders Petrie 1904, pp. 64–69). The negative is then removed from the surface, boxed in, and plaster of Paris is poured over it to create a positive, highly accurate, impression (Nordbladh 1981, G10-G11; Seidl 2016, p. 13; Stuart 1978, pp. 194–195). The positive is lined with muslin cloth, hessian, and or iron grids to give it rigidity (Löw 2015, p. 189).

Figure 6: *One of the plaster cast panels created by Wirth in the 1930s. Photograph by Rich Potter.*

This method is no longer used due to the obvious damage that it can cause to the surface of the rock by pouring material onto it (Gustafsson and Karlsson 2021, p. 33), but also because storage of the output is impractical due to its size and weight (Stuart 1978, pp. 194–195). Yet, examples like the historic casts created by Herman Wirth[2] in the 1930s (Löw 2015) remain a valuable resource in terms of Scandinavian rock art, as they are a highly accurate snapshot of the carvings.

3.3. Squeeze

Squeezes appear to have mostly been used in the field of epigraphy and Egyptology, but are mentioned here as they use some of the same principles as other methods. There are two methods, wet and dry squeezes, depending on the materials used to create the impression. In principle the method of wet squeezing consists of pressing a soft, malleable substance, i.e. paper pulp or latex, onto the surface, compressing it until a negative impression is formed, and then allowing it to dry (Barmpoutis et al. 2010, pp. 989–990; Booth 2018, pp. 32–34). From as early as 1904 it was recognised that this damaged the surfaces, and dry squeezing was developed instead (Flinders Petrie 1904, pp. 62–64).

Dry squeezes are created by pressing a dry, thin, malleable medium such as a metal foil with a wax or latex backing which is then further pushed onto the surface using a brush. This again creates a negative impression of the surface, which is stabilised by the wax material on the back of the foil (Booth 2018, pp. 34–38).

Both of these methods require a lot of interaction and direct manipulation on the surface and are not preferred methods of recording, though they are still used in epigraphy (Bruun and Edmondson 2015).

2. Although, the Nazi ideology and reasoning behind the creation of the plasters by Herman Wirth, who tried to use the rock carvings to support the superiority of what he perceived to be ancient Germans, is abhorrent (Foster and Curtis 2016, p. 123).

Figure 7: *Paper squeeze of XII Dynasty Goddess Nekheb, reproduced from Flinders Petrie 1904 (Image 33).*

3.4. Tracings

In Scandinavia the first step of this method typically involves a tactile survey and chalking the surface of the recognized rock art. After that, the tracings are created by placing a plastic sheet over the surface of the rock art and drawing round the carvings (Jaillet et al. 2017, p. 4; Toreld and Andersson 2015, p. 15). This allows the tracer to mark in different colours and patterns areas which might indicate damage, carvings they are not sure about, and natural features such as cracks, etc. (Scotland's Rock Art Project 2018c, p. 4). Elsewhere chalking is not common practice (Sanz 2014, p. 6353, Seidl 2006, p. 13). More recent tracings use stippling to demonstrate depth (Andersson and Toreld 2021). Tracings produces large rolls of plastic with outlines of rock art scaled at 1:1 (Horn et al. 2018, p. 83; Nordbladh 1981, G10-G11). A major flaw of this method is that it requires the tracer to be extremely knowledgeable about the surface they are recording, and to be able to look and understand a surface that is obscured by see-through plastic (Sanz 2014, p. 6353). It is common in Scandinavia that the surface is painted with a chalk-based mixture prior to the tracing to add contrast and make it more visible to the tracer, despite this being considered damaging to the surface and leaving a residue on the surface (Brady et al. 2017, p. 15). As this is a method which requires direct and repeated contact with the surface of the panel, it can be described as potentially detrimental to the rock art and requires training to carry out the process (Brady et al. 2017, p. 13). It is also a comparatively time consuming method (Scotland's Rock Art Project 2018c, p. 4; Seidl 2016, p. 2).

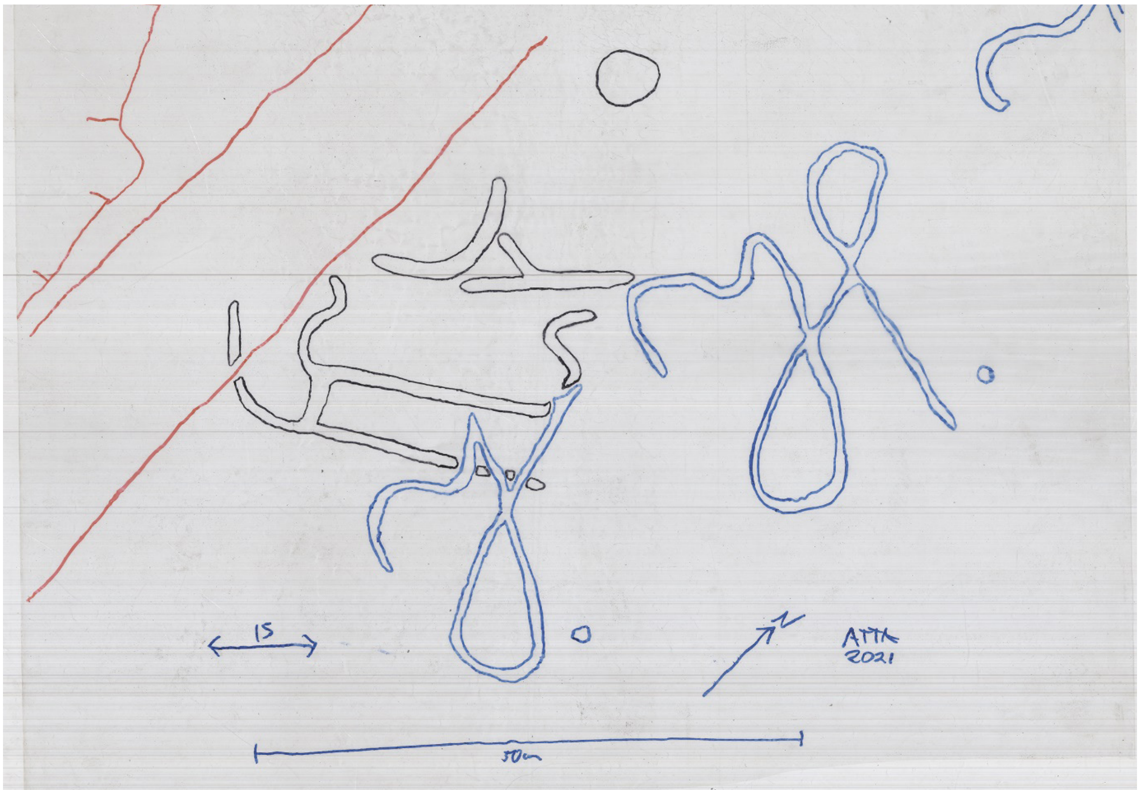


Figure 8: *An example of a tracing from Kville 1:1, created by Stiftelsen för documentation av Bohusläns hällristningar, 2021.*

Tracings can also be created away from the panels through the medium of photo manipulation software or drawing directly on prints of photographs of the rocks (Brady et al. 2017, p. 18; Sanz 2014, p. 6355).

3.5. Rubbing

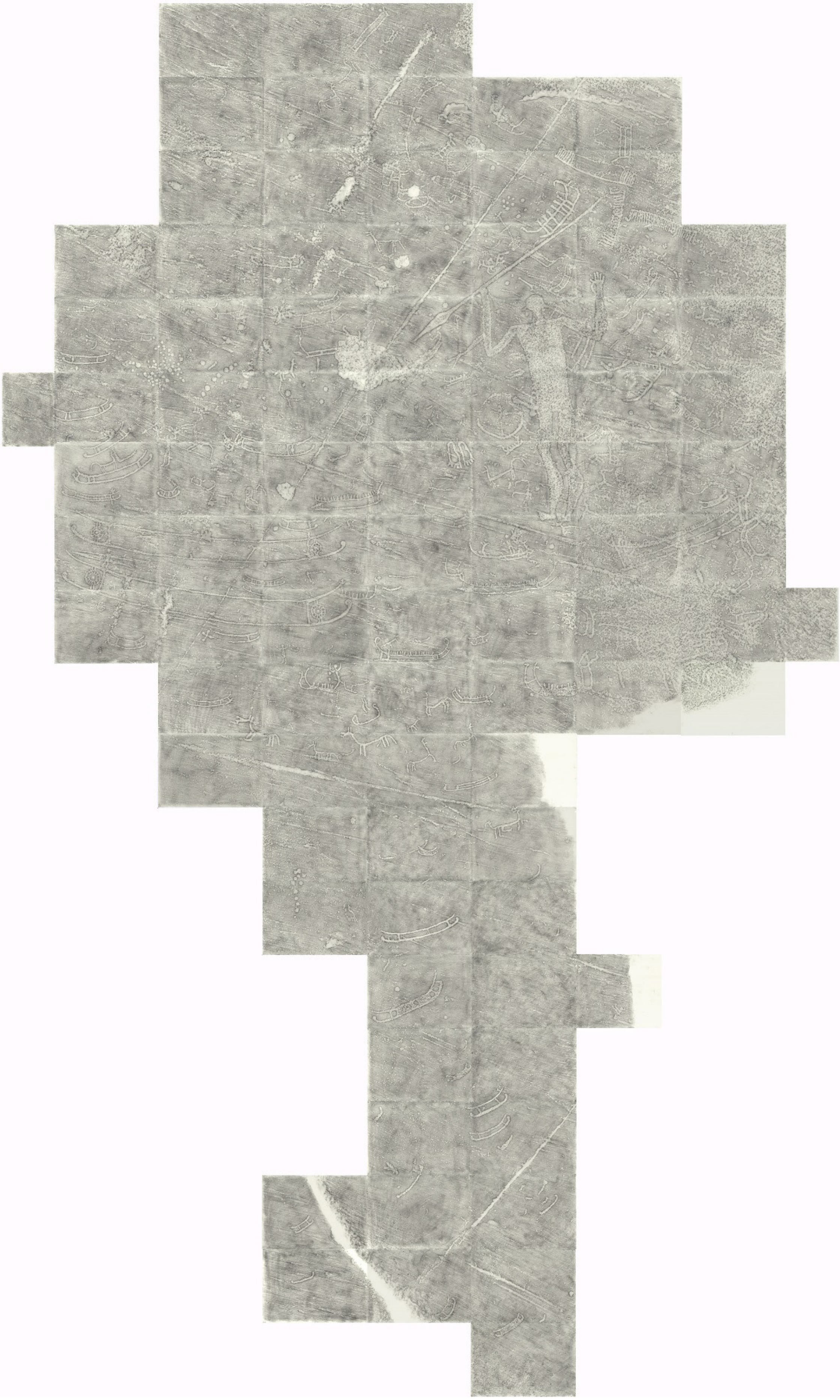
Rubbing, or frottage, is one of the most common and well-known examples of a traditional method. Although additional procedures such as night photography (see below), tactile surveys, and chalking the surface often take place alongside the production of rubbings (Milstreu 2020, pp. 10–12), at its core the Scandinavian method involves a large format sheet of paper (70 x 100 cm) being affixed to a rock art panel, and then graphite or carbon paper being rubbed over it (Bertilsson 2018, p. 274; Sanz 2014, p. 6353). The carbon sticks better to areas that have rock directly underneath them, and produces a lighter area where there is less material, i.e. carvings or depressions underneath the surface. The carbon is then fixed by rubbing grass over the paper (Milstreu 2020, pp. 9–10; Scotland's Rock Art Project 2018, p. 1; Seidl 2016, p. 13).

The result is a scaled 1:1 accurate reconstruction, which gives a very clear representation of what has been carved into the surface. Although contact is made with the rock surface, the pressure applied is minimal, meaning that damage to the rock surface is limited. This method is still used today in rock art documentation and is an excellent companion to 3D material, as will be discussed later (Milstreu 2020, p. 9; Potter et al. 2022).

On larger panels this method can be problematic as the number of sheets can grow to become unwieldy (Scotland's Rock Art Project 2018c, p. 1), and difficult and time consuming to stitch together. An example of this is shown below from Tanum 75:1 in Bohuslän, Sweden.

Figure 9: *Frottage from Tanum 75:1 created by Dietrich Evers in 1970.*

Figure 10 (overleaf): *Rubbing of Tanum 75:1 in Bohuslän composed of 87 sheets. Note that in the corners of the sheets, there is frequently a different level of graphite than in the centre. Rubbing created by Tanums Hällristningsmuseum Underslös, reproduced with permission from SHFA.*



3.6. Photography / Oblique Lighting

Oblique lighting photography is another common and still used method of documenting rock art. The principle is essentially that the carvings are enhanced by holding a light at a low raking angle to the rock surface at night, which creates shadows in the carved areas where the light does not reach (Horn et al. 2019, p. 2). The area is then photographed and produces very illustrative, dramatic and, easy to understand images.

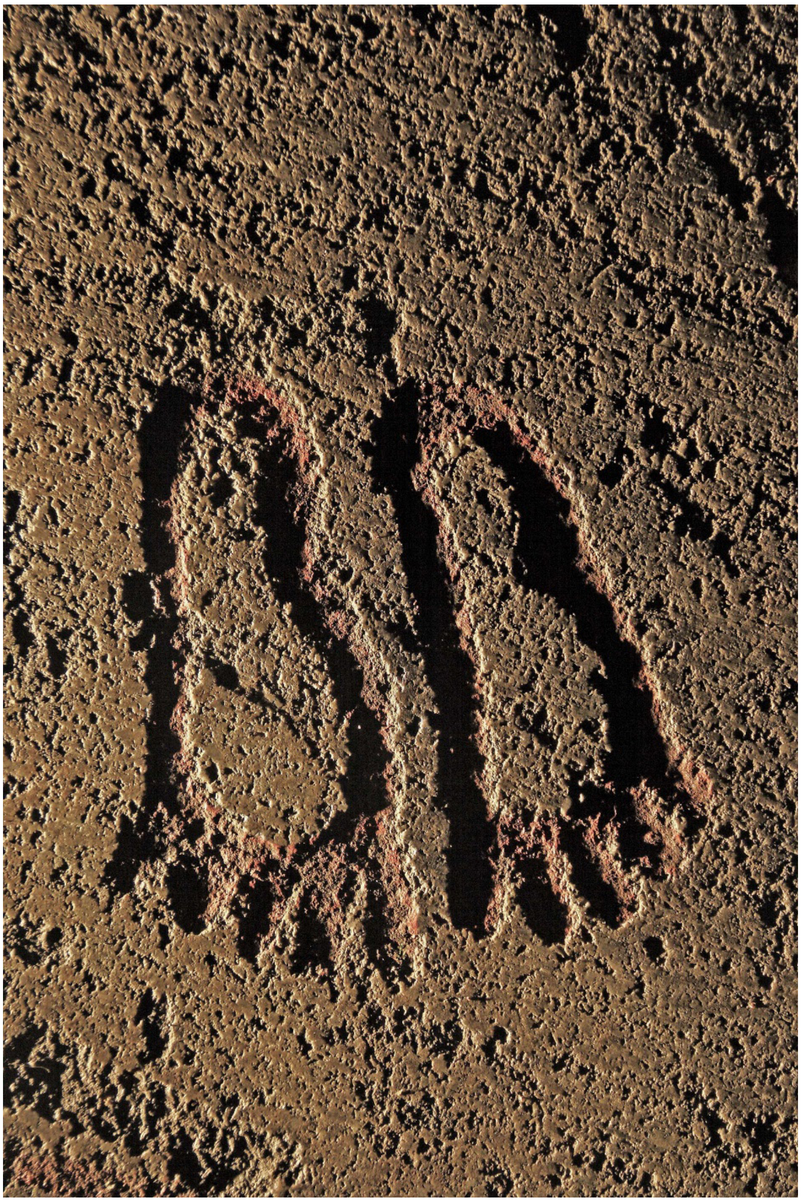


Figure 11: *Oblique photography shot of Tanum 75:1 created by Ellen Meijer reproduced with permission from SHFA.*

Since no contact is required with the rock art surface, except for perhaps cleaning of the surface prior to photography, this method remains extremely useful and is still used today. Museums such as Underslös Museum offer night tours with oblique photography as this is a very easy way for an interested public to see and experience the rock art.

3.7. Interpretive bias

Several of these methods contain an inherent interpretive element in how the material is recorded (Hamilakis and Jones 2017, p. 81; Scotland's Rock Art Project 2018, p. 2; Valdez-Tullett and Figueiredo Persson 2023, p. 3), which is largely determined by the skill of the recorder, time spent (Milstreu 2020), whether they are actively looking for new material or just trying to record the known carvings, as well as an over reliance on the capabilities of the senses (Brady et al. 2017, p. 13).

This is less so with frottage (Bertilsson 2018, p. 278), but most apparent with methods such as tracing, where what is recorded is directly decided upon by the tracers who interpret the panel prior to tracing it (El-Hakim et al. 2004, p. 345; Espinosa et al. 2021, p. 163; Nordbladh 1981, G9). Although frottage largely records what is present on the surface it is applied to, bias can still be seen to some extent on some examples where there is heavier rubbing and therefore more colour in areas of interest, i.e. over known motifs, and areas where nothing is expected are lightly rubbed or not included (Brady et al. 2017, p. 2; Bryan 2009, p. 2).

Stiftelsen för documentation av Bohusläns hällristningar (a group working in Tanum) suggest that working in tandem and confirming or disputing each other's interpretations helps achieve a more accurate result (Meijer and Dodd 2018, p. 291; Toreld and Andersson 2015, p. 15). A lot of digital methods have strived to remove the inherent bias that these methods introduce by recording the entire panel equally, though there are still problems, which will be discussed in later sections.

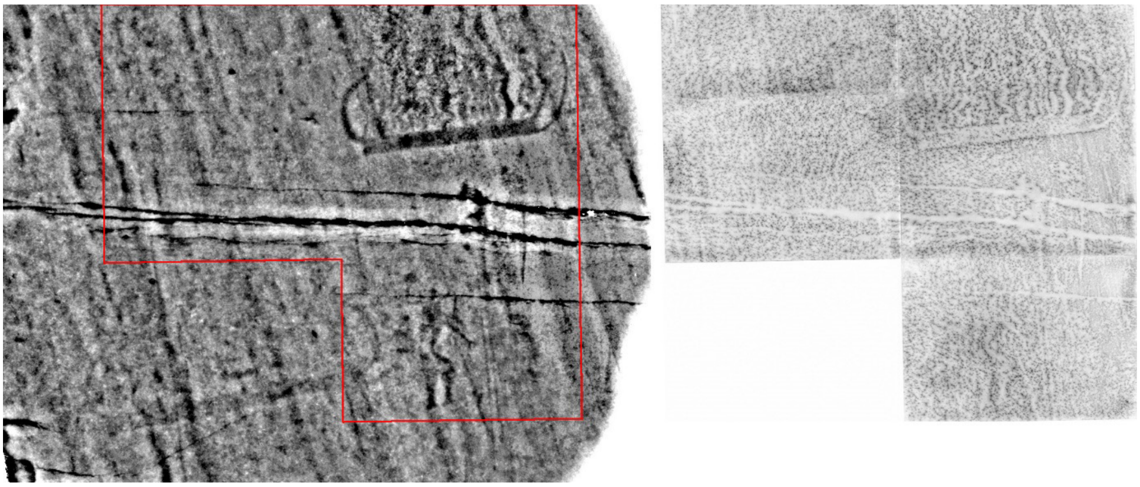


Figure 12: *An example of unintentional bias in traditional methods, where the rubbing misses the majority of the boat in the lower left quarter. Rubbing created by Tanums Hällristningsmuseum Underslös, SfM and visualisation created by Rich Potter.*

Some forms of documentation, i.e. photographs of chalk paintings, should not be considered accurate as they are interpretations. As such, they should be considered as illustrative rather than an accurate recording of what is actually on the surface (Milstreu 2020, p. 13).

3.8. Current uses

Nearly all of the material that was created using these methods is still of significant use to rock art researchers today, and in the case of rubbings, this is primarily one of the types of visualisations that we have found ourselves trying to recreate digitally (Horn et al. 2019; Horn and Potter 2019; Potter et al. 2022). In terms of practical use in a digital age, the tracings are extremely useful as they are essentially predefined outlines of carvings that are ready to be digitized and used in methods such as image detection with artificial intelligence (Horn et al. 2022b; Sanz 2014, pp. 6352–6353).

The traditional methods are very useful as they often produce correct 1:1 scale information of the original material (Sanz 2014, p. 6352). However, this can also be problematic with methods such as squeezes and tracing where the rock surface is not level, as there is a certain amount of manipulation and stretching of the material over the surface (Nordbladh 1981, G10-G11). A problem with the majority of these methods is that the result is a flat 2D representation of a 3D surface, which means that, as well as distortions in the 2D image, an entire dimension of information is lost (Bryan 2009, p. 2). Digital methods have helped to solve this issue by producing both 2.5D and 3D representations, as will be demonstrated in the following sections.

Figure 13: *Photo of the SHFA's scanner and tracings ready to be scanned.*

The easiest way to digitize traditional media is with a large format scanner i.e. A0. These are, however, very expensive to purchase, and difficult to maintain long term as they are often produced in small numbers by short lived companies.

The SHFA's digitalisation efforts of traditional media are not common practice amongst archives (Bertilsson 2007; Ling 2022), which means that the majority of researchers will need to travel to view the physical materials if they wish to use them (Barmpoutis et al. 2010, pp. 989–990). Another issue is the storage of the recordings produced by traditional methods, which can take up rather a lot of space, and that the materials themselves eventually degrade (Barmpoutis et al. 2010, pp. 989–990; Bertilsson 2007, p. 111; Scotland's Rock Art Project 2018c).

Chapter four: Digital recording techniques

This chapter introduces three digital recording strategies which are frequently used in the documentation of rock art: Reflectance Transformation Imaging (RTI), laser scanning, and Structure from Motion (SfM). In the following, each of the methods is introduced in terms of how it works, followed by a brief description of how it is applied to rock art, and then some of the positives and negatives of using the techniques are discussed. A brief overview of how it is beneficial to rock art studies is then given. Articles related to my work within each field are presented after the appropriate sections.

The systematic documentation of rock art in Scandinavia has been taking place for over 150 years, but in the past 20 years or so there has been an explosion in the use of digital methods to document this cultural heritage (Bertilsson 2015; Nordbladh 2015). While paper documentation is an excellent resource, it is not the easiest of mediums to work with -especially remotely. This has improved with the possibility of digitizing paper drawings, but there are still persistent issues with scaling, orientation, human bias, and the problematic nature of capturing a 3D surface with a 2D medium (Bertilsson et al. 2017; Horn et al. 2018; Monna et al. 2018, p. 117; Seidl 2016). While these issues are not entirely resolved by 3D methods, the raw data and the output of these digital recordings can be considered more accessible as it is relatively easily shared and can be processed independently to verify and test results (Kansa and Kansa 2014). The 3D models associated with digital methods can also be easily distributed and can be pre-processed with interpretations, or open to further testing, as will be discussed in chapter five

3D documentation further helps preserve the carvings as it prevents the further application of chalk paint used in traditional recording methods, which has been shown to cause damage (Bertilsson et al. 2021, p. 18). Additionally, it also creates a recording of depth, which would otherwise be lost if only traditional methods were used.

4.1 Reflectance Transformation Imaging (RTI)

RTI is a technique which effectively creates a 2.5D[3] representation of a surface based on a light moving around a fixed object. The output is an extremely detailed replication of the documented surface which is viewed in a software that allows you to change the angle of a light and thereby observe how the surface is affected (Mudge et al. 2010, p. 114). The effect is close to that of oblique lighting of rock art, as described in the previous section.

The software is based on Polynomial Texture Mapping (PTM), a method which was developed by Hewlett Packard Laboratories in 2001 (Malzbender et al. 2001) and adapted into Reflectance Transformation Imaging (RTI) in collaboration with the Cultural Heritage Imaging group in 2005 (Mudge et al. 2005; Mudge et al. 2006). The RTI methodology was initially created as an affordable black box[4] tool to democratise/ facilitate the process of museum staff recording material without the need for re-education or support from IT professionals (Mudge et al. 2008, p. 5; Mudge et al. 2010, p. 113).[5]

3. A 2.5D surface contains no specific 3D information, but is able to give the impression that it has 3D dimensions (Jaillet et al. 2017, p. 11). While 3D surfaces contain information pertaining to all three dimensions, 2.5D surfaces are technically only 2D surfaces which contain information about the the third dimension. For RTI the 2.5D surface is used to create shadows when a light is moved in the software to give the illusion of depth.
4. Black-boxes here refers to software where the user inputs data and obtains an output without understanding how the software processes the input data. For a full definition and overview of black and glass boxes, see Huggett 2021.
5. For a detailed overview of the processes see Mudge et al. 2012.

Figure 14*: An RTI output, shown in RTI Viewer. Note that the position of the light has been moved using the sphere in the top right-hand corner.*

4.1.1 The RTI process

Highlight RTI, a simpler form of RTI based on the position of highlights which is commonly used in heritage studies, is a relatively simple method to undertake. In essence the process revolves around a static camera with a moving light (Happa et al. 2010; Mudge et al. 2010, p. 120). The position of the moving light is captured via highlights on a reflective sphere which gives the software enough information to create a 2.5D surface (Mudge et al. 2005, pp. 29–30; 2008, p. 8). Various filters can then be applied to this surface, changing its appearance, and it is possible to change the angle of the light (Mudge et al. 2010, p. 126).[6]

Practically, this is achieved by placing a camera on a secured tripod with the lens facing the surface. A flash gun is moved around the surface in an umbrella shape maintaining as similar a distance from the surface as possible by using a stick and a string to orientate oneself. Remote shutter releases need to be used in order to ensure the camera does not move, and so that the flash goes off at the correct time (Cultural Heritage Imaging 2013b).

6. For a detailed overview of the filters see Palma et al. 2010.

Typically, around 60-70 images are taken per session (Díaz-Guardamino et al. 2015, p. 41), although depending on circumstances and space, this can be considerably more or less (Díaz-Guardamino and Wheatley 2013, p. 194). The photographs are processed using RTI builder, an open-source software from Cultural Heritage Imaging (Cultural Heritage Imaging 2011). During this process the sphere is recognised in the photos by the software, and subsequently highlights are obtained from the spheres. The software then compiles a polynomial texture map (PTM) which is exported and viewed in RTI Viewer (Cultural Heritage Imaging 2011).

Figure 15: *A typical RTI setup.*

RTI Viewer is also an open-source software provided by Cultural Heritage Imaging (Mudge et al. 2010, p. 124). The software itself allows the user to move the light across the surface and manipulate filters including specularity and a normal visualisation (Beale and Smith 2018, p. 174; Cultural Heritage Imaging 2013a; Jones et al. 2015, p. 1085; Mudge et al. 2010, p. 126). Users are also able to take snapshots, zoom in to the surfaces, and place bookmarks at specific points of interest (Díaz-Guardamino et al. 2015, p. 53). Additionally, it is possible to entirely remove the surface colour of

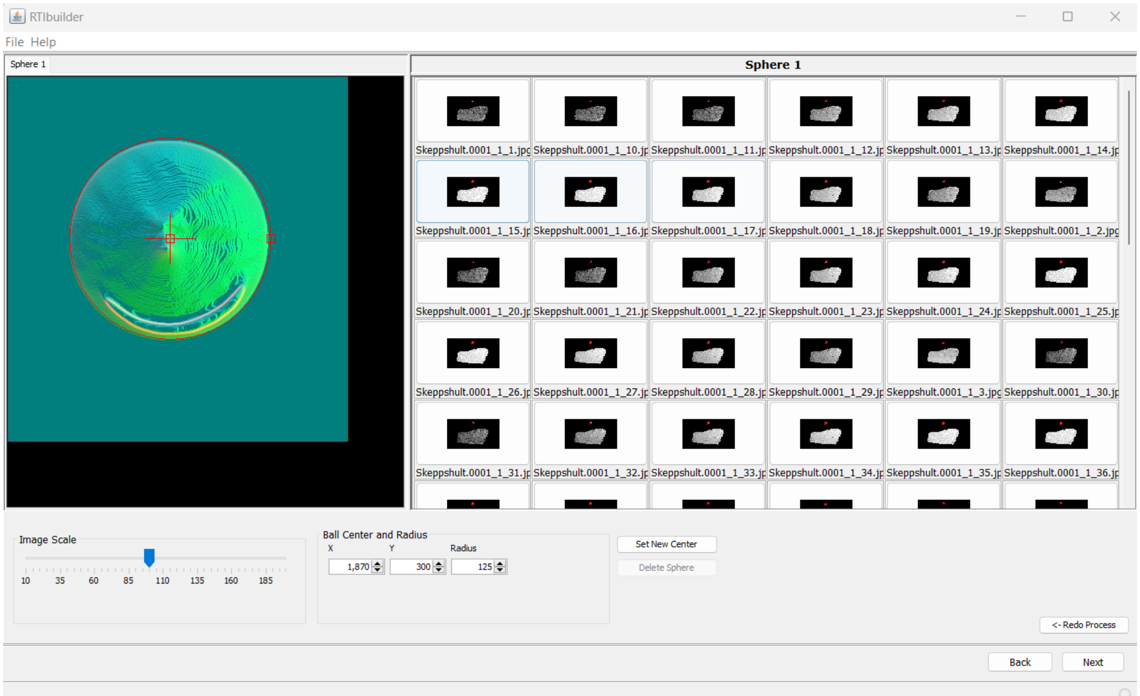


Figure 16: *RTI builder at the "detect sphere" stage.*

the object in order to view only the topography of the surface without the distraction of its colours (Hammer and Spocova 2013). RTI Viewer also allows users to push parameters past what would be physically possible using real world lighting and viewing scenarios by enhancing the surface characteristics, such as specularity, colouration, and gain intensity, i.e. increasing the perceived depth of the height variations (Desmond et al. 2021, p. 222; Mudge et al. 2010, p. 117).

An additional method of RTI is Virtual RTI (vRTI), in which a virtual "studio" is created in a 3D software (for example in Blender)[7], where lighting is moved in a pre-set way, and renders of a high resolution SfM model are created akin to how the photographs would be taken in the field (Green 2018, p. 3; Mudge et al. 2010, p. 118; Pires et al. 2015, p. 418). These renders are then processed in the same way as regular RTI photographs would be. The results, particularly for areas which would be very difficult to capture with the regular RTI methodology, are often very good, with perfect lighting.

7. https://www.blender.org/

Figure 17: *RTI with the colour removed and the specularity increased.*

RTI has been used in the documentation of portable objects, including coins (Mudge et al. 2005), paintings (Mudge et al. 2008; 2010), the Folkton drums (Jones et al. 2015), bones (Desmond et al. 2021), and immovable objects like rock art (Andreeff and Potter 2014; Bertilsson et al. 2017; Díaz-Guardamino et al. 2015, p. 42; Horn et al. 2018; Horn and Potter 2018; Mudge et al. 2006). RTI has even been used at both the microscopic scale (Earl et al. 2011), and at a macro scale to find and map new features at a landscape level (Goskar and Cripps 2011; Pires et al. 2015, p. 418).

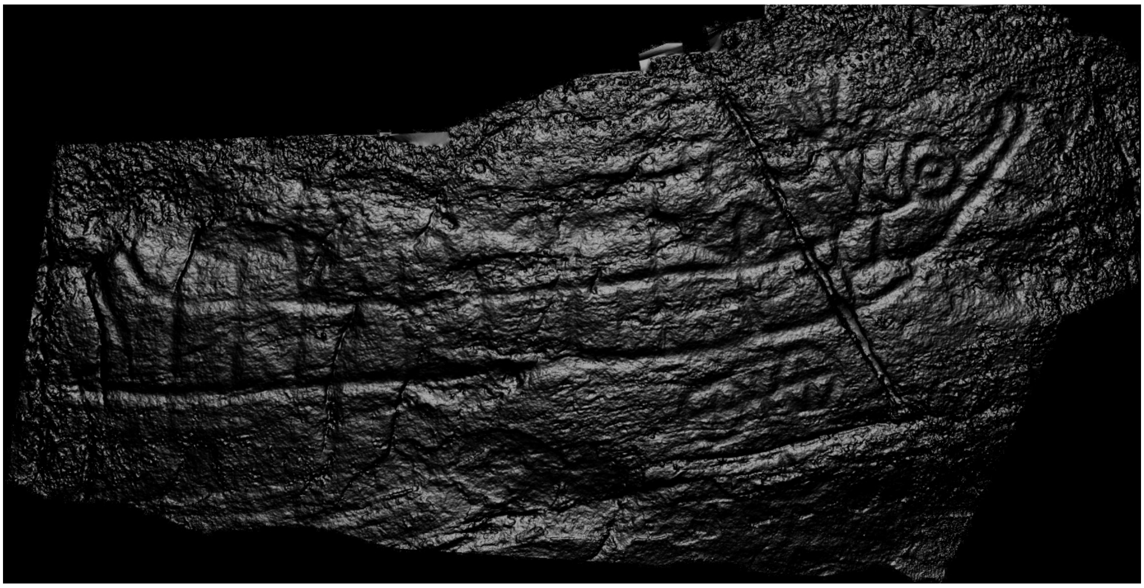


Figure 18: *The result of a vRTI calculation.*

RTI has regularly been used by researchers working with Iberian stelae, and has been developed and championed by Díaz-Guardamino as an effective tool for uncovering new details (Díaz-Guardamino et al. 2015, p. 53; Díaz-Guardamino 2023; Rivera Jiménez et al. 2021). It has also been used to demonstrate that some carvings on decorated objects in Ireland were erased and recreated several times (Jones and Díaz-Guardamino 2022, p. 396). Because of the detail offered by RTI, it has been used to successfully evaluate the chaîne opératoire of the production of carvings (Díaz-Guardamino et al. 2015, p. 46; 2019; Horn and Potter 2018).

4.1.2. RTI as a method

RTI is an excellent way of producing high detail visualisations of carved surfaces. RTI offers a very affordable option for documentation (Mudge et al. 2010, p. 114). Both RTI Viewer and RTI Builder are open-source and free to download and use, and most of the kit that is required is fairly standard for anyone working with rock art or cameras in general (Díaz-Guardamino et al. 2015, pp. 52–53). The spheres can be produced cheaply and easily by hot-gluing a bolt to a snooker ball. The more expensive elements of the set up are the lighting and the triggers, which depending on the size of the surface that is to be recorded, might become more expensive. However, for most scenarios a regular flash usually does the job unless working in direct and very bright light (which can be solved cheaply with a tarpaulin).

Figure 19: *Christian Horn attempting to create shade for an RTI documentation.*

Newer cameras and flashes have the possibility to connect wirelessly to each other and can be triggered by connecting to a mobile phone, reducing the need for expensive triggers. However, even triggers can now be picked up relatively cheaply.

RTI is a non-destructive method, particularly when recording vertical surfaces or objects as no elements are required to touch the surface (Desmond et al. 2021, p. 218). For horizontal surfaces, there is of course some contact with the tripod, but rubber feet on the tripod negate any issues this might cause. Naturally there are also concerns about walking on the surface, but this is an unavoidable necessity when recording any horizontal surface and will not be considered as a factor in any of the following.

The output of RTI Builder, .ptm files, are relatively small files, usually below 200mb, meaning that they can easily be distributed using free file sharing applications, or even via disk. The ability to add annotations to the .ptm files also adds an extra level to their dissemination (Díaz-Guardamino et al. 2015, p. 53). The free nature of the software and ease of use as well as extensive user guides available also mean that it is easy to disseminate finished files (Cultural Heritage Imaging 2013a).[8] It has also been shown to be an effective technique to teach students and community groups (Beale and Smith 2018).

That said, there are several variables that can create issues or even cause the method to fail completely. The most significant issue of these, particularly when working outdoors, is the need to control lighting (Andreeff and Potter 2014, p. 685; Horn and Potter 2018). As the rotating light needs to be visible on the sphere, it is important that the flash is stronger than the ambient light, as issues can arise if there are two highlights on the sphere. This can however be solved in the software, if necessary, by manually selecting the correct highlights for each sphere, assuming the flash has managed to produce adequate highlights and shadows on the surface.

Additionally, since the tripod must not move throughout the documentation process, inclement weather can be a problem: wind can and will move the tripod ever so slightly, often unnoticed (Díaz-Guardamino and Wheatley 2013, p. 189). In the field there are frequently moments when there is no option but to set the tripod up on non-ideal terrain, and it can easily be compressed or moved should there be an unseen root or stick underneath the surface (Rabinowitz et al. 2010).

Lighting issues because of the tripod legs can be a problem when starting out, but are easy to overcome with a little practice. Additionally, space around the tripod can cause problems, especially in cramped conditions (Bertilsson et al. 2017). Both of these issues are completely mitigated with the vRTI method, as the need for a tripod

8.E.g. GU's RTI tutorials: https://www.youtube.com/playlist?list=PLOKjUngLFMc1UFZ03XsVkrzH05p7fh7pb (accessed 20/07/23) is removed. This can also be solved by the use of an RTI dome (Desmond et al. 2021, p. 219; Earl et al. 2011).

One of the main potential issues with RTI is that there is a high risk of the software becoming obsolete. There are already several problems related to the last update of RTI Builder being in 2012 which causes compatibility issues with newer operating systems, including the installer being recognised as a malware, and being deleted unless anti-virus shields are disabled.

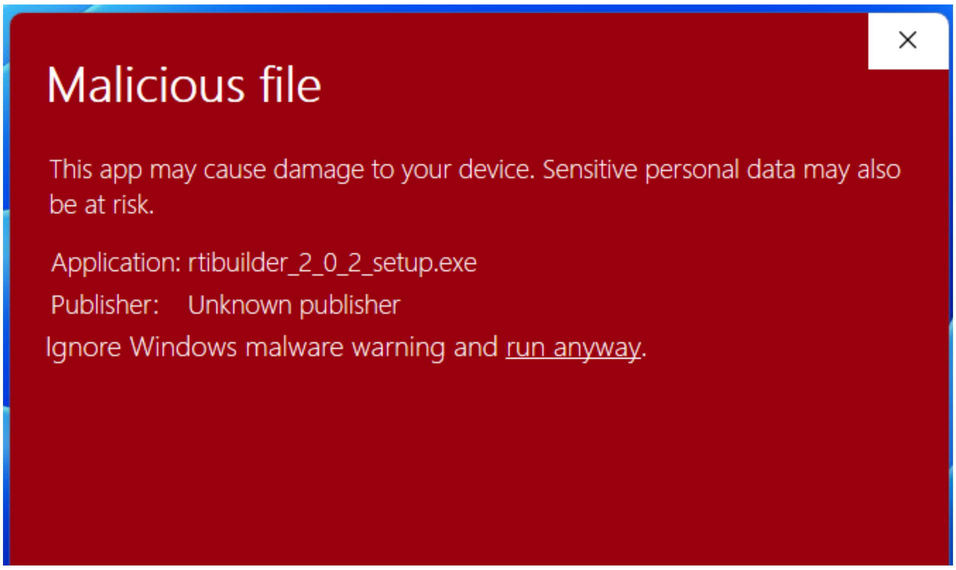


Figure 20: *RTI Builder being recognised as a virus by Windows Defender.*

Additionally, the PTM fitter plugin, essential to the process of creating an RTI, is no longer supported or hosted by Hewlett Packard. This means that the only real way to get the plugin is to download it through the Dropbox folder of Carla Schroer,[9] one of the creators of the software, as they are not licensed to host or publish it directly on their website or with the software. This is unfortunately not sustainable in the long term and will potentially lead to the software becoming obsolete. While the software is open-source and could technically be taken over by anyone, there is a distinct aura of ownership around the software (largely based on respect) which seems to

9. PTM Fitter download FAQ – CHI forum page. https://forums.culturalheritageimaging.org/topic/615-ptmfitter-software-download-link/ (accessed 20/07/23).

be preventing others from taking over. It is not clear what would happen should the current CHI RTI software become obsolete, but it is likely that someone else would eventually produce something comparable. It is also possible that with the increase in real time lighting solutions in software like Unreal Engine,[10] a new similar visualisation method will be created. It is unlikely that it will be as open source, useful, accessible, or feature the same tool set and support of the current RTI suite, however.

RTI has been beneficial to rock art documentation due to the fact that it produces a highly detailed interactive documentation of a surface (Desmond et al. 2021, pp. 217–218), upon which there is the possibility to remove textures (Hammer and Spocova 2013), while also being able to apply various filters and enhancements (Palma et al. 2010). The files that are produced are able to be annotated, and are small enough that they are easy to disseminate (Desmond et al. 2021, p. 218; Díaz-Guardamino and Wheatley 2013, p. 200). The results, which can be viewed in open-source software, are generally highly recognizable and understandable.

10. https://www.unrealengine.com/en-US (Accessed 30/11/23)

4.1.3. Related articles

The following presents three articles that are related to my work with RTI. The first documents the recording and analysis of picture stones on Gotland, a Swedish island off the east coast, the second covers the documentation of the Kivik tomb using various techniques including RTI, and the third covers the documentation and analysis of a rock art motif in Finntorp, Sweden, where RTI was successfully used to determine the order of carving. Each article is introduced with a brief overview, along with a description of how I contributed to them. For a more detailed breakdown of my contribution, see figure 1.

Article one: Imaging picture stones: Comparative studies of rendering techniques

Andreeff, Alexander; **Potter, Rich** (2014): Imaging picture stones: Comparative studies of rendering techniques. In Henrik Alexandersson, Alexander Andreeff, Annika Bünz (Eds.): *Med hjärta och hjärna. En vänbok till professor Elisabeth Arwill-Nordbladh*. Gothenburg: Gothenburg Archaeological Studies (GOTARC Series A, 5), pp. 669–689.

My contribution to this article was primarily the recording of the standing stones using RTI, processing, and analysing of the output. I also wrote elements of the article **(overall contribution 25%)**

This article evaluates the recording and visualisation of several Iron Age standing stones on Gotland, an island off Sweden's eastern coast, using traditional and digital methods. The article presents three picture stones from the late 8th to 9th century CE, on which an RTI documentation was undertaken. I had introduced RTI to the Department of Historical Studies, at the University of Gothenburg prior to being invited to Gotland. The RTI was undertaken in tandem with frottage (rubbings) of the stones so that a comparison could be made. The RTI produced results of human made carved lines on all three of the picture stones, though on the latter two it was not possible to discern understandable motifs as they were unfortunately too eroded to be coherent. The work demonstrated that RTI was a valuable method and allowed the stones to be reinterpreted based on previously undocumented carvings on the "blind" picture stones (i.e. stones where there was too much erosion on the surface to be able to see carvings with the naked eye).

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Imaging picture stones: Comparative studies of rendering techniques

Alexander Andreeff & Rich Potter

The results from different rendering techniques will be shown in this article and briefly discussed with regard to investigations of the pictorial surface on three picture stones from Gotland, Sweden. The island is the largest in the Baltic Sea and is well-known for its very rich and outstanding archaeological material, especially from the Viking Age and Early Medieval period. The picture stones that are the case studies for this article originate from three different sites on Gotland: Fröjel Bottarve, Fröjel Stenstugu and Buttle Änge. All of these sites are located in rural areas with rich agricultural lands and an abundance of ancient remains that speak of habitation and land use since at least the Bronze Age to present day. Fröjel Stenstugu and Buttle Änge are still standing at their original sites while Fröjel Bottarve was found re-used in a grave.

This study is a part of Alexander Andreeff's PhD-project about the Late Iron Age Gotlandic picture stones. The article is part of a work in progress and only preliminary results are presented here; a more comprehensive presentation and discussion will be available in forthcoming publications. Rich Potter was responsible for executing the RTI- and photographic analyses. The RTI renderings were made during a field study in May 2013.

About 570 picture stones of all types have been found on Gotland (Widerström 2012: 36). These Iron Age carved stones are mostly found re-used and inserted into the floors and walls of medieval stone churches on the island. The stone churches were built between the mid-12th until the mid-14th century incorporating stones from ancient remains in the vicinity as a building material; the picture stones were often placed with the pictorial side outwards, probably to be viewed. Whether or not this had a symbolic significance has been a topic in the scholarly discussion (Johansen 1997). Picture stones can also be found reused in pre-Christian inhumation graves that are mostly

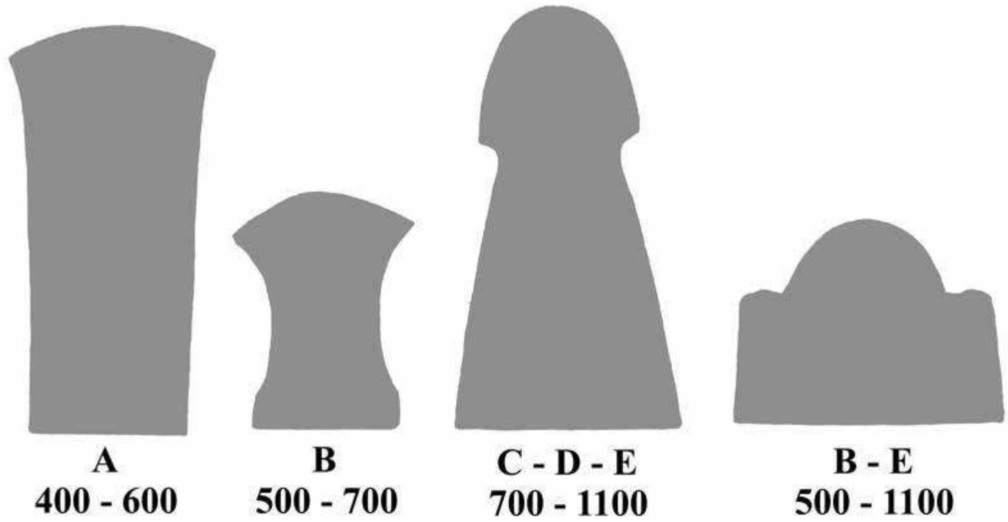


Fig. 1. *Typology of the picture stone according to Lindqvist, modified by Nylén and Lamm. After Nylén & Lamm 2003: 172.*

from the 10th and early 11th century (Måhl 1990; Burström 1996; Rundkvist 2012), however only about 15 picture stones are still found in the landscape at the site that they were originally erected. Picture stones as runestones are located in the landscape near pre-historic roads, cross-roads and fords, often at borders between farms and older districts (Andrén 1989, 1993; Måhl 1990; Nylén & Lamm 2003; Andreeff 2012).

The picture stones are usually divided into five distinct types regarding typology and chronology (Fig. 1). This typology was created by Sune Lindqvist, the most prominent scholar within picture stone studies in the mid-20th century (Lindqvist 1941, 1942). The earliest type A is dated to the Late Roman Iron Age and Early Migration period, the type B to the Late Migration period and Vendel period, the type C to the Late Vendel period and the Early Viking Age, the type D to the Viking Age. The latest type E is dated to the Late Viking Age and Early Medieval period (Lindqvist 1941, 1942; Andrén 1989, 1993; Nylén & Lamm 2003; Herlin Karnell (Ed.) 2012; Varenius 2012; Andreeff, forthcoming).

Erik Nylén and Jan Peder Lamm divide the picture stones into four types according to shape, as seen in Fig. 1, which is a slight modification of Lindqvist's typology. Early period picture stones equate to type A, Middle period become type B, Late period type C/D/E, and lastly cist stones which are classified as a separate group (Nylén & Lamm 2003; Varenius 2012). What it is that the different shapes represent has been an ongoing discussion within picture stone research: axe, door, world tree, animal hide and phallus are among the suggestions (Arrhenius 1970; Andrén 1989, 1993, 2014).

The three picture stones presented here are all of type C, dated to late 8th and 9th century on typological and contextual grounds. A consensus regarding the exact time frame for the different picture stone types has not been reached by scholars. The type C picture stones have a phallic or keyhole shape with the pictorial side showing a rather schematic set of figures and scenes divided into horizontal picture panels; they are always only carved on one side. They regularly repeat the same kind of motifs from top to bottom, rider and horse, women with a drinking horn, procession of warriors and sailing ship. In type D these motifs are also common but not in the same fixed order as is the case with type C. It is characteristic of type D that the scenes are blurred and interlinked with each other, often making it hard to distinguish one scene from another. These two later types have attracted the most interest from scholars and are the richest in iconography. When these monuments are found at the original site they stand alone or in groups in the landscape.

Methodology

Studies with different photographic and alternative documenting techniques and re-examinations of earlier rendered motifs of picture stones and runestones on Gotland have recently been completed by Laila Kitzler Åhfeldt (2002, 2009a, 2009b, 2010, 2012) and Sigmund Oehrl (2009, 2010, 2011, 2012). Kitzler Åhfeldt has scanned the carved image surfaces of over 68 picture stones with a portable optical 3D-scanner (Kitzler Åhfeldt 2012). Her results are made public through the Swedish National Heritage Board website (www.raa.se). Kitzler Åhfeldt's studies focus on cutting techniques and the potential use of templates in order to determine if it is possible to identify individual stone carvers or workshops (Kitzler Åhfeldt 2012). Oehrl is more interested in re-interpreting the figural motifs with comparative studies with textual sources and analogies with similar imagery from continental Europe (Oehrl 2012).

The two main methods used in this study were frottage and RTI. Regular photography with the help of raking lights was also used in one case. The aim was to compare the various rending techniques to determine whether they would give different results.

The frottage or rubbing method involves placing a piece of paper on the carved surface, and then rubbing the paper with a piece of graphite. Carvings, lines and other depressions emerge by way of light patches on a dark background, or the opposite if the figures are made in high relief. This low-technology method has been used on rock art, runestones and picture stones in Sweden since at least the 19th century. It is still used in initial investigations, but needs to be complemented with photographic methods to give reliable results.

RTI is a method that involves a static camera and a moving light source in order to digitally create a normal map – a colour coded image that can be used to digitally simulate the surface of the picture stones. It is essentially a more modern variant of the raking light technique which produces an interactive picture in which the light can be moved dynamically on a computer.

The technique is fairly simple involving a black ball, tripods, a flash, a camera and various remote triggers (while there is no scope in this article to provide an in depth description of the technique, more information can be found at http://culturalheritageimaging.org/Technologies/RTI).

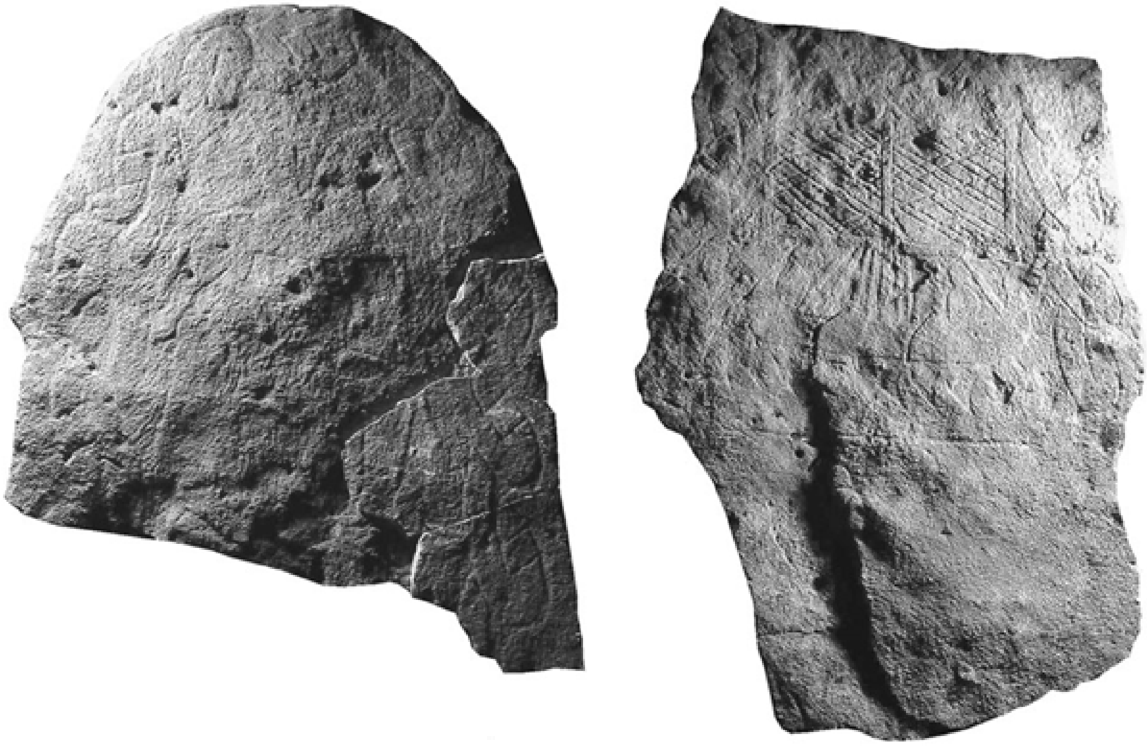


Fig. 2. *Fröjel Bottarve. Photos not according to scale in relation to each other. Photo: Helena Andreeff & Alexander Andreeff.*

Fröjel Bottarve

The picture stone from Fröjel Bottarve was found in two parts inserted into an inhumation grave on the northern cemetery at the Late Iron Age and Early Medieval trading place and harbour in Fröjel parish during archaeological investigations in 1999. Dan Carlsson conducted extensive archaeological excavations at the site mainly in the late 90s and early 00s. The investigations have unearthed remains from a seasonal settlement with workshops and two cemeteries from the Late Iron Age. In earlier excavations closer to Fröjel Church, Carlsson found an Early Medieval Christian cemetery and the remains of a stone house foundation, possibly a late 12th or 13th century vicarage. Fröjel parish is situated about 40 km south of the town of Visby on the west coast on Gotland. The site was one of the more important ports of trade along the Gotlandic shore during the 10th and 11th century (Carlsson 1999a, 1999b, 2004; Ahlquist, Olsson & Andreeff 2002).

The grave was not visible above ground prior to excavation and was constructed as a pit burial in which the individual had been laid down at the bottom and covered by a stone pavement. The larger lower part (62.5 x 90 cm) of the picture stone was placed at the feet of the male skeleton and the upper part (52.5 x 55.2 cm) at the head end in the grave. The lower part had fallen into the burial over the man's lower limbs, but the headstone was still relatively vertical close to the cranium. The pictorial side of both parts of the stone were facing the skeleton. The grave did not contain any grave goods, but the surrounding burials at this cemetery were mainly dated to the 10th century; this grave probably also originates from this century in the Late Iron Age. Because the stones were protected from weathering in the grave for over a thousand years, their images could be seen with the naked eye. The total length of the picture stone is 145.2 cm when the parts are put together (Dahlström & Eriksson 2000; Andreeff 2001; Carlsson 2004; Norderäng & Widerström 2004).

The picture stone is currently displayed in the parish community house next to Fröjel Church. In 2001 Helena Andreeff and Alexander Andreeff examined the two pieces. The stone was so sharply divided before it was inserted in the grave that it could be perfectly pieced together for the renderings. The stone was first photographed with the help of raking lights (Fig. 2), and then a frottage was made of the pictorial side. The frottage of the stone gave excellent results due to the good preservation of the imagery (Fig. 3).

The RTI presented here was taken from the lower part of the picture stone which displays a ship with a rig and a sail, waves and crew members (Fig. 4). The weather vane at the top of the mast is also visible. In the RTI taken at the top of the stone there are also various carved figures including what appears to be a rider on a horse, a figure holding a drinking horn, a bearded figure and a long necked wading bird.

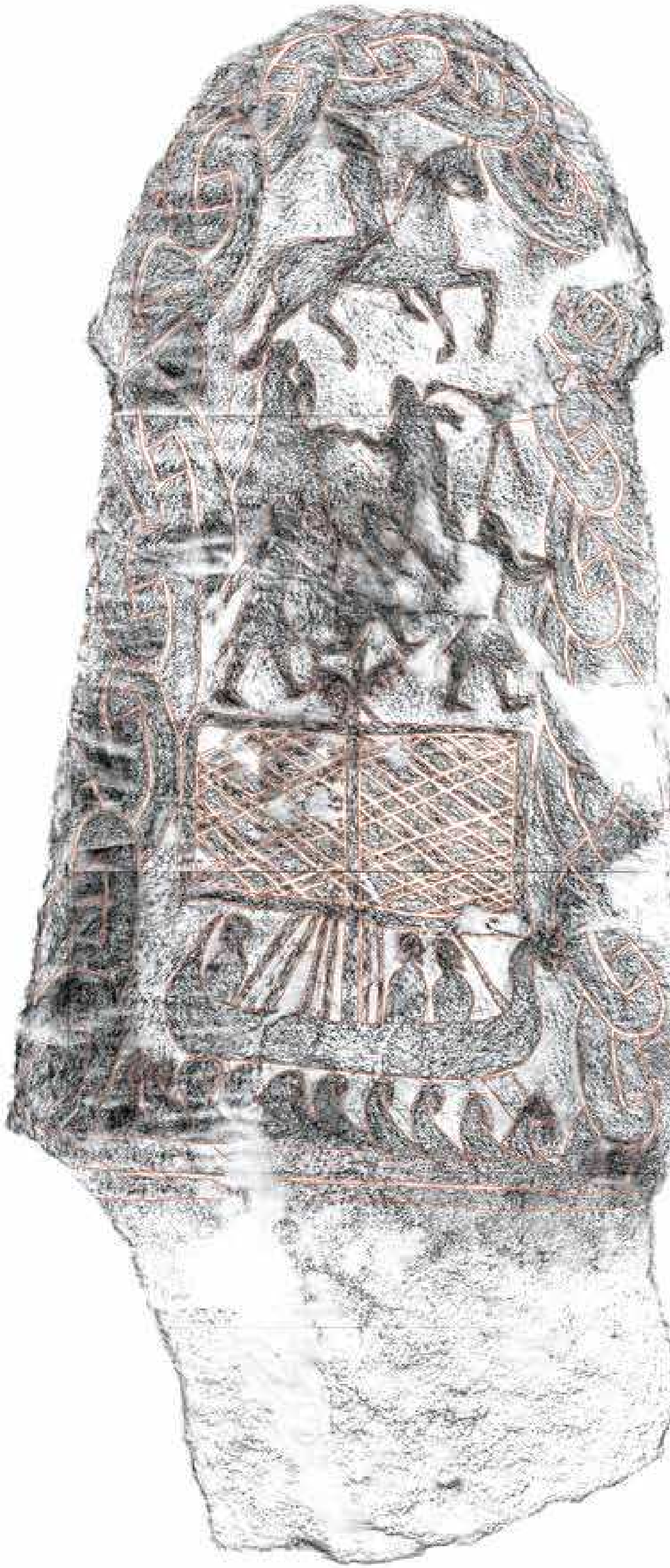


Fig. 3. *Fröjel Bottarve. Frottage: Helena Andreeff & Alexander Andreeff.*

Fig. 4. *Fröjel Bottarve. Lower part with ship with sail. RTI: Rich Potter.*

RTI samples were taken over the whole of the carved stone. The carved lines were very evident in all of the RTIs taken, but since they were mostly visible to the naked eye this was not entirely surprising. The results were also particularly good due to the dark conditions they were taken in.

Due to the excellent preservation state of the picture stone, all three methods gave great results. On the lower half of the stone a ship, a rig and chequered sail can be seen. On top of the mast there is a wind vane or a bird, and there are rolling waves under the ship's keel. On board the ship are three human figures, a steersman at the stern and two bearded figures at the prow which has an elaborated dragon's head. In the partly damaged midsection, due the breaking of the stone prior to its insertion into the grave, three human bearded figures carrying different objects (weapons?) can be seen walking in procession. Above these figures a human figure in a long dress holding a drinking horn is facing a bearded figure who is followed by a wading bird. A bearded rider on a horse is seen at the top of the stone. The motifs are enclosed by an intricate braided edge ornamentation.

Fröjel Stenstugu

Fröjel Stenstugu is also situated in Fröjel parish, but in the inland bordering Klinte parish towards the north. The picture stone is still standing at what is presumably its original site on the farm Stenstugu (Fig. 5). It is located adjacent to a pre-historic road, which is still used by farmers, near the present parish border. The picture stone is 1.97 m above ground and 1.06 m wide at its base. It is badly weathered and no carved images can be discerned. Due to its specific shape the picture stone can be classified as a Late Iron Age type. The illustrator of antiquities C.G.G. Hilfeling described, measured and sketched the picture stone as early as in 1799 on one of his trips to Gotland (Hilfeling 1799). The stone is also mentioned and documented by Lindqvist. On his photographs it can be seen that the landscape was much more open in the 1940s than today (Lindqvist 1942: 42, 44). The area is currently comprised of forest and pastures.

Prior to the excavation, the picture stone was at a 30 degree backward slant in relation to the former road which runs directly north of the picture stone. This road is marked on the 18th century map, and runs between Klinte and Fröjel parish church on a ridge, the Litorina Bank - a shingle beach ridge formed during a developmental stage of the Baltic Sea.

Today the boundary between Fröjel and Klinte parishes is situated not far from the picture stone. Its location near the later parish boundary may reflect a former border between the areas that existed when the picture stone was erected. The area in the vicinity of the picture stones is very interesting with plenty of pre-historic remains such as a hill fort, stone house foundations, Celtic fields, grave mounds and cairns.

Greta Arwidsson, the principal antiquarian at the time with the responsibility of the ancient remains and monuments on Gotland, sent a letter to the National Heritage Board in 1947 asking them to contact the County Board of Administration to establish a fine, and also urging the local police authorities to carry out an investigation. The matter at hand was that the picture stone Fröjel Stenstugu had been damaged by graffiti. Arwidson states in her letter that she had been examining the stone and had reported that she could see both older and newer graffiti. Among the older graffiti were the glyphs 1928, HP, R and AM (in two places), the graffiti that she interpreted as newer was Arnold, Holger, Elis, Lubbe Olsson, TL (on two places), AV or AK and the number 10/12 1942 (Gotlands Fornsal, Dnr. 150/47). In the following police investigation it was revealed that it was local farmers and farm labourers who had defaced the stone but that they had no knowledge that the stone was an ancient monument protected by law. The local police stated that the period of prosecution had expired for the alleged crime, and that the inscriptions were very shallow anyway, only about 0.5 mm, and could therefore easily be removed. The police then deemed the damage as slight and closed the case (Gotland Fornsal, Dnr. 143/48: Avskrift 1605/48). Traces of these letters and numbers cannot plainly be seen today, except maybe AV in the upper left corner of the picture stone.

The excavation of the picture stone site was conducted by Andreeff in July 2007 with the help of archaeologists and students from the University of Gothenburg and former Gotland University (Fig. 6). The immediate area at the base of the picture stone and a narrow cross section of the

Fig. 6. *Excavation. Fröjel Stenstugu. Photo: Alexander Andreeff.*

former road were excavated, about 27 m^2 in all. Following the field work, the picture stone was straightened up to minimize the risk of further weathering of the surface (Andreeff 2012: 131-133; Andreeff & Bakunic Fridén 2014).

A low oval-shaped earth filled stone pavement, about 3 m in diameter and 15 cm deep closest to the picture stone was discerned when the turf was removed. Cremated highly fragmented bones were found scattered in the stone fill, concentrated in a semicircle in front of the picture stone. Artefacts of iron and bronze, 16 fire damaged glass beads and a fragment of a silver bracelet were also found. The iron objects comprised of nails, rivets and an arrowhead. Bronze objects included various mounts, a belt buckle, a strap end mount and a button-shaped mount with animal art ornaments. These bronze objects may have been attached to leather straps. A spindle whorl of red quartz was also among the finds. These finds are probably the remains of a cremation that was placed here as a deposition at the picture stone. The artefacts can be dated through typology to the Late Vendel period or Early Viking Age (Andreeff 2012: 132-137; Andreeff & Bakunic Fridén 2014).

Fig. 5. (image to the left) *Fröjel Stenstugu. Photo: Alexander Andreeff.*

A total of 846.9 g of cremated skeletal material was unearthed at the excavation. The bones are overall very fragmented and the colouring and state suggest high temperatures. They were found scattered in a semicircle mostly around the pictorial side of the stone with a concentration towards the front. The bone material was analysed by osteologist Emelie Franzén (2013) who classified at least one individual of the following animals: domestic pig, dog, cattle and seal. Unburnt teeth fragments were preserved from the pig, the cattle bones were partly burnt, but the dog and the seal bones were cremated at high temperatures. The dog was identified through teeth and a mandible and the seal through metacarpals and metatarsals. The very fragmented human bones consisted of parts of the cranium and limbs belonging to at least one individual, the fragmented skull bones had adult characteristics. It was not possible to sex the material due to its fragmented state (Franzén 2013). Two ^{14}C analyses of cremated bones were carried out by Radiocarbon Dating Laboratory, Lund University. The samples cover a time span from the 8th until the 9th century (Andreeff 2012: 134; Andreeff & Bakunic Fridén 2014).

Helena Andreeff and Alexander Andreeff created a frottage on site at Fröjel Stenstugu in 2012 (Fig. 7). Some carved lines could be detected, but the overall results were inconclusive.

The results of the RTI showed carved/cut lines that could clearly be detected, though they were difficult to interpret and merge into understandable motifs as the lines often did not connect or were not diagnostic (Fig. 8). In the upper left corner there are cut lines that look like letters and/or numbers, it is not clear but it is thought that these may represent the modern graffiti mentioned above. In the centre there is a house like feature which may have two human figures inside. There is potentially a small boat to the left of the house shown by what could well be the prow of a ship. Down to the left there are potentially figures in a procession with helmets. The lower part of the picture stone is less cognitive. There appear to be some wave formations or at least hatching over a larger part of the stone which may well be indicative of a ship or a sail. Lines and patterns around the outside of the picture stone demonstrate that there was almost certainly a decorative edging round the picture stone.

Fig. 7. *Helena Andreeff securing the sheet of paper for the frottage on the picture stone Fröjel Stenstugu. Photo: Alexander Andreeff.*

Fig 8. *RTI interpretations from the top and bottom half of the Fröjel Stenstugu. The top was created with a regular flash, the lower with a halogen lamp. RTI: Rich Potter.*

The applied methods of the picture stone from Fröjel Stenstugu gave very different results. In this case the frottage gave no certain information, but human made carved lines could be distinguished with RTI. Further analyses of the RTI photographs must be done to distinguish which inscriptions are traces of early 20th century graffiti and which motifs may stem from the Late Iron Age.

Buttle Änge

Two picture stones of the Late Iron Age type stand in their original location next to the farm Änge in Buttle parish: Buttle Änge I and II (Fig. 9). A pre-historic road runs adjacent to the picture stones, with the preserved section of the road embankment being about 200 m long and 3-3.5 m wide. The carved surfaces on the picture stones face north towards the road, which was once the main communication route through the parish from the south. In the surrounding area there are many pre-historic remains, including several Early Iron Age house foundations, Celtic fields and cemeteries.

The larger picture stone is 1.85 m wide at the foot and rises 3.85 m above the ground surface making it Gotland's tallest picture stone of the later type. The north side has a distinct and very well preserved image surface with numerous interesting motifs and figures including a ship with a sail at the bottom. The adjacent picture stone is 2 m tall and 1.67 m wide at the foot, though it may have been taller, since the top is damaged and it has signs of breaking.

Fredrik Nordin investigated many picture stone sites in the late 19th and early 20th century on Gotland. His results were first published by Lindqvist in the volumes *Gotlands Bildsteine* I och II (1941, 1942). Nordin opened a trench at the foundation of two stones at Buttle Änge, where he found charcoal, animal bones and pottery (Lindqvist 1942: 38; Måhl 1990: 23). Behind these two stones he found five smaller picture stones, four of which, according to Lindqvist's interpretation, formed a smaller stone cist (Lindqvist 1941: Taf. 49, Fig. 120-124; 1942: 38-39). This stone cist has now been reconstructed and is on display in the picture stone hall at Gotland Museum.

Re-investigation of the site was initiated by Andreeff in 2009 as a part of his PhD-project. Continued excavations were conducted in 2013 and 2014 as a regular university field course in archaeology for Uppsala University. The excavation season in 2015 is also planned to take place at the site. The first two years of Andreeff's excavations focused on the area around the two picture stones. The aim of the re-investigation was to try and find undisturbed cultural layers similar to those Fredrik Nordin reported from Buttle Änge, which bear witness to ritual activities- and other practices in relation to picture stones. If further finds and undisturbed layers are unearthed, it will contribute to an increased chronological and contextual understanding of the relationship between the picture stones and other archaeological materials and features at this site, while offering a comparison with other picture stone sites such as Fröjel Stenstugu.

In 2009, part of a Medieval or Early Modern house foundation with two stone clad post holes was excavated directly north of the picture stones. One of postholes was constructed partly of lime stone slabs consisting of re-used fragments of extremely weathered picture stones. Frottage of these stones gave promising results,

Fig. 9. *Buttle Änge picture stone site. Photo: Alexander Andreeff.*

but these results need to be confirmed with other rendering methods. On the east side about 1.5 m from Buttle Änge II a large lime stone slab was found that may have been the top part which had been broken off. A cross section of the road was also investigated (Andreeff 2012; Andreeff, Melander & Bakunic Fridén 2014).

In 2013 two main trenches were opened, the first south of the standing pictures stones and the second through a supposed clearance cairn about 20 m west of the monuments. The trench at the picture stone was aligned with Nordin's trench, excavated in 1911, and the excavation trench from 2009. This trench was later extended in several directions. The same kind of thick black ceramics Nordin had reported at the foundation of the picture stones were found in the part of the trench closest to the standing picture stone (Lindqvist 1942: 38; Måhl 1990: 23). About two metres south behind the larger picture stone a 15 cm deep pit with dark thick soil, charcoal, cremated bones and a few metal artefacts, including part of a javelin from the Late Vendel period or of Early Viking Age type. In the same area, but

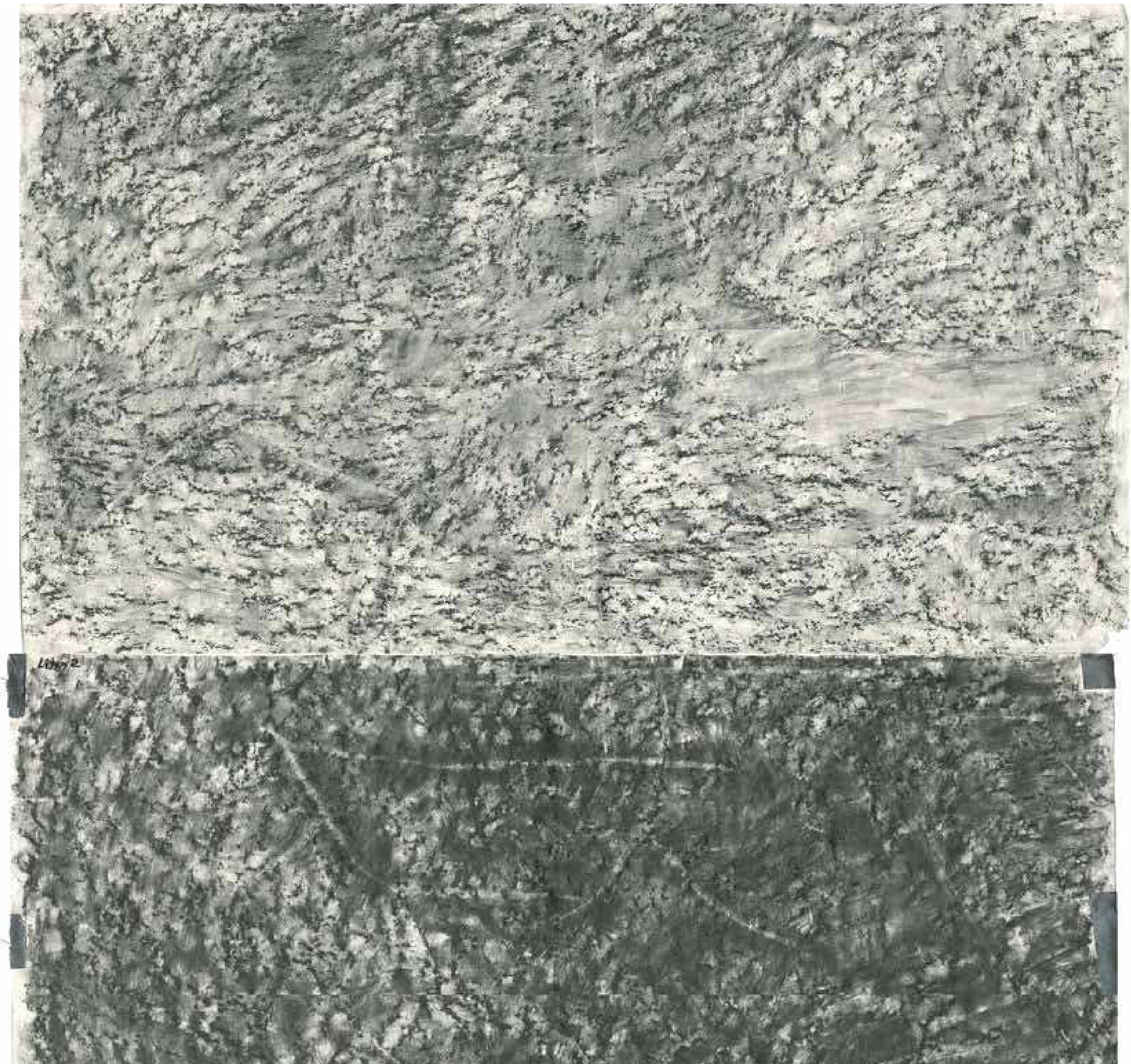
Fig. 10. *Buttle Änge picture stone site with reconstructed stone setting. Photo: Alexander Andreeff.*

outside this deposition, finds of bronze and glass beads were also made. Some of this material may originate from disturbed or destroyed cremation burials. This material is probably part of the remains from cremations similar to those known from Fröjel Stenstugu (Andreeff 2012; Andreeff & Bakunic Fridén 2014) and Nordin's excavations of picture stone sites (Lindqvist 1941, 1942).

The other trench was placed through a feature registered as a clearance cairn that consists of an oval shaped low mound of earth and gravel on which stones have been thrown throughout centuries of agricultural work. Only a few larger stones, that were revealed to be part of a circular shaped stone setting, were seen prior to our excavation. The dumped stones were removed and the stone setting was uncovered and fully investigated. Along the south end of the stone circle, cremated bones, glass beads, comb fragments, iron rivets and bronze objects were unearthed, mostly directly outside, but also under the stones. Among the recovered bronze objects were a pair of tweezers, several mounts and fragments of pendants. The most remarkable find was a lunula pendant of silver-copper alloy. Analysis of the findings shows that the grave artefacts are from two different burials or depositions, with part of the material belonging to a "female" burial in the 9th century, and the rest from a "male" burial that was probably from the later part of the 10th century. The sexing of the material is formed through traditional gendered divisions of the artefacts; the osteological material is yet to be analysed (Andreeff, Melander & Bakunic Fridén 2014). The stone setting was reconstructed after excavation (Fig. 10). The relation between the picture stones and the stone circle, depositions and burials will be further discussed in future publications.

Fig.11. *On the ladder making frottage in front of Buttle Änge I, Michael Markström to the left and Alexander Andreeff to the right. Buttle Änge II in the background with the half completed frottage attached seen on Fig. 12. Photo: Helena Andreeff.*

Frottage were made of parts of both Buttle Änge I and II as a workshop for students in 2013 (Fig. 11). Buttle Änge I is very well preserved and Lindqvist has created a very good rendering of this stone (Lindqvist 1941: Taf. 50, 1942: 37; Herlin Karnell (Ed.) 2012: 45). Anton Snell Redon made the frottage of the upper central part of Buttle Änge II (Fig. 12) - the relatively smaller standing picture stone at the site, but in all other circumstances should be counted among the larger picture stones with a height of 2 m; as previously stated, the top part was been damaged and may have been broken off. On Buttle Änge II no carvings have hitherto been recorded. Lindqvist reported the stone as "blind",



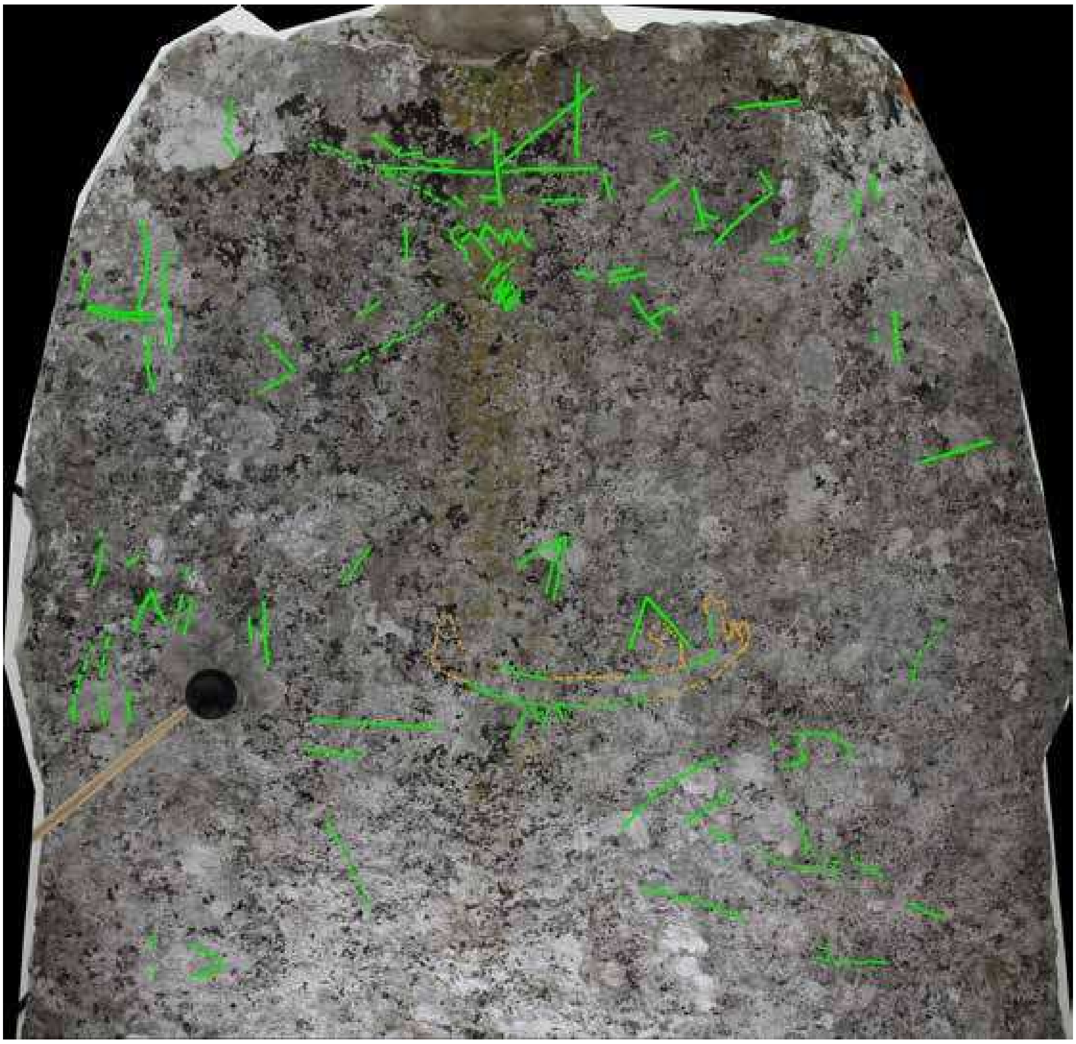


Fig. 13. *Buttle Änge II, upper half. RTI: Rich Potter.*

but with an ocular examination of Buttle Änge II and through the frottage, rather deep straight carved lines can be seen in the upper part that probably represented a sail (Fig. 12). The curved lines at the border up to the right may be the remains of the edge ornamentation.

The extremely sunny weather conditions and the placement of the stone made obtaining a good RTI image relatively hard. A tent was used as covering in order to create some shadow, but it was relatively ineffective. The marginally translucent nature of some elements within the stones caused some issues with the light being reflected back from both the sunlight and the flash.

The RTI of the upper half of Buttle Änge II shows what appears to be a small ship with at least one

Fig. 12. (Image to the left) *Buttle Änge II, central upper half. Frottage: Anton Snell Redon and Michael Markström.*

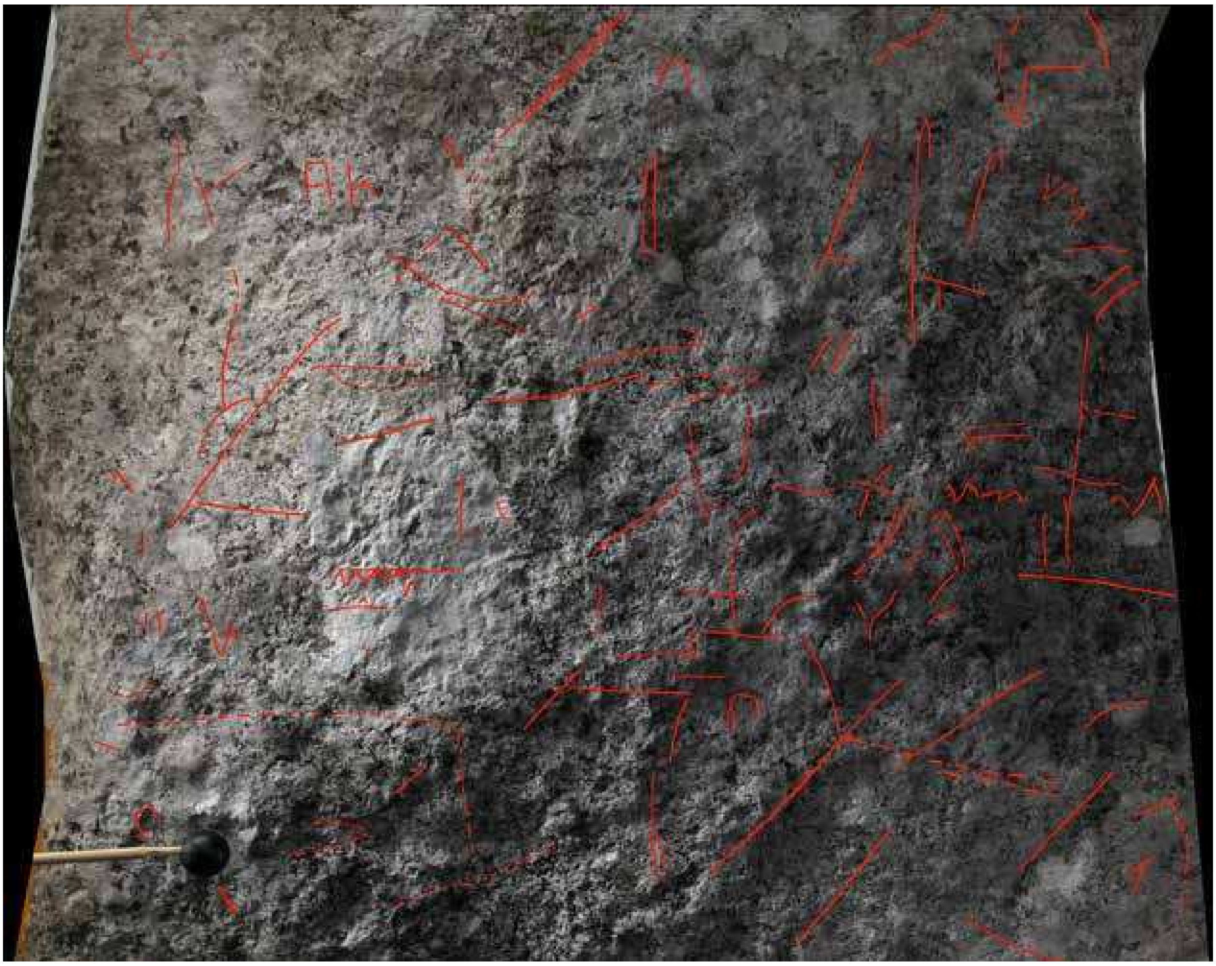


Fig. 14. *Buttle Änge II, lower half. RTI: Rich Potter.*

potential crew member, there also appears to be a larger second ship at the top of the stone given the size of what appears to be a mast and a sail (Fig 14). Although most of the lines are not diagnostic, it is clear that this stone was carved, but only a limited amount of material is currently detectable. It is evident that there was also a decorative edging on the border of the stone. The RTI of the lower half of Buttle Änge II shows a lot of carving activity, but none of which is particularly diagnostic (Fig. 14). It is possible that there are some sort of waves, or at least a hatched pattern, there also appears to be some continuation of the edging round the border of the stone.

The methods applied to the picture stone from Buttle Änge gave fairly similar results as those from Fröjel Stenstugu. In this case the frottage showed distinct human made carved lines that could also be distinguished with RTI. Further analyses of the RTI photographs must be done in order to distinguish further patterns. It may also be beneficial to return on a less bright day to retake samples.

Conclusion

So called blind picture stones have their own category in Lindqvist 1941, 1942. They are stones that are either weathered to the point that all traces of carvings are gone, or they were never carved. It has been suggested that they might instead have been painted (Nylén & Lamm 2003: 16-17). It is doubtful that this category is valid in its own right as when re-examined many of these reported "blind" picture stones, such as Fröjel Stenstugu and Buttle Änge II, have the remains of motifs, although they are often inconclusive regarding precise figures and motifs.

RTI photographs gave good results on all the picture stones, even though the method is light sensitive and using a tent to shield the sunlight is preferable. Due to the good preservation of the picture stone from Fröjel Bottarve very good results could be gained from all methods. In the case of Fröjel Stenstugu the RTI method proved that human made carvings were present on the surface, however the results from the frottage were inconclusive. At Buttle Änge II, although the frottage indicated that there were carved lines and curves, more information could be discerned from the results of the RTI.

This study highlights the necessity of using different rendering techniques to obtain a reliable end result. As mentioned earlier in this article, this study very much represents a work in progress. The experience learnt is that diverse techniques sometimes give quite different results. No one technique is better than the other, but all three techniques working together allow for the development of a clearer and more reliable result. Further work may include the addition of further techniques to expand the comparison and to evaluate the strengths and weaknesses of the methodologies of recording picture stones.

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Article two: The Kivik tomb - Bredarör enters into the digital arena - documented with OLS, SfM and RTI

Bertilsson, Ulf; Ling, Johan; Bertilsson, Catarina; **Potter, Rich**; Horn, Christian (2017): The Kivik tomb: Bredarör enters into the digital arena — documented with OLS, SfM and RTI. In Sophie Bergerbrant, Anna Wessman (Eds.): *New Perspectives on the Bronze Age*: Archaeopress Publishing Ltd, Oxford. pp. 289–305.

My contribution to this article was through the RTI documentation of the stones at Kivik, the processing of the data, and analysis and discussion of the results with co-authors. I also wrote sections of the article. **(overall contribution 15%)**

In this article we developed an integrated approach that drew on three complimentary methods to document the slabs at the famous cairn of Bredarör, Kivik to determine whether new information could be obtained from the carvings. During the process we used laser scanning (overseen by Maskin Laser Teknik (MLT)), Structure from Motion (SfM), and RTI. The results of these documentations were contrasted with older frottages and those from a recent tracing investigation by Toreld and Andersson (Toreld and Andersson 2015). Through this evaluation we were able to confirm and dispute several areas of contention in the tomb, primarily on slab 2 and slab 7, including features such as the axe type, the prows of the boats, the chariot box, the fish, and the “hats”. We were also able to confirm Evers’ disputed interpretation of a fish motif (Toreld and Andersson 2015, p. 12).

The article critically assesses the processes carried out by Toreld and Andersson and suggests at how digital methodologies improve upon them. In retrospect, the article was somewhat more negative towards traditional methods than it needed to be, partly due to the novelty of the digital methods that we were coming to terms with.

The Kivik tomb: Bredarör enters into the digital arena — documented with OLS, SfM and RTI

Ulf Bertilsson, Johan Ling, Catarina Bertilsson, Rich Potter and Christian Horn

Abstract

The Bredarör cairn in Kivik sparked the interest of researchers by presenting the rare combination of rock art within a burial context. A recent documentation project that employed the traditional tracing method has sparked a new debate about the precision of older tracings and frottages. This paper presents the results of a holistic recording of the slabs in the Bredarör cairn using three modern methods: Structure from Motion (SfM), Optical Laser Scanning (OLS) and Reflectance Transformation Imaging (RTI).

In discussing SfM, OLS and RTI, the paper demonstrates the power of these tools to expand the capabilities to record rock art in an unbiased fashion and in greater detail. In contrast to older methods, the depth and texture of features on the rock are documented and human error is reduced, because everything is recorded.

Some observations of the earlier documentation efforts were confirmed, and more details added, such as information on ship prows and horse design. This allowed an in-depth discussion of the dating and use of rock art in the Bredarör cairn. It is argued that although there is evidence that the slabs were transformed several times, the majority of the carving activity was carried out during Period II of the Nordic Bronze Age. It suggests that an important individual, possibly connected to long-distance trade, was interred in the cairn that subsequently served as a necropolis until the Late Bronze Age.

Key words: rock art, 3D documentation, slabs, burial, mound, Scania.

Background

The famous cairn in Kivik — Bredarör — featuring rock art carved into the slabs of the central stone tomb, constitutes one the most spectacular funerary sites of the Nordic Bronze Age (Figure 1). Over the centuries, it has spurred scholars to document the petroglyphs, the first known recording being that by Feldt in 1756. Since then, there have been numerous other attempts by investigators (with mixed success) to record the rock art (Goldhahn 2013).

Many attempts to interpret the spectacular petroglyphs have taken place since its official discovery in the mid-18th century. Interpretations have ranged from claims that the images represent religious symbols to social structures, death rituals and memories of glorious and heroic deeds (Goldhahn 2007, 2013). Some assertions are fanciful and tenuous at best (e.g. Nilsson 2013). Many prominent Scandinavian Bronze Age scholars have researched this magnificent site, and have presented diverse interpretations about the meaning of the images and/or their age (Goldhahn 2013).

Some scholars, e.g. Randsborg (1993), Goldhahn (1999, 2005, 2013), Kaul (1998) and Kristiansen and Larsson (2005), have emphasised the special circumstances and unique features inherent in the figures found in the immense Bronze Age tomb Bredarör, often known as the Kivik grave. The rock art is stylistically sophisticated with no direct parallels; for example, most of the slabs are framed by lines forming an elaborate structure arranged in a series (Randsborg 1993: 119; Kristiansen and Larsson 2005). In fact, no open-air rock art locality possesses this kind of structured serial arrangement. Moreover, the site includes certain types of images that are not found at any open-air sites in the landscape.

Other noteworthy differences include the small number of ship images and the total absence of cup-marks (Randsborg 1993: 119; Goldhahn 1999, 2005: 39–42, 105). However, the greatest difference is that the individual images and their spatial arrangements are considerably more stylised and static compared to the figurative sites in the landscape. Accordingly, some scholars argue that the structured arrangement of the slabs indicates that the rock art images played an important narrative role in a specific funeral event (Randsborg 1993; Kristiansen and Larsson 2005).

One of the main topics of debate has been the question of whether the rock images were made before, during

FIGURE 1. SOUTH- AND NORTH-SIDE SLABS DOCUMENTED WITH SFM BY CATARINA BERTILSSON, SHFA.

or after special funeral events (see Goldhahn 2007). Goldhahn's (2007) analyses have shown that at least five individuals were buried in or in connection to Bredarör. Another topic of debate has been the question of dating the rock art. Most scholars have argued for a dating to a late phase of Period II, 1400–1300 BC (Randsborg 1993; Goldhahn 2013). However, some researchers argue for a slightly earlier date, 1600–1400 BC (Kristiansen and Larsson 2005).

Goldhahn's (2013) significant book on Bredarör is exemplary in the way it covers the history of documentation and interpretations of the site to date. Therefore, we will not go into detail about these issues here. There is, however, one thing that all previous efforts have in common, namely that they are based on traditional two-dimensional techniques which produce results that are more or less subjective, depending on the degree of manipulation required by each technique.

In 2015 Toreld and Andersson presented a new study of the rock carvings on the Bredarör slabs, which produced some interpretations that merit further comments and consideration (Toreld and Andersson 2015). The reader is referred to the resulting publication in Fornvännen, and its accompanying illustrations in particular, to compare the results of the different documentation techniques discussed here. Their documentation was made by using traditional tactile two-dimensional techniques, both rubbing on paper and tracing onto plastic sheeting. There are two major problems with traditional tactile, two-dimensional rock art documentation techniques: the rather high degree of manipulation used and the lack of transparency of the documentation process. The main drawback is the difficulty in confirming or reproducing results. In fact, there are so many manipulative steps and subjective judgments associated with the use of this traditional tactile documentation methodology that the results tend to reflect more about the investigator than the original images in stone being investigated (Figure 2). As a consequence, the contentious and somewhat fanciful results spurred us to re-examine the Bredarör slabs using state-of-the-art digital techniques — Optical laser scanning (OLS), Structure for Motion (SfM) and Reflectance Transformation Imaging (RTI).

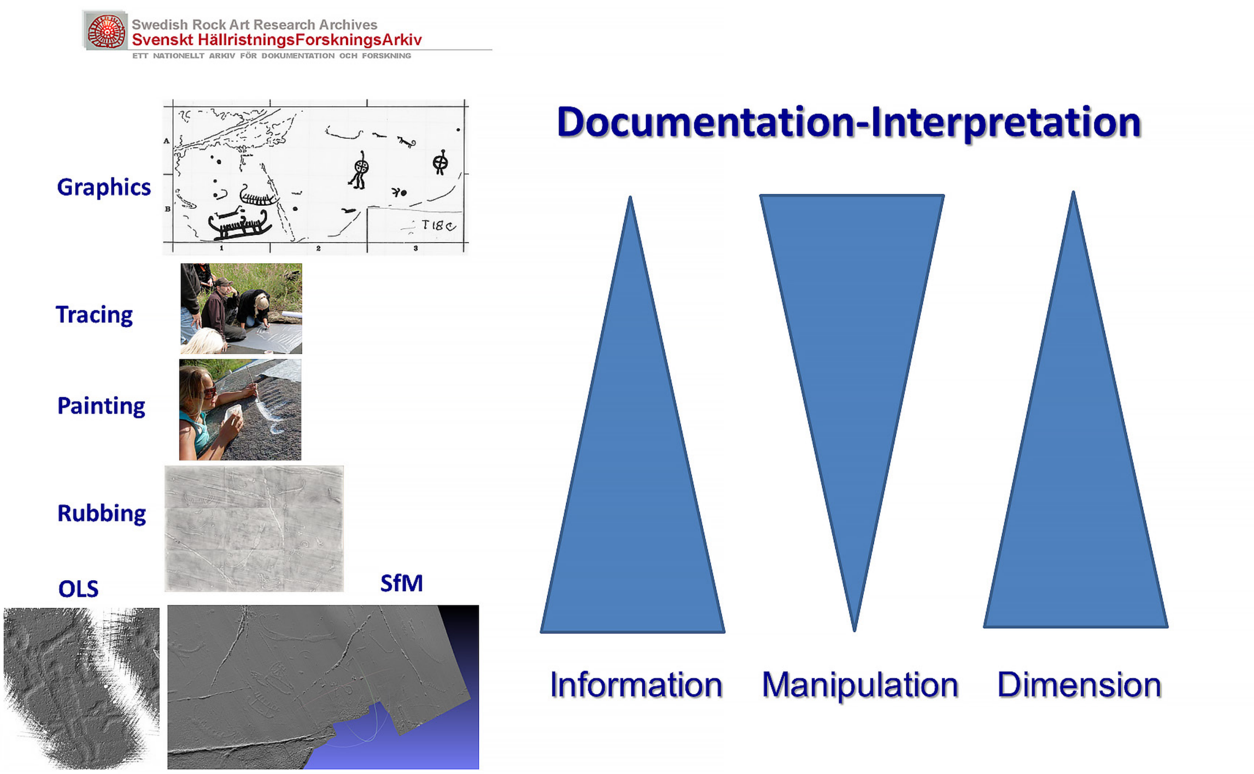

FIGURE 2. ILLUSTRATION OF THE DIFFERENT STEPS OF ROCK ART DOCUMENTATION IN TERMS OF INFORMATION, MANIPULATION AND DIMENSIONS. ILLUSTRATION MADE BY JOHAN LING.

Digital techniques have several obvious advantages over traditional methods. For example, the high-resolution digitised techniques employed provide a very high level of detail that is unattainable when using old, traditional, tactile techniques (Figure 3).

'Researchers in cognitive psychology have found a positive relationship between the ability to visualise and the use of visualisation tools. The implication is that the better the visual tool, the better the explanation and the comprehension of information' (Hermon and Nikodem 2008). The new digital 3D documentation will now allow researchers to unlock the complexities of rock art. This new evidence demands a similar re-theorising of the role of visual images and cognition, as well as the role of the carver. Thus, the new 3D techniques provide a more objective and less interpretative method than the traditional manual approach (Ling and Bertilsson 2016).

Moreover, laser and 3D-photo imaging provides new opportunities for analysis of the carvings at the micro-level and also enables discussion of the materiality of the stone (Goldhahn 2015). Additionally, these methods are non-invasive and thus reduce the need to paint or chalk the figures or to otherwise touch them. In this way, the documentation of petroglyphs through the use of digital technique prevents the rock art from being exposed to the often-damaging effects of physical contact. Sadly, investigators have subjected the petroglyphs at Bredarör to repeated instances of physical intervention since the mid-1700s (examples of this are described in Goldhahn 2013). This also applies to the recent documentation, which left obvious traces in the form of chalk powder. The combination of chalk powder and the earlier painting of the figures in red is extremely arbitrary, and make the carvings very difficult to perceive (Figure 1).

It is within this historical context that the Svenskt Hällristnings Forsknings Arkiv (SHFA) employed cutting-edge digital documentation techniques to study the petroglyphs on the Bredarör slabs. Having contacted the County Chief Antiquarian in Scania, and after securing the necessary permits obtained from the National Property Board (i.e. the owner of the Kivik tomb), the SHFA documented the rock art over the course of a day in September 2015; RTI was conducted over two days in February 2016.

Below, we present the results of the first non-tactile high precision digitised documentation of the Bredarör slabs at Kivik. This documentation was performed using the most advanced three-dimensional techniques. First, scanning with optical laser (OLS) and digital photography to be used in Structure from Motion (SfM), and later the similarly photography-based Reflectance Transformation Imaging (RTI). These results are

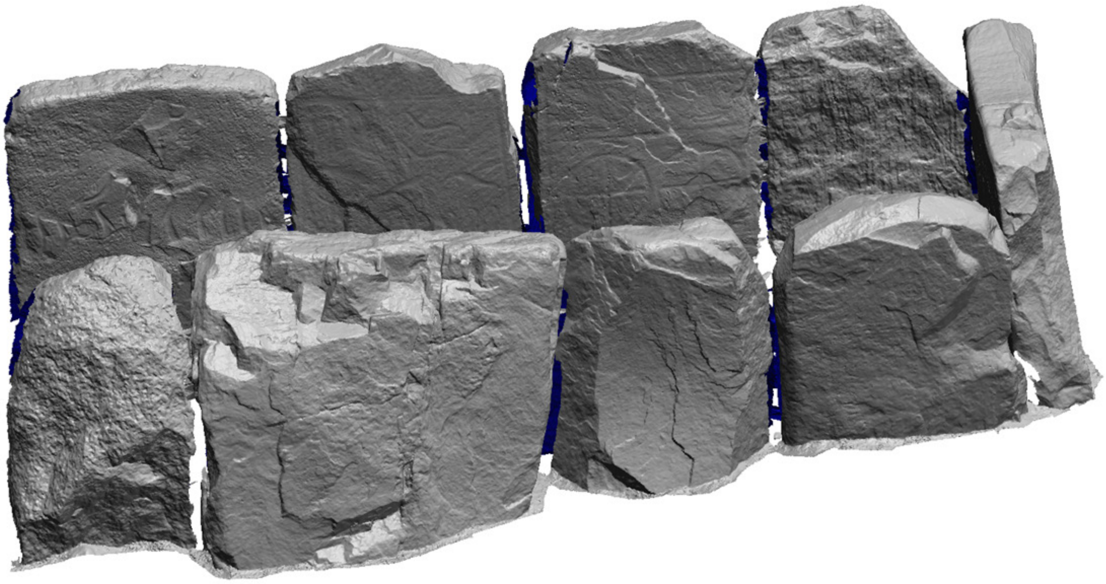

Figure 3. Laser scanning of the entire Bredarör stone cist. Scan MLT © SHFA.

interesting in themselves, but also complement, and sometimes produce better results than, the traditional tactile rubbings made by German graphic artist Dietrich Evers in the 1970s and the tracing (i.e. plastic sheeting) by Toreld and Andersson (2015).

Method

Documentation of petroglyphs with optical laser scanning

A project scanning petroglyphs using advanced digital technology took place in early 2015 when the County Administrative Board of Västra Götaland started to record a number of carvings at the Tanum World Heritage site. The scanner used in this project was provided by the Maskin och Laser Teknik (MLT) Company in Gothenburg. Since this Tanum project produced promising results, the opportunity to employ the same techniques under the special conditions (i.e. an indoor context) present at Bredarör emerged as an exciting possibility.

At Bredarör, all slabs (both the engraved front sides as well as the backs) were scanned using a Handyscan 700 with red lasers. The Handyscan 700 sends out about 480,000 measurement points per second, which reproduces the carved panels with an accuracy of 0.03mm. Thus, the main objective with the Handyscan is to detect 'mechanical' impact at 0.03mm, this is clearly something the bare eye or fingertips cannot achieve.

The documentation process consisted of the following steps:

- Establishment of the equipment at the site.
- Setting out of reference points on the hob.
- Scanning of the slabs with the Handyscan 700.
- Data from the scanner is immediately shown on a laptop during input.
- Data from the scanner software is exported.
- Removal of reference points.

In the years around 2000, the ATOS scanner technology was developed to document the open-air rock carvings at Tanum for the National Heritage Board's Rock Care Project (Johansson and Magnusson 2004). The ATOS scanner is highly accurate, but not as powerful or precise as the Handyscan 700. Later, Joakim Goldhahn tested the technique of documenting petroglyphs using lasers some 10 years ago at Bredarör. Moreover, since the documentation from the Goldhahn scan at Kivik has unfortunately never been published, the results remain unknown.

The documentation with the optical laser was carried out on all of the carved slabs in the grave with a resolution of 0.06mm while Slab 2 and Slab 7 were scanned at the highest resolution, which corresponds to 0.03mm. The scanner was connected to a laptop, which enabled investigators to check the results directly and to immediately take the necessary steps within the documentation, filling any gaps from the first attempt if necessary.

The laser documentation addressed here was accomplished in one afternoon taking approximately four hours of work at Bredarör. The results will be presented with comparisons to the findings put forth by Toreld and Andersson, who employed traditional tactile recording techniques.

Documentation of petroglyphs with Structure from Motion (SfM)

3D technology in the form of Structure from Motion (SfM) was already employed with great success at Tanum in 2014 (Bertilsson *et al*. 2014; Bertilsson 2015a).

The rocks on the long sides of the tomb at Bredarör were recorded using this same technique in September 2015 (Figure 1). However, due to time constraints, a more complete SfM-documentation of the slabs was postponed to a later date. Some additional shooting was then undertaken in June 2016 concentrating on slabs 2 and 7 to enable a comparison with other techniques.

For SFM, pictures are taken with a 60–70% overlap and processed over a relatively long time frame, up to a day (although newer technology is reducing this time scale dramatically), to obtain the final results, depending on the number of photos taken. However, this depends heavily on the specification of the computer and the software used. There will be substantial improvements to the processing time frame in the future due to the development of technology. Testing of new software (RealityCapture) indicates that the processing time can be shortened by up to 80%.

Documentation of petroglyphs with Reflectance Transformation Imaging (RTI)

Reflectance Transformation Imaging (RTI) using Polynomal Texture Maps (for a recent review see Mudge *et al*. 2012) is a method that computes pseudo-3D files from the surface reflections of a photographed object ('Highlight RTI'; cf. Mudge *et al*. 2006). A static camera takes 60–70 photos with lighting from oblique angles including raking light. The Cultural Heritage Imaging group (CHI) has created free open source software which compiles and shows the RTI files, as well as guidelines for its use (Cultural Heritage Imaging 2013). Advantages of the method include the unlimited adjustability of the lighting position in the viewer and the observability of intersecting carved lines using filters that the software provides. Comparatively, RTI is a cheaper method than optical laser scanning and SfM, files are calculated faster than SfM and the file size is generally smaller. However, this comes at the cost of RTI not producing real 3D files.

Regarding the outcome of the scans, the following observations were made on the individual panels:

Slab 2

The scan revealed that the ship located at the lowest part of this particular panel has modestly in-turned prows (Figure 4). This is supported by the investigation using RTI. Thus, this observation supports Faith-Ells' documentation of the panel, as opposed to the documentation created by Toreld and Andersson (2015). The result of the scan indicates that this ship represents a type that belonged to the early phase of the Nordic Bronze Age, Period IB–II (1550–1400) and does not support Toreld and Andersson's (2015: 110) dating of the ship to a late phase of Period II. First of all, in accordance with the dating criteria for rock art chronologies, ships with modestly inward facing prows and horizontal or slightly upturned keel extensions, belong to Period IB or to the early phase of Period II, rather than to the later phase of Period II (Kaul 1998: 92; Ling 2008: 105). During the last phase of Period II, the horse head becomes a common feature on prows, and keel extensions in general are more upturned than the ones featured on this particular ship in Bredarör (Kaul 2013; Ling 2013).

However, if all the circumstances are taken into account, we do agree that this particular ship was probably produced during Period II rather than IB. In support of this assumption are the new observations of details in the features above the ship (previously said to depict axes or oars), suggesting that these were representations of shaft hole axes of the late Period II type. The scan verified these details, and we agree that these images most probably represent shaft-hole axes from Period II (not socketed axes as Toreld and Andersson [2015] state). However, it should be stressed that there are no observations favouring a dating of these axes to the late phase of Period II, but rather, to the early phase of Period II (cf. Montelius 1917:58, 849, 882).

For instance, the famous Stockhult hoard from Scania dates to an early phase of Period II (1500–1400 BC), and included three specimens of shaft hole axes that strongly resemble those carved on Slab 2. This hoard also includes artefacts dated to Period IB (cf. Montelius 1917:58, 849, 882). This dating suggests that, along with the ship, all of these images were produced in the early phase of Period II. However, we would like to stress that Toreld and Andersson's new observations about these particular axes are highly important (even if we find their dating inaccurate), as it contributes to our understanding of the chronology of this particular slab. The leading trends in dating the Kivik tomb will be discussed in more detail below (Randsborg 1993; Kaul 1998; Goldhahn 2007, 2013; Kristiansen and Larsson 2005).

Figure 4. A Close-up scans of slab 2 with ship and axes. Scan MLT © SHFA.

Nevertheless, the most noteworthy observations made by Toreld and Andersson were about the 'hat shaped' features that occupy the mid-section of Slab 2. They appear very clearly in the scan as well. However, there have been some interesting earlier speculations about these images that call for a certain degree of caution regarding their suggested interpretation. First of all, the surface of these specific images does *not* seem to appear to have weathered to the same degree as rest of the images on the slab. This is very obvious when compared to, in particular, the ship and the axes. The latter images exhibit clear signs of weathering while the hats do not appear to have been affected as much by this phenomenon. In fact, the hats look in in general to have been carved more recently (Figure 4). Notably, Toreld and Andersson themselves report that the hats appear much brighter and deeply carved than the other images on this slab. This could of course indicate that they were made during a later phase than that of the ship and axes, something that in turn would be contrary to Toreld and Andersson's assertion that the hats are contemporary with the other images present on the slab.

Another interesting and noteworthy aspect is the position of the 'hats' on the panel. Both images are located in a substantially lower part of the panel in which a certain portion of the surface seems to have already fallen off in prehistoric times (Figure 4). In fact, the carved images on all of the other slabs in Kivik seem to have been placed, more or less, on the same altitudinal level on a similarly even surface. The question is why did the prehistoric carvers choose to depict these spectacular 'images' on a considerably more uneven and heavily damaged slab with altitudinal differences? Although the reason is not apparent, we believe that this might be the actual reason why most scholars examining this particular slab have dismissed these 'hats' as not being carved images, and instead considered them to have resulted from other influences and processes.

For instance, according to Goldhahn, Hallström documented all of the panels in connection with the restoration of the monument, cleaned all of the slabs and analysed them, one by one, stating that this particular slab was damaged by severe flaking off and weathering (Goldhahn 2013).

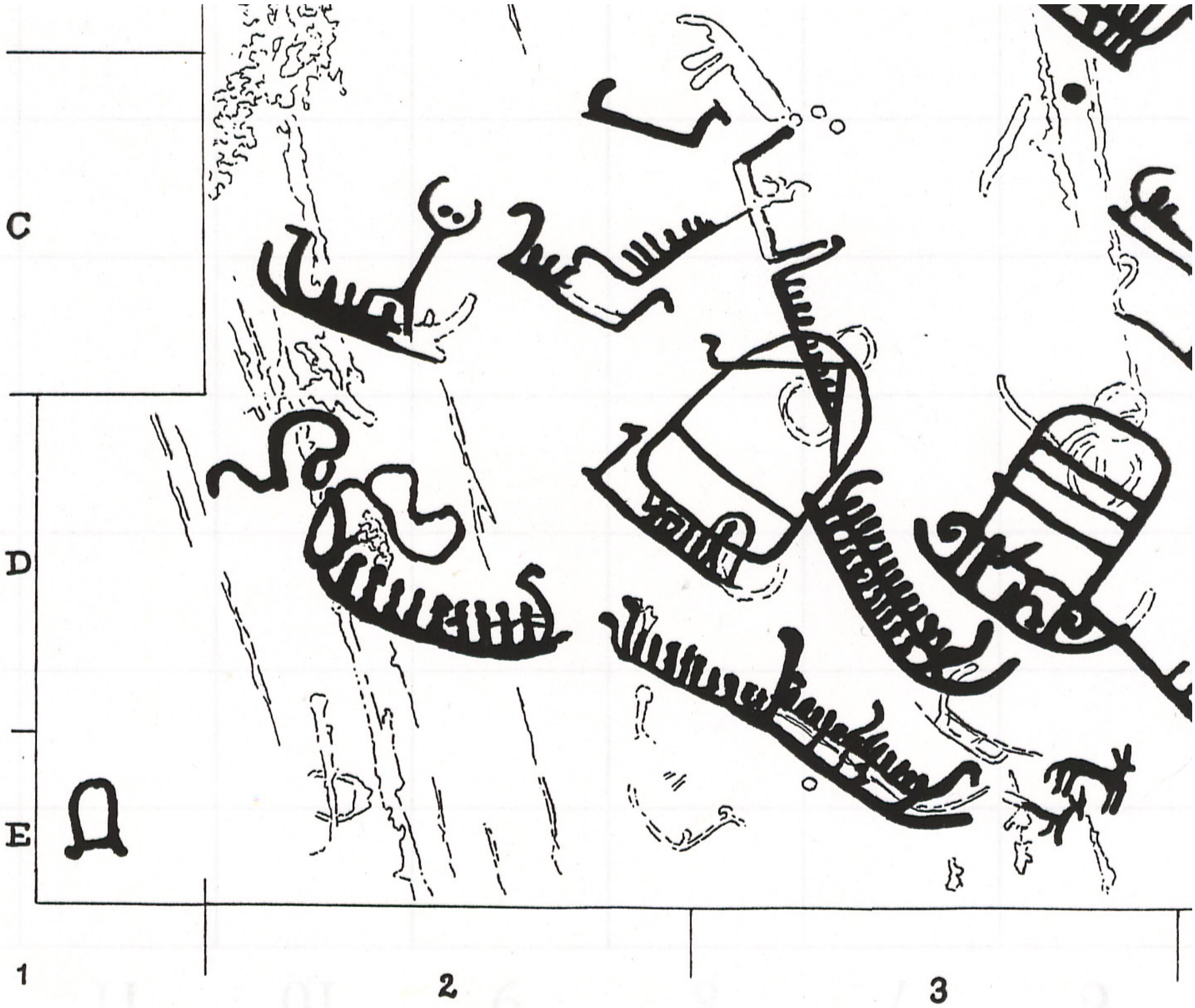

Figure 5. Aspeberget, with hat-like images. Source: SHFA Graphics: Tanums Hällristningsmuseum Underslöse. © SHFA and Tanums Hällristningsmuseum Underslöse.

In addition, Toreld and Andersson (2015) argue that the hat-like images are similar to the conical hats on the figure from the Stockhult hoard and the hat-like pommel, all of which date to Period II, but also that they are similar to the gold hat from Schifferstadt, Germany. However, they are aware that all of these analogies are rather tenuous. The conical hats from the figures in Stockhult are quite different from the images presented on this slab, both in terms of shape and size. Another analogy stressed by these authors is that they resemble the so-called 'war caps' found in the Danish oak coffin graves, dating to Period II (see Randsborg 1993). However, it is important to note that cloth war caps do not possess brims, in contrast to Toreld and Anderson's (2015) hat-like figures found on this slab.

Since it is very hard to find any good analogies for the hat-like images in Bredarör, these particular and peculiar petroglyphs should accordingly be regarded as anomalies. However, if we accept that these features are actually chipped rock art images, a possible analogy, in our view, can be found at Aspeberget on Tanum 18:1. This panel includes some remarkable images that resemble the hat-like images from Kivik (Figure 5). Moreover, a direct comparison of these panels in terms of the respective size and form offer an almost perfect fit. The hat-like images on the panel at Apseberget connect to and overlap ships that date to the latest phase of the Bronze Age, Periods V–VI.

Regarding the dating of the Kivik tomb, Goldhahn (2009, 2015) obtained several radiocarbon dates from the bones and teeth found inside or just outside the enclosure at Kivik. These samples were obtained during an investigation that took place back in the 1930s. The carbon dates from five different individuals, mostly teenagers (see Goldhahn 2009, 2015) indicated three different phases: the first between: 1450–1250/1200

BC, the second between: 1250–1000 BC and the third between: 900–700 BC (Goldhahn 2013). Therefore, Goldhahn (2007) argues for a continuous use of the site during the Bronze Age as opposed to the prevailing interpretative paradigm that claims that the site consists of a single primary burial for one prominent person. the interpretation of a buried chief and/or shaman must be challenged…there are certainly no obvious candidates for a veteran chief or senior shaman here and the most likely scenario is that the cist was never finally sealed, but remained accessible for later burial…This result has support from modern excavations of Bronze Age barrows, which have revealed that they were in use for burials over a considerable period. Burials from the Late Bronze Age and the Early Iron Age are commonly found in barrows that were erected in the Early Bronze and the famous Bredarör in Kivik does not seem to be an exception to this rule (Goldhahn 2007).

The fact that the monument was in use over a long period and that the closest analogy for these hats can be found in rock art dating to Period V (900–700 BC), is a strong indication that the hat-like features were made at a later date than the other images on Slab 2.

Toreld and Andersson (2015), argue that all of the rock art at the site was made more or less during one event before the slabs were erected, since it would have been very difficult to add or update images once the slabs were in place as there would not have been room enough to swing a rough hammer stone; we note, however, that there was plenty of room for two modern researchers and their equipment to work in the cist, and it is unlikely that carvers in the past would have needed more space. In our view, many of these images are so finely carved that it is unlikely that they were produced using the direct swinging technique. A recent study on this topic indicates that the carving of such images was likely accomplished by using stone tools via an indirect percussion technique (Lødøen 2015). There is indeed ample room inside the Bredarör stone cist for the carving of images using stone tools via an indirect percussion technique.

Continuing with the rest of the discoveries/interpretations made by Toreld and Andersson (2015) with regard to this particular slab: the two ring-shaped images at the lower right end and the four zoomorphs. The ring-shaped feature located between the 'hat' and the ship at the lower right end of the slab, bears a greater resemblance to a hat than to a ring. However, the lower image does seem to correspond better to a ring. The newly discovered zoomorphs on this slab, as claimed by Toreld and Andersson (2015), seem rather arbitrary since they have not been fully verified by scanning. However, they appear clearly on SfM documentation and are thus verified. This shows that the laser technology is not always 100% accurate, and may not record every image detail. One possible reason might be that the quartzite sandstone is very rough and heavily weathered at these spots. The three figures are horse-like with four legs, and are arranged in a succession that occurs in parallel on a rock carving at Villberga in Boglösa, Uppland (Bertilsson 2004; SHFA). Although, in that case the horses are more stylised and only show two legs. Depictions of a trio of horses in a similar formation do also occur in Bronze Age carvings on Mount Suleiman-Too in Osh, Kyrgyzstan in Central Asia (Bertilsson 2004). In that case, the procession is interpreted as the horses bringing a deceased person's soul to the land of the dead.

Slab 7

This slab contains one of the most well-known images from Bredarör. It depicts some spectacular scenes and processions, for example the war chariot in the upper part of the panel along with the procession of anthropomorphs in the lower part. Many scholars have studied the war chariot in the top right section of this slab and compared it to Bronze Age war chariots in the Aegean or Egyptian world (cf. Randsborg 1993; Kristiansen and Larsson 2005).

Evers executed the most detailed documentation of the chariot in 1970 (Södra Mellby 42 Kivik SS Evers 34b 234_Rw SHFA_id3011). There are some phenomena that stand out in his documentation in comparison to that made by Faith-Ell (1942) and by Toreld and Andersson (2015). Firstly, it was evident that the mouths of the horses are fitted with a bridle with reins, which are intentionally attached and clearly marked above and in front of the horses in our scan, although it is difficult to detect and demonstrate this in a two-dimensional illustration. However, there is help available from unexpected quarters, the oddly shaped three-piece bridles are also visible on Toreld and Andersson's (2015) rubbing which thus confirms Evers' earlier documentation. Secondly, our scan clearly shows that the charioteer is standing on a small stand or box, which also confirms Evers' documentation (Figure 6a). Moreover, regarding the line of warriors in the top left section of the panel, the scan revealed that some of these warriors are depicted with weapons; the most obvious are the first and the third warrior, (Figure 6b) something which also is evident in Evers' rubbing.

The zoomorphs at the right mid-section of the slab have traditionally been interpreted as hounds or wolfs. The scan indicated that these zoomorphs might have ears. However, it is almost impossible to determine if they have tails, and Evers' suggestion of a phallus on the right animal cannot be verified or denied. It is, however, important to stress that Evers experimented

Figure 6a. RTI recording of charioteer standing on a box by Christian Horn and Rich Potter.

Figure 6b. Rubbing of Slab 7 made by Dietrich Evers. Source: SHFA © SHFA.

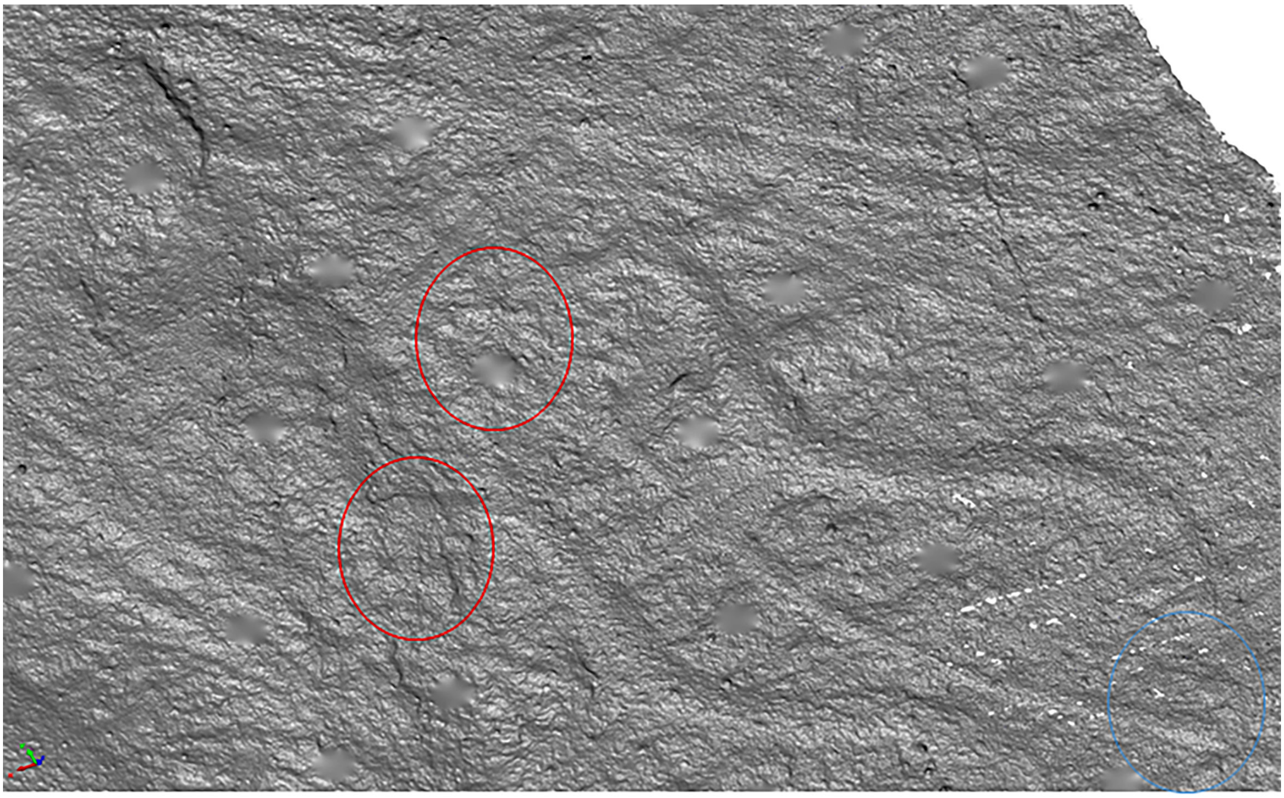

Figure 7. Laser scan of Slab 7 with horse bits marked. Scan MLT © SHFA.

with different paper qualities of different weights and densities when recording rock art in order to obtain the best possible results. In doing so, he never claimed that any particular procedure was superior over another. It could sometimes result in different interpretations, though, which Evers openly reported.

Therefore, it seems somewhat exaggerated when Toreld and Andersson claim that 'Evers has imaginatively created his own motives of frottage paper by retouching it using a pencil and eraser. A clear example of this is the two completely different versions that are published by the fish-like figure and a beast on Slab 7. Ever's frottage cannot be said to have any greater scientific value' (Toreld and Andersson 2015:12 our translation). This appears clear given the fact that many of the details that can be observed in Evers' rubbings have been verified by the results of our laser scanning (Figure 6a). Ironically, more of these details also appear, e.g. the peculiarly shaped bridles and the box on which the charioteer stands, on Toreld and Andersson's (2015:13) own rubbing. The opposed animal figures which was previously interpreted as a quadruped, and then possibly a dog or wolf, requiresr a more detailed analysis in order to verify this observation.

Toreld and Andersson claim that Feldt's 1756 work was the most reliable with regards to all the documentation available prior to their work being published in 2015. For, instance Feldt argued that some of the anthropomorphs (on the lost Slab 8) were depicted as wearing hats. Toreld and Anderson (2015) take this bold interpretation as confirmation of their own observations of hat-like shapes on Slab 2. Moreover, Toreld and Anderson (2015) believe that the alleged spearheads on Feldt's depiction of the now missing Slab 1 do not represent spears from the Bronze Age, but instead swords from Period II and III, similar to those depicted in several rock carvings in Norrköping**.** The authors' reasoning on this point is difficult to follow and the conclusions are tenuous. To the contrary, we argue that Feldt's supposed spearheads might well be correct if you specify a certain time frame for the images in question. They are then just as likely to be spearheads of a Bronze Age type, such as Montelius No. 911 and 912 dated to the Period II. There is also a certain similarity to Montelius No. 999 dated to Period III (Montelius 1917:61, 66).

Toreld and Andersson's (2015) general dismissal of Evers' documentation seems rather odd given that the rejected rubbings were of high quality and produced detailed images. The fact that Evers' documentation efforts did not always result in complete success should not be surprising. The comparison between the 3D documentation and Toreld and Andersson's (2015) documentation shows that the latter endeavour produced considerably less in terms of details. This should be of no surprise when considering the different processes that these two technologies employed; laser scanning and SfM produce high-resolution images of rock carvings that are immediately available for interpretation, while the images produced using traditional tactile plastics technology are the result of an elaborate five-step process that involves night lighting, chalking, painting and finally interpretation and tracing on plastic sheets (cf. Gell 1998).

Since the application of the invasive, traditional, touch-based technique involves multiple steps there is a high possibility that important information may be gradually deselected when an investigator deems it to be uninteresting or insignificant. This means that this process, regardless of who uses it, includes a number of subjective choices that require a large number of on the spot decisions. Thus, it goes without saying that the results cannot be repeated or controlled. In contrast, laser scanning and digital photography produce, in comparison to the traditional tactile technologies, vastly more detailed and informative images of petroglyphs. Such recordings therefore also provide much higher quality data for use in interpreting rock art. To abstain from using such advanced digital technologies in the documentation of rock art would be analogous to refusing to use radiocarbon methods to determine the age of a datable artefact, and relying instead only on typology and seriation relative dating methods. Having said that, it should be stressed that no technology is perfect, and there will always be a development towards producing more detailed information.

A very positive aspect of using digital technologies is that it requires no chalking or painting on the carvings. The images are instead captured in detail in the camera or directly on a computer screen. This means that physical contact and the sometimes-harmful cleaning methods that have been used (especially on the Bredarör slabs, cf. Goldhahn 2015) can be avoided from now on. Moreover, the digital records produced using such techniques also provide exciting new possibilities for visitors to the site with the help of modern video technology.

Another observation may be made regarding the form located beneath the succession of warriors; this figure has traditionally been interpreted as some kind of aquatic creature, such as a fish, dolphin or whale (Goldhahn 2015). Evers (Figure 6b) and Faith-Ell from 1942 (after Goldhahn 2013) depict it having several small fins or barbels, however, Toreld and Andersson (2015) ignore most of these depictions and argue that only three hooked lines are connected to this feature. However, the digitised scan data and RTI-images reveal that several small lines are connected to this form, once again, corroborating Evers' documentation (Figure 8).

Regarding this interpretation, we think that Goldhahn offers a plausible analogy: that of a fish engraved on a Bronze spearhead from Haga, Gotland, dated to Period IB. Another example is the classical spearhead from the Valsömagle hoard in Denmark on which two fish are engraved (Goldhahn 2013; Vandkilde 2011: 370; Figure 9a). It is notable that the fish motif appears on both these early Bronze Age artefacts. However, there is at least one further image on a bronze object that resembles the alleged fish: the stylised fish depictions on razors dated to the Late Bronze Age Period V (Kaul 1998). The engraved fish on the razor from a Bronze Age burial at Möen in Denmark exemplifies this (Figure 9b; Bertilsson 2015b: fig. 9).

This fish on the Möen razor is certainly stylised, but it is also depicted with characteristic wattles, which suggest that they may be the same species. If so, it might be an image of Europe's largest freshwater fish, the wels catfish (*Silurus glanis*), or its African relative (*Clarias gariepinus*), which is smaller, but can 'walk' short

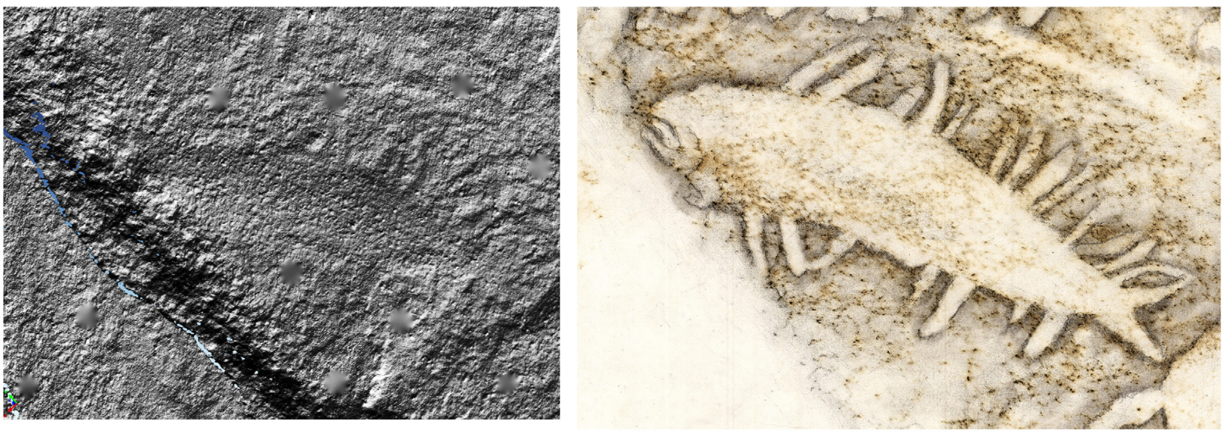

FIGURE 8. COMPARISON OF DEPICTION OF THE FISH ON SLAB 7 BY TWO DIFFERENT TECHNIQUES; LEFT SCAN BY MLT; RIGHT PAPER RUBBING BY EVERS © SHFA. CF. GRAPHICS BASED ON PLASTIC SHEETING BY TORELD AND ANDERSSON IN FORNVÄNNEN 2015, FIG. 4.

Figure 9a. Late Bronze Age razor with engraved fish with barbels. After Bertilsson 2015b.

Figure 9b. Valsömagle spearhead from Period IB with engraved fish with barbels similar to fish on 8a. Photo: Christian Horn.

distances on land and has a sound similar to that of a crow. Considering this unusual appearance, it may very well have been perceived as a mythical creature during the Bronze Age.

Since the fish image on the Bronze razor is considerably later in date and much more stylised than the one on Slab 7 in Kivik, one should not promote any far-reaching conclusions except to remark that both images seem to indicate the importance of the fish in Bronze Age imagery and narratives. This concern is not limited to the Nordic Bronze Age, as another fish image, strikingly similar in form to that depicted on the dagger, was carved on a rock at Bedolina, close to Cemmo in Valcamonica, on a panel that is otherwise known for its numerous and detailed map images (Figure 10; Anati 1976, 2004). Although the main focus of our study is not to conduct a detailed analysis of Bronze Age petroglyph fish images, our findings indicate that depictions of fish are not uncommon in this period's

Figure 10. Depiction of a fish with barbels on the Bedolina panel in Valcamonica, Italy. Photo: Gerhard Milstreu, THU. Reproduced by permission from Gerhard Milstreu.

imagery. At Valcamonica, there are other fish images that are difficult to date more precisely. Similar images, which are considerably older and date to 7000–6000 years BC, are present. Fish images also appear at Tassil N'Ajer in the Sahara (Sansoni 1997).

In terms of the small structures that emanate from this feature, to a certain extent it also bears a resemblance to the boat depictions on the so-called Cycladic 'frying pans' from the Aegean Bronze Age, or a fusion of boats with fish from this context. Nevertheless, another aquatic analogy is that it represents a highly stylised flatfish.

Moving a bit further down on this part of the slab, there is an anthropomorphic figure depicted on the lowest section of the slab. The scan clearly reveals that the figure has two arms, which are held in a classic worshipping adorer position. It does not have only one arm, as alleged by Toreld and Andersson (2015; Figure 11). This, however, is evident on Evers' frottage (Figure 11), again showing the validity of his documentation. The most remarkable observations made involved the carvings found on the lower part of the slab.

They depict a procession of anthropomorphic beings with beak-shaped heads that seem to approach the adorer. These images have been interpreted either as humans in costume, dressed up in birdlike fashion, in mourning, as women, and/or as priests. Previous documentation has illustrated these figures as having no legs or wearing coat-like dresses. However, the digitised scan reveals that some of these figures indeed do have legs (Figure 12). These new findings are more in line with similar anthropomorphic beings depicted on the open-air rocks. For instance, in the rock art rich region of Bohuslän in western Sweden, there are some sites depicting similar figures, often in sexual positions (Figure 12; see the site in Varlös, Tanum 273 and also in Åby, Tossene 73:1). In conclusion, it seems that, generally speaking, Evers' documentation of this particular slab is largely correct.

The remaining slabs

The scan of Slab 3 revealed that all four horses are depicted with ears. These are highly detailed and appear with great clarity in the scan. In this context, it is interesting to see that Burenhult (1973) had already argued that this was the case for at least two of the horses**.** In terms of the other slabs (4, 5, 6, and 8), no particular observations were made that merit further commentary.

Figure 11. Comparison of depictions of the adorer on slab 7 with two different techniques; left scan by MLT; right paper rubbing by Evers. Source SHFA

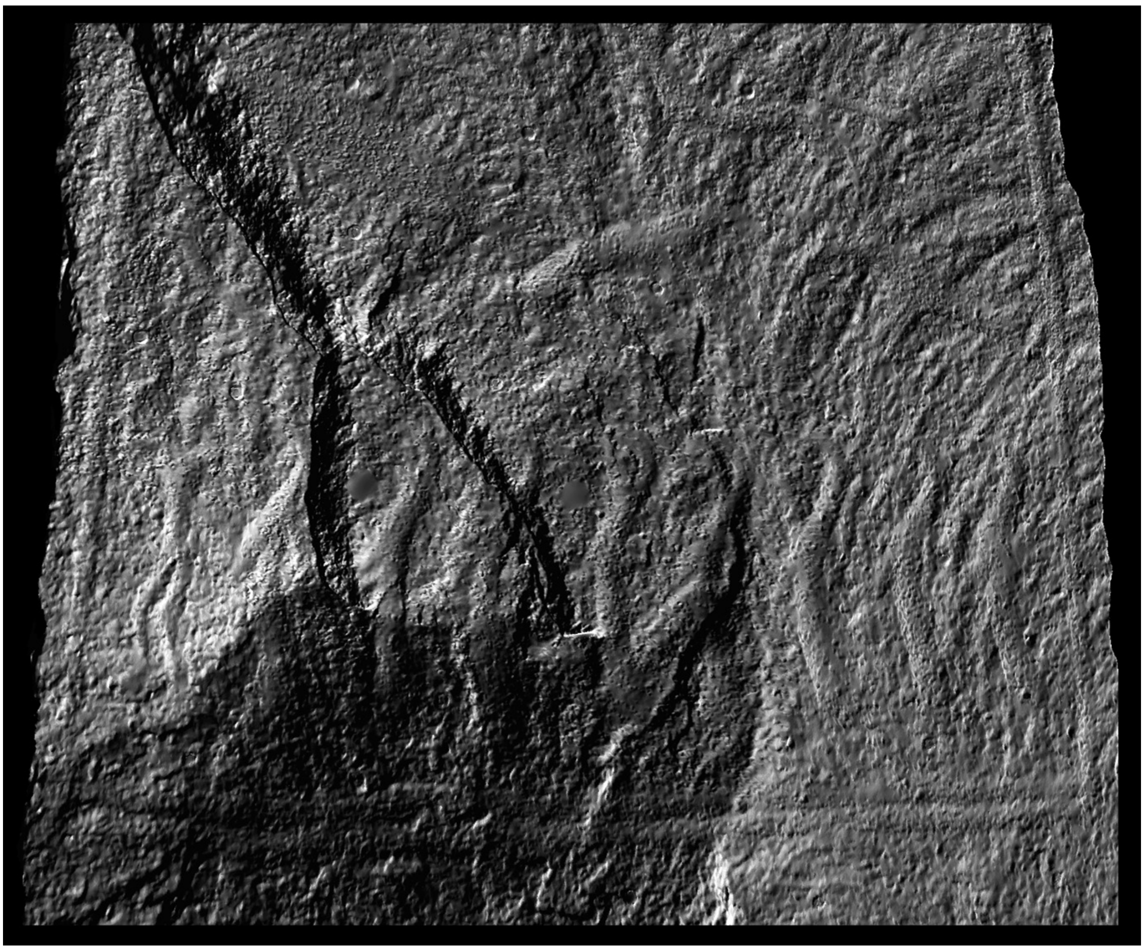

Figure 12. Adorer and procession of anthropomorphs with legs in bird-like dresses on Slab 7. Scan MLT © SHFA.

Discussion

In this last section, we will discuss the dating of the rock art that was presented in the introduction and the parts dealing with new observations. At the end of this section, we will put forth some ideas about the functions that the rock art may have fulfilled, and discuss how the petroglyphs at Kivik may have been used.

In terms of dating, given the highly fragmented bronze bowl that was discovered during the excavation of the region along with the local rock art, Randsborg (1993) argued for a dating of the late phase of Period II. This seems to match well with the dating of the carvings that many researchers have suggested (compilation Goldhahn 2013:569). However, some of the carved figures might indicate early Period II or even late Period IB (Kristiansen and Larsson 2005). This applies, above all else, to the clearly inward curving prows of the ship at the bottom of Slab 2. It is also important to note that the ship on the missing Slab 1 seems to have been carved in a similar fashion. In this context, it is important to stress that the prows of both of these ships are not depicted with horse heads, a feature that is regarded as a characteristic element from the late phase of Period II or early III (Kaul 2013; Ling 2013). The in-turned prows that are depicted on this particular ship are typical for Period IB–II (Kaul 1998; Ling 2013).

However, taken as a whole, we do agree that this particular ship was probably carved during Period II rather than IB. Supporting this assumption are the new observations of axes represented in the ship. These particular shaft-hole axes are generally dated to an early phase of Period II (Montelius 1922), mainly because of the findings of such axes in the so-called Stockhult bronze hoard. However, it should be stressed that this hoard also includes axes dating to Period IB.

The dating of these images to the early phase of Period II is also supported by some of the metal finds from this site. In particular, this concerns one pommel of a sword or a dagger and two fragments from a fibula (Kristiansen and Larsson 2005). In this context, it is intriguing to note that Montelius argued that Period II started in 1550 BC and terminated by late 1400 BC or early 1300 BC (Montelius 1922: 27). Furthermore, Montelius argued that Period II had two phases: one 1550–1400 BC and a second: 1400–1300 BC (Montelius 1922: 27). It is tempting to suggest that most of this rock art might date to 1550–1400 BC. In this light, it is important to stress that Kristiansen and Larsson (2005) argue in favour of an even earlier dating.

Moreover, the aquatic fish-like creature depicted on Slab 7 could tentatively, on the basis of it being analogous to bronze spearheads from Haga on Gotland and Valsømagle, be dated to Period IB. However, the rest of the figures on this panel seem to date to Period II.

Although such a dating is both possible and likely, the mortuary finds and radiocarbon samples (Goldhahn 2013) do not support such dates. It should be stressed, however, that there is a radiocarbon date from a bone which dates to the Late Neolithic along with a barbed and tanged flint arrowhead, which is characteristic of Bell Beaker period (Goldhahn 2013: 574–575). Since these items were found just outside the Kivik tomb area, this indicates that important activities were taking place at this location long before the Bronze Age. However, it is important to stress that the radiocarbon dates of bones recovered from inside and outside the tomb cannot be used to ascertain the age of the rock art in question.

One must also consider the possibility that the tomb in Bredarör may have initially contained metal objects that were better preserved and older than those recovered in fragmentary condition. Looters in the 18th century (or earlier) would have sought out such metal objects for their value (Goldhahn 2013). This would certainly be the case if the Kivik area had remained relatively accessible to grave robbers for three millennia. It is entirely possible that the poor finds in Bredarör may be the result of such looting. This speculation finds support from Bohuslän. At this location, bronze artefacts have been found in the numerous Bronze Age cairns that are still covered with roof slabs and rock fill of varying thickness, while the cairns where the stone packing has been removed and the stone cists broken up are often empty.

If you look at other identifiable images, such as the axes, on the same slab, they seem to date to an early phase of Period II with the exception of the so-called hats (see above). In our view, this analysis requires a careful examination of the entire surface of the images along with its geological substrate before any firm conclusions can be made about these particular petroglyphs.

The Beaker arrowhead as well as other later findings and radiocarbon dates indicate that the Kivik site was used and altered many times through prehistory. Thus, parts of the monument could have been erected at an early stage with other sectors being altered and/or transformed over the years (Goldhahn 2013). However, in our opinion, the enclosure with the carved panels was most probably constructed during one particular phase. With regard to the dating of the rock art mentioned above, findings strongly indicate that the actual erection of the stone slabs together with the enclosure took place during the early stages of Period II or perhaps even during the transition between Periods IB–II.

The highly stylised design of the Bredarör images and the structured arrangement of the slabs indicates that a highly skilled carver or carvers may have made these in connection to a specific funerary rite during this phase. Further, it implies that the rock art and the production of it played an important role in this event. The images may even have been carved as a gesture of reverence to the deceased buried nearby (Kristiansen and Larsson 2005). The iconography has clear links to a pan-European symbolism and cosmopolitanism that may refer to a buried individual who had travelled in Bronze Age Europe or had connections to international affairs and exchange partnerships (cf. Kristiansen and Larsson). These findings seem to indicate that the deceased person was of elite status as opposed to being a local peasant or herder. Perhaps this individual was a warrior and/or a long-distance trader-traveller who had achieved chiefly status (Kristiansen and Larsson 2005).

Goldhahn (2013) stresses the importance of Baltic amber in this region and argues that some of the richly furnished graves in southern Scandinavia (not explicitly Kivik) could belong to individuals who controlled trade in long-distance luxury goods such as amber. We also think this may be a plausible explanation. But then how are the later features explained? We here refer specifically to the radiocarbon dating of the bones from inside and outside the enclosure and some of the elements on the slabs dating to the Late Bronze Age. For instance, the hat-like images on boats appear to be more recent as suggested by the presence of similar images on 'open air' rock art from the Late Bronze Age. As stressed above, in line with Goldhahn's (2013) theory that the Kivik site seems to have served as a necropolis for a long period of time, it is tempting to assume that both the location, as well as some of the carvings, were transformed and altered many times throughout prehistory.

Concluding remarks

The scan of the representational rock art in Bredarör revealed many new and complex details and features. Simultaneously, it brought to light many important issues and topics. Hopefully, this will propel debate on how the rock art could and should be interpreted and dated. The scan, SfM and RTI documentation has also verified some of the observations made by scholars such as Evers (Figure 6b) and Toreld and Andersson (2015), but also demonstrated deficiencies in earlier documentation efforts. However, the most important result is that it has enabled the production of considerably more complex and detailed images of Kivik rock art.

The scan results support a general dating of many of the images to an early phase of Period II (1500–1400 BC). There is much that supports Goldhahn's (2013) idea that the Kivik site was used and transformed many times throughout prehistory. We, however, argue that most of the images were made in connection with the erection of the slabs during an early stage of Period II. The highly stylised design of the images and their structured arrangement on the slabs seems to support this.

Finally, this case study illustrates the usefulness of new 3D digital technology. This technology is more accurate, effective, transparent and rapid when compared to old, traditional, tactile and subjective paper rubbing or plastic sheeting techniques.

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Henrik Zedig Länsstyrelsen Västra Götaland, Kristoffer Axelsson MLT and Ann-Louise Svensson-Ferngård Asmiroca.

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Article three: Transforming the Rocks – Time and Rock Art in Bohuslän, Sweden.

Horn, Christian; **Potter, Rich** (2018): Transforming the Rocks – Time and Rock Art in Bohuslän, Sweden. In *European Journal of Archaeolog*y 21 (3), pp. 361–384. DOI: 10.1017/eaa.2017.38.

My contribution to this article was through the creation and processing of the RTI photosets that were used for the analysis within the article. As well as being heavily involved in the analysis and discussion of the result, I also wrote sections of the article. **(overall contribution 50%)**

The focus of this article was on the creation and analysis of an RTI documentation of a Bronze Age rock art panel in Finntorp, Bohuslän. On this panel there are carvings including a shield and spear bearing warrior figure that was the focus of this investigation. RTI was used to determine the order in which the carving was created, as well as to evaluate whether the carving was updated. We found that it was possible to pick apart the order of carving, based on the depths of the carvings and by evaluating which element cut through which. We were also able to identify areas that had been updated, specifically the spear tip, and make comparisons to other sites in the nearby area that had also been similarly updated. This considerably strengthened the ongoing discussion about rock art being updated and transformed to match evolving traditions at the time, keeping the rock art relevant and relatable to its Bronze Age observers.

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Transforming the Rocks – Time and Rock Art in Bohuslän, Sweden

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Human representations are one of the most important groups of depictions in rock art in southern Scandinavia. These humans have long been discussed as complete, stable, and temporally-fixed images. The results of a new survey challenge this view. Recording rock art with Reflectance Transformation Imaging (RTI) enabled us to discern a possible sequence of production of individual human representations, their bodily features, and associated objects. Figures from a rock art site in Finntorp (Tanum, Sweden) will be used as an example. Differences in the dimensions of the engraved lines, the chronology of the depicted objects, and the placement of body parts suggest that several individuals may have been involved in making human representations on the rocks, and that their appearance as complete figures is the result of repeated transformations. The results presented demonstrate that Scandinavian rock art is not stable in time. We suggest that rock art is best understood as the creation of communities over time, which enables them to engage with the past by transforming the rocks.

Keywords: prehistory, rock art, Nordic Bronze Age, anthropomorphic representations, RTI

INTRODUCTION

Scandinavian rock art of the southern tradition is an immensely rich source for our understanding of Bronze Age society. The southern tradition is defined as a separation from the northern tradition of rock art, which is attributed to hunter-gatherers and has a somewhat earlier chronology and image programme that may have inspired the later southern tradition (Sognnes, 1998; Goldhahn, 2002). Besides the omnipresent cupmarks, it is a tradition rich in naturalistic and abstract depictions of objects and living beings. There are canoes, footprints, wagons, ards, axes, humans, deer, horses, birds, and many other images. Rock art panels were completed over long periods of time (Bertilsson, 1987; Nordbladh, 1989; Bradley, 2000: 68; Fredell, 2003; Bengtsson, 2004: 75–82; Ling, 2008; Skoglund, 2016). Taking a *longue durée* perspective, rock art panels involved multiple individuals creating the appearance we encounter today. It has been suggested that similar motifs may have been engraved by different individuals (Bengtsson, 2004: 95–112). The reworking of individual figures has been discussed for anthropomorphic figures and canoe images (Fredell, 2003; Hauptman Wahlgren, 2004; Ling, 2008), and researchers have attempted to record such changes—especially for reused cupmarks (for example Fredsjö, 1971). Recently, Per Nilsson suggested the possibility that individuals interacted with rock art long after it had been carved (Nilsson, 2012). One way of distinguishing the different individuals involved in making rock art is to identify different engraving

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techniques (see Burenhult, 1980). Different engraving techniques have been observed on the stone slabs of a burial in Sagaholm (Wihlborg, 1978), which Goldhahn attributes to separate individuals being present at the burial (Goldhahn, 2016: 33–55).

Our aim is to elaborate on these notions by using a methodology we think will improve the recording and understanding of rock art. In the following, four figures from a large rock art panel in Finntorp are analysed (Bohuslän, RAÄ Tanum 89:1 [Swedish National Heritage Board inventory number]; see Figures 1–2): the large spearman, an axe bearer, and a pair of warriors with bent legs. The team, consisting of Christian Horn (University of Kiel) and Rich Potter (Gothenburg University), visited the panel four times between 2013 and 2015. This made it possible to undertake an in-depth analysis. Reflectance Transformation Imaging (RTI hereafter), a recording method previously unused at the site, was employed to study the panel. It is a method uniquely suited to observing the order in which individual lines were engraved.

We hope to demonstrate that some figures are better understood as a sequence of events. Such images are not static entities that were complete after one event. We will argue that the images were not conceived and engraved by a single individual. Further, we suggest that people actively engaged in rock art in the

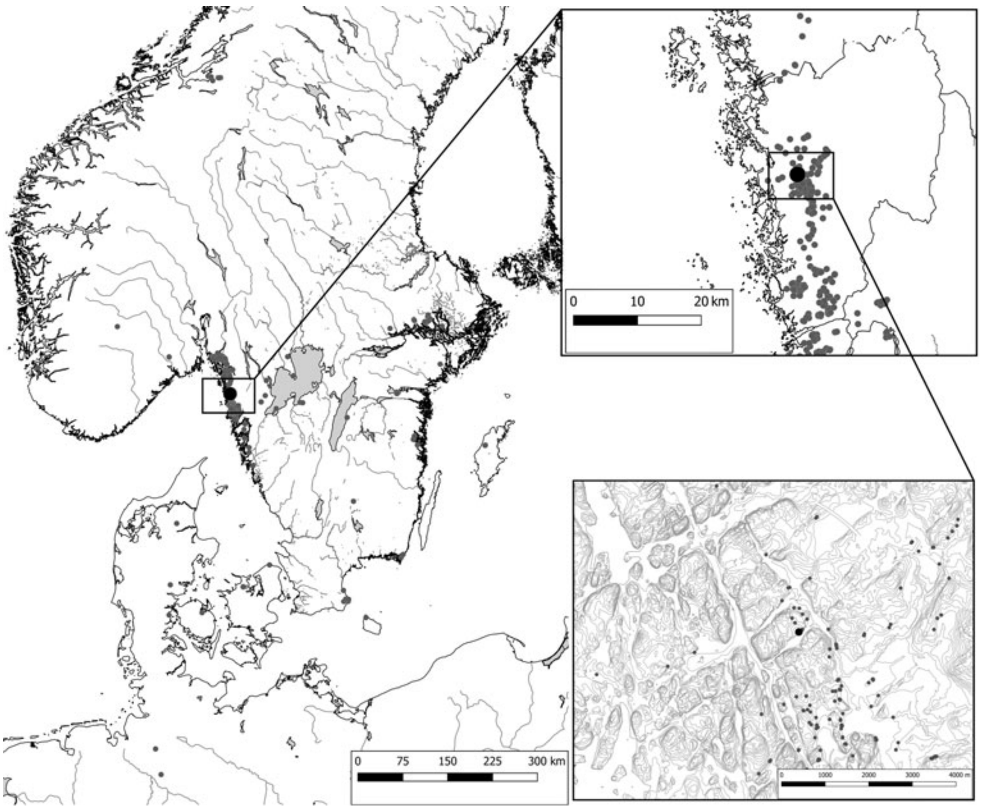

Figure 1. *Overview of the location of Finntorp (large, black circle; RAÄ Tanum 89:1) in relation to other sites with anthropomorphic rock art (smaller circles).*

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past. This approach is complementary to large-scale analyses focused on the social setting of rock art panels (see Bertilsson, 1987; Ling, 2008). However, the in-depth analysis of the process of production gives us an indication of how people encountered the past, curated their heritage, and demonstrates how time coalesced on the rocks.

Method

The individual figures on the panel at Finntorp were recorded with RTI using Polynomal Texture Maps, an invention by Tom Malzbender of Hewlett Packard in 2000 (Malzbender et al., 2000, 2001; Mudge et al., 2012; for a recent review see Earl et al., 2010). We used a method called 'Highlight RTI' as described by Mudge et al. (2006). This method computes a pseudo-3D or 2.5D file from the surface reflections. A static camera is set up on a tripod to take a series of images with lighting from oblique angles such as raking light. The Cultural Heritage Imaging group (CHI) provided guidelines, with which we complied (Cultural Heritage Imaging, 2013). Ideally, 60–70 photographs should be taken (Díaz-Guardamino et al., 2015). However, wind and sudden rain during our fieldwork seasons necessitated completing the work quickly. We aimed to take as many photographs as possible with a Canon 7D dSLR and a Canon Speedlite 430EX flash unit, and achieved good results with 40–50 images. In order to not disturb the tripod while taking images, the camera was remotely operated by Phottix Stratos 2 triggers. The panel was cleaned with a brush beforehand. There was lichen growth on the panel, but it was minimal and did not affect the engraved lines enough to impair the analysis. The photographs were converted into ptm files with RTI Builder Version 2.02. Afterwards, analysis was carried out in RTI Viewer Version 1.1. Both software programmes are open source, and CHI provides them on their website (http://culturalheritageimaging.org). RTI Viewer computes surface normals (that is, a vector which is perpendicular to a given pixel; a normal map is an image which stores these directions) and creates an artificial representation of the shape of the surface. The application of filters and the dynamic movement of the lighting enhances the visibility of features. We primarily used the diffuse gain and specular enhancement filters.

Superimposition has been used in studies of painted rock art to infer relative painting sequences (for example Schaafsma, 1986: 14; Bednarik, 1992). Equally, for engraved rock art, it has helped to establish relative chronologies of, for example, canoe petroglyphs and individual panels (see Bednarik, 1992; Ling, 2008: 238; Fredell, 2009). Mudge and his colleagues have shown that RTI is an excellent tool to observe sequences in the production of rock art by analysing a Portuguese goat image dating to the Palaeolithic (Mudge et al., 2006). In recent years, an analysis of the Folkton drums (incised Neolithic chalk objects from Yorkshire, UK) has shown a sequence of production using RTI to detect intersecting and cross-cutting lines and features (Jones et al., 2015). Another analysis carried out on Bronze Age stelae from Spain focused, like our work, on the sequence of production of the petroglyphs and on superimpositions (Díaz-Guardamino et al., 2015). Despite these endeavours, the production sequence of individual figures has not been considered much; instead, the focus was on the production of entire panels (Bertilsson, 1987; Nordbladh, 1989; Bradley, 2000: 68; Bengtsson, 2004: 75–82). It has been demonstrated that lines in Scandinavian rock art have been re-engraved at later times (Hauptman Wahlgren, 2002; Goldhahn, 2011), which would hamper our analysis; but, at Finntorp, only the spearhead showed signs of this sort of activity. We relied on a combination of four aspects: line thickness, line depth, superimpositions, and the relative dating of the objects depicted. To a lesser extent, we relied on differences in engraving techniques, because most engravings were made using a similar technique in Finntorp. Frottage (taking rubbings) was very useful to judge the different width of the lines. However, frottage is less suited to record superimpositions or give a good perception of depth because it only picks up the highest surface features, while features within grooves are left out. RTI is very good for judging line depth and, therefore, for recognizing superimpositions. Generally, superimposition indicates more recent additions (Mudge et al., 2006; Jones et al., 2015), although we allow for the possibility that more recent lines could have been shallower than earlier ones. The idea that time depth existed between separate engravers was based on the comparison of parallels for the engraved objects in the archaeological record. Thus, it is a combination of features that allows us to argue for separate carving events. In the future, macro RTI and photogrammetry will be carried out in further fieldwork to test our methodology (see Plisson & Zotkina, 2015).

Site and Documentation

The rock art panel RAÄ Tanum 89:1 is located in Finntorp, Tanum, close to Vitlycke museum. Its exact location is: Finntorp, Tanum, Bohuslän, Sweden, N 58° 42' 18,98", E 11° 19' 26,73" (WGS84; Figure 1). Figurative rock art was engraved on a rock outcropping in the lower part of a gentle slope overlooking a shallow depression in the landscape. The rock itself is Bohus granite, a very hard Precambrian type of rock (Eliasson & Schöberg, 1991). The images generally avoided quartz intrusions so that no change in technique was required when applying the image to the rock. If different techniques were used, then it was by choice, not by necessity. The panel consists of seventeen or eighteen anthropomorphic figures, four canoes, at least seventeen individual cupmarks not incorporated into figurative petroglyphs, and a number of individual lines without coherent composition. There were probably more figures engraved in the past, but the upper part of the panel broke away some time after the Bronze Age. The area itself is rich in rock art panels. At least four larger compositions with more than one engraved image, and an even larger number of single image panels, have been discovered in Finntorp. The scenes described below are separated by two natural cracks that divide the panel into four or five different canvases (Coles, 2000).

The panel is well known and has been documented by several researchers. In 1889, Lauritz Baltzer produced a graphic of the panel (for a history of research, see Bertilsson, 2015). It shows the scene in good, but not full, detail; the damage on the upper part of the rock is already visible (Figure 2a). Torsten Högberg's 1970 tracing paper documentation records the phallus and other features, but the spear point of the big spearman is missing (Figure 2b). Furthermore, the figures seem somewhat out of proportion. Lastly, Tanums Hällristningsmuseum in Underlös documented the scene in 2005 using frottage (Figure 2c). All the details of the spearman are visible. Nevertheless, due to the problems outlined earlier, the order of intersecting lines was recorded very weakly or not at all.

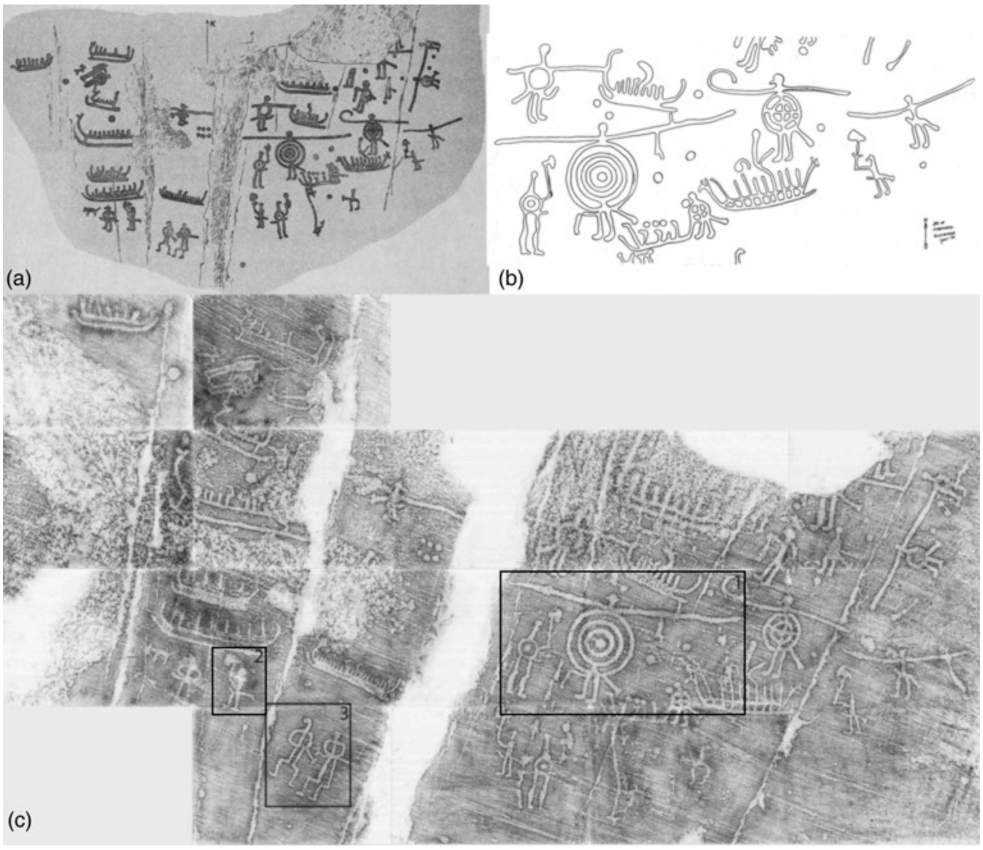

Figure 2. *History of documentation of Finntorp (RAÄ Tanum 89:1). (a) graphics by Lauritz Baltzer, 1889; (b) tracing paper by Torsten Högberg, 1970; (c) frottage by Tanums Hällristningsmuseum Underslös, 2005. Figures discussed in the text are indicated.*

The Big Spearman

Description

The spearman is a large figure, roughly 40 cm tall, located on the south-eastern section of the panel (Figure 3). The figure holds an 82.5 cm-long spear, a shield, and a sword. His two legs and feet are visible and there is a phallus. No arms could be recognized, and were probably never engraved. On the head, there are two small circular features that could be ears or earrings. In light of the large, anthropomorphic figure from Litsleby (RAÄ Tanum 75:1), we will use the term earrings in the following.

RTI was carried out three times on the big spearman. First in August 2014 and then twice in July 2015 under difficult circumstances due to high winds. Nevertheless, an investigation of the RTI files revealed several cross-cutting features. Starting from the top, the spear is cut by the largest concentric circle (Figure 3.1.1). The neck of the figure cuts the outer concentric circle and the spear (Figure 3.2.1). The head potentially cuts the neck, but in another image it seems more likely that the neck cuts into the head (Figure 3.2.2).

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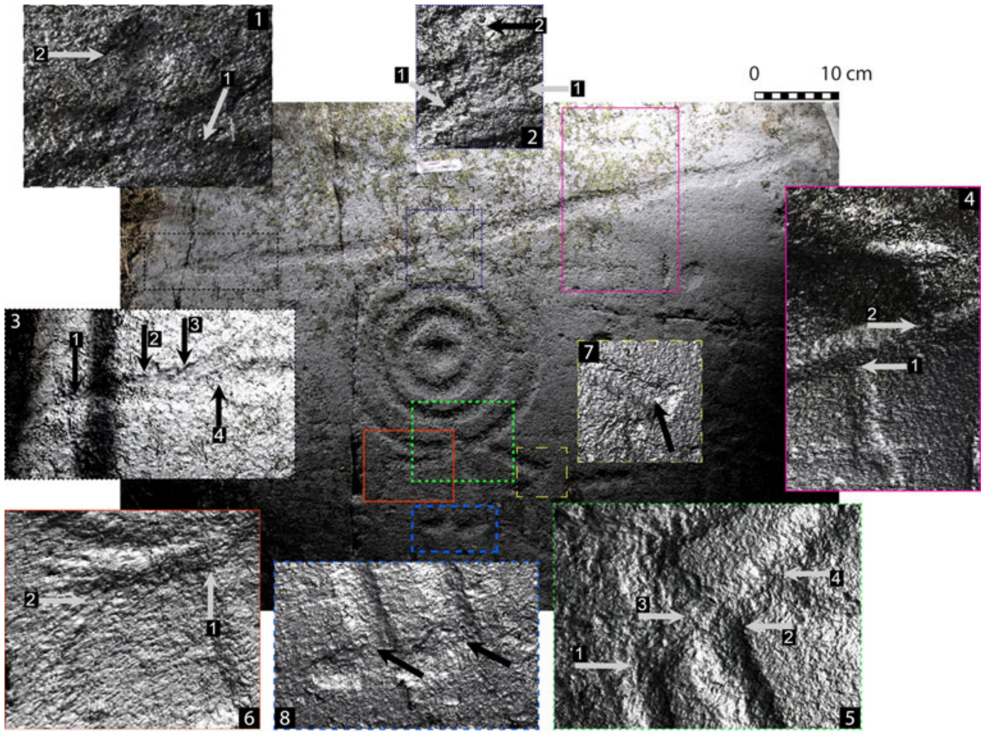

Figure 3. *RTI documentation of the big spearman. 1: cupmark and shield rim; 2: neck; 3: spear points; 4: spear shaft with small human and line; 5: legs, sword sheath and lower shield; 6: phallus; 7: sword sheath; 8: legs and feet.*

Although the earrings are not cut as deeply as the head, chipping of the rock inside the head indicates that they were later additions (Figure 3.1.2). There may be up to four different spear points, each of which has a smaller point which cuts into the successively larger spear points (Figure 3.3.1–4). On the other side, there are two lines, one of which intersects with the spear shaft. No direct cutting could be observed on the line closer to the spearman's body (Figure 3.4.1); however, the inside of the shaft was slightly chipped by this line. Further along the shaft, there is a second line that intersects with the shaft and the canoe above (Figure 3.4.2).

Cross-cutting can also be observed in the lower part of the figure. Both legs intersect the outer shield circle (Figure 3.5.1–2). It is possible that the right leg formed a major part of the lower torso that bisects the second concentric circle. Nonetheless, the left leg cuts into the right leg (Figure 3.5.3). Interestingly, the sword sheath cuts the outer concentric ring, but does not intersect with the right leg (Figure 3.5.4). Conversely, the phallus was engraved deeper into the outer circle as well as the left leg (Figure 3.6.1). There is a line on the tip of the phallus, but it does intersect with the phallus (Figure 3.6.2). The chape cuts through the lower part of the sheath itself (Figure 3.7). Lastly, both feet cut into the legs (Figure 3.8).

Production sequence

Perhaps the earliest feature to be carved in the composition was the cupmark that was

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later incorporated into the composition as the head of the figure. If this is so, it may be reasonable to assume that other cupmarks, like those at the centre of the concentric circles, were also engraved before the figurative features were applied (Figure 4.1). Both cupmarks were ground or smoothed after engraving, unlike all the other lines. Individual cupmarks on the panel open up the possibility that Finntorp was originally a cupmark panel (see for example Bengtsson, 2004: fig. 6.2a). Based on the observed superimpositions, the shaft of the spear was perhaps engraved next, together with the largest spearhead (Figure 4.2). Subsequently, gradually smaller spear tips were engraved, suggesting at least four separate events (Figure 4.4–6).

The outermost concentric circle was engraved before the neck that connects the head, shaft, and the circle. Therefore, these circles may have been next in the sequence (Figure 4.3). Since all the rings have the cupmark rather precisely at their centre and maintain an equal distance to each other, the rings may have been engraved from the inside outwards. Similar imagery has been interpreted as sun symbols (Almgren 1927; Bradley, 2009: 155–61); but, in Finntorp, the circles are in close proximity to the spear, which suggests that an interpretation of it being part of a warrior's equipment is more likely. That, however, does not mean that this was the only meaning this engraving possessed. The colour of bronze shields could have contributed to the imagery and meaning attributed to sun symbols (Horn, 2016). Individual concentric circles in combination with individual spears are known on other panels, for example in Hede (Bohuslän; RAÄ Kville 125:1). Therefore, with the additions of the circles, in Finntorp the cupmark was transformed into a shield. The concentric rings and the neck may, therefore, have been engraved in separate events (Figure 4.4). The initial idea may have been to carve objects, such as a spear and later a shield. This is plausible because the engraved lines of the shield and the legs differ in width and depth. Therefore, interpreting this figure as a human is perhaps a more recent development.

The legs were engraved next, the right before the left. It is impossible to distinguish whether the sword sheath was applied before or after the legs (Figure 4.4). Given their similarity, we assume that these additions were made during the same art-making event. Feet were then added to the figure. Judging by the superimposition, the right foot may have been engraved after the left, which inverts the order the legs were engraved in. Due to their stylistic similarity, the chape and the feet were possibly added directly after the sheath and the legs.

The phallus and the earrings deviate in style from all of the other lines. Compared to their diameter, the earrings appear to be relatively deep, and they are made very coarsely. The line of the phallus is narrower than that of the shield and the legs. Although the earrings and phallus are potentially the last additions in the overall sequence, they do not appear to be made by the same individual (Figure 4.6). The line in front of the phallus may have been added even later, but it is entirely uncertain whether this line was intended to be an addition to the spearman at all (Figure 4.7). The completed figure includes two possibly coincidental additions along the spear's shaft (Figure 4.8).

An Axe Bearer

Description

This figure is situated to the west and slightly to the south of the big spearman.

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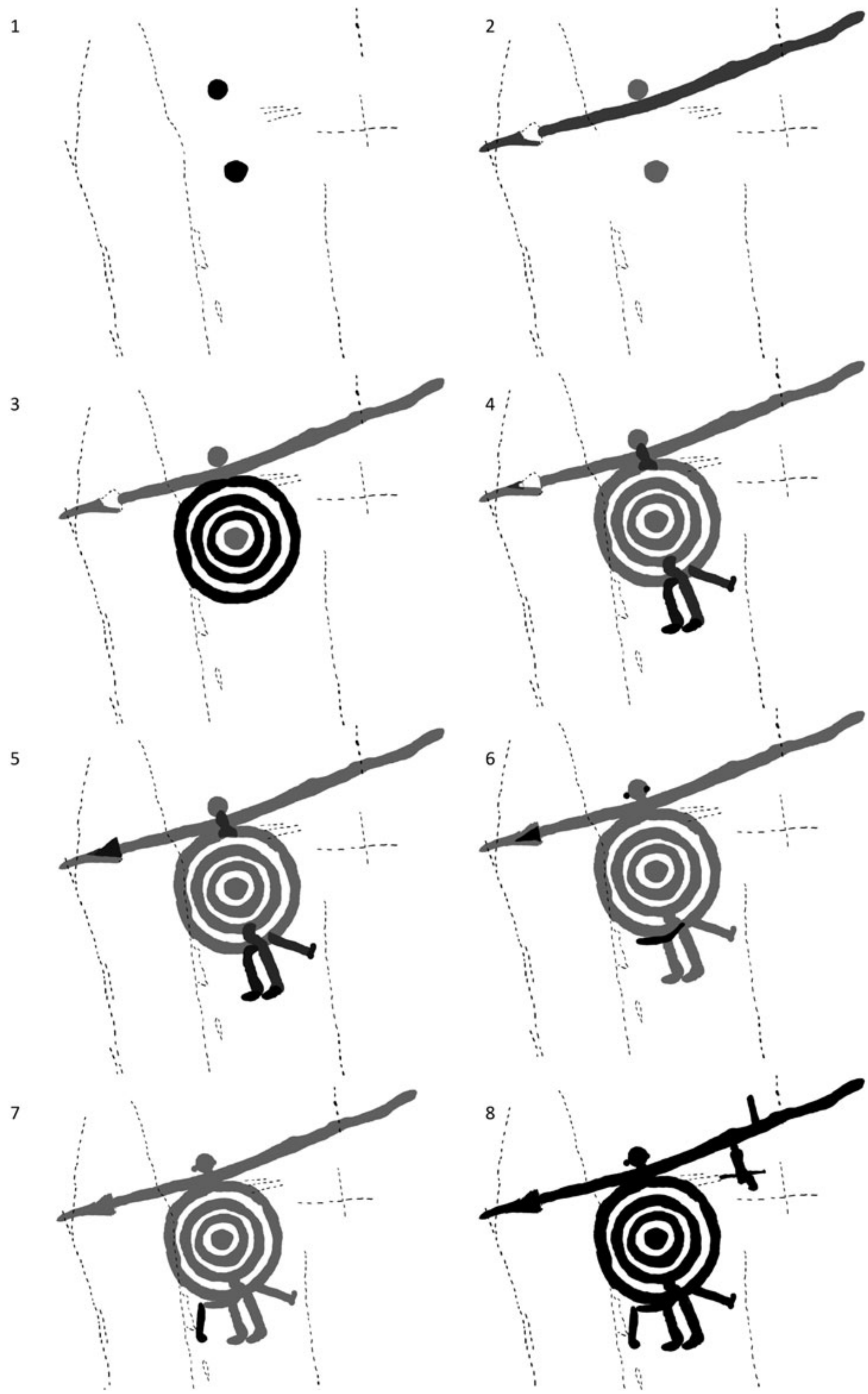

Figure 4. *Engraving sequence of the big spearman.*

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Overall, weathering caused its appearance to be less clear than that of the spearman. On the upper body and neck area there is some chipping on the rock surface, but it is not severe enough to destroy the area. The axe bearer is approximately 16 cm tall, which is considerably smaller than the spearman figure, but observations are still possible (Figure 5). We carried out RTI in 2015 which allowed us to construct a tentative sequence of actions on the rock.

Starting from the top, the axe head has been re-engraved, and a smaller axe (Figure 5.1.1) was cut into the larger one (Figure 5.1.2). The handle overlays the lower part of the larger axe head (Figure 5.1.3), but is itself intersected by the smaller axe head (Figure 5.1.4). The head of the figure cuts into the neck and the body (Figure 5.2.1). The upper arm marginally cuts into the head (Figure. 5.2.2) and the lower intersects with the body (Figure 5.2.3). Due to the damage noted above, the position of the arms is difficult to interpret. It seems that the arms intersect the handle (Figure 5.2.4), although this can only be inferred for the upper arm. Lower down, the sheath cuts into the body line (Figure 5.3.1). The figure seems to possess two erect male genitals (Figure 5.4.1–2). Both overlay the sheath (Figure 5.4.3), the body line, and the frontal leg (Figure 5.4.4). The longer phallus cuts into the axe handle (Figure 5.4.5), but is itself intersected by the smaller phallus (Figure 5.4.6). The feet cut their respective legs (Figure 5.5.1), with the front foot intersecting the other (Figure 5.5.2).

Production sequence

Unlike the big spearman, the image of this axe bearer could not have started with a

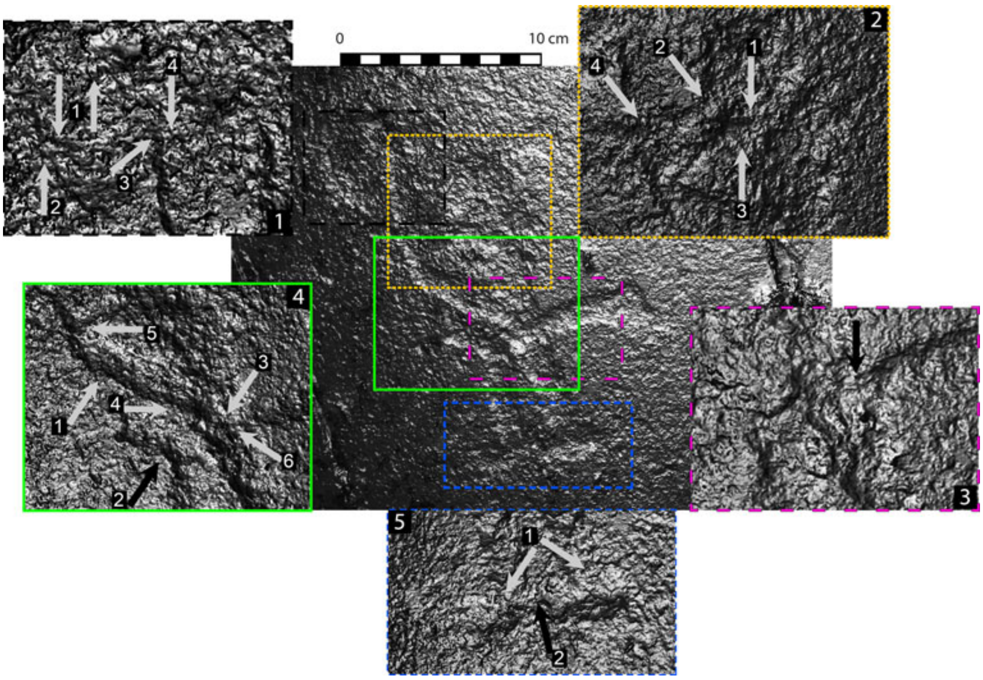

Figure 5. *RTI documentation of the axe bearer. 1. axes; 2: head, arms, and upper body; 3: leg and sword sheath; 4: lower body; 5: lower legs and feet.*

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cupmark since the head intersects the bodyline and is flat, rather than spherical. Compared to the other lines of the figure, the larger axe head is not cut very deeply into the stone. The first petroglyph was possibly the larger axe that is likely to have been engraved without a handle, because the smaller axe and the handle cut through this image (Figure 6.1). The handle, therefore, was potentially engraved at the same time as the smaller axe head since it fits its upper and lower side. This petroglyph might have originally been intended to be an individual object (Figure 6.2).

The human figure was potentially started by engraving the line that forms the hind leg and body (Figure 6.3). From a stylistic perspective, the legs are parallel to those of the big spearman with the front leg splitting away from the rear leg in a slight curve. Although overlaid by phalli and the sheath, the body/leg may have been engraved continuously as both line up. The figure could also have started with the front leg, as the phalli obscure the intersection with the rear leg. However, since the foot on the front leg cuts the foot of the rear leg, it is perhaps more likely that the rear leg/body line was engraved first, then the foot on that leg, and afterwards the front leg and its foot (Figure 6.3). The similar width of the lines may indicate that they were engraved during the same event. If that is the case, then the arms were not applied at that time, because they are considerably narrower and deeper. These arms may have destroyed the original arms, if there were any. Applying these arms may be what damaged the upper torso (Figure 6.4). If the figure had no arms to begin with, then the first attachment to the axe may have been the first phallus. Alternatively, it could also represent a somewhat misplaced arm. Following that, the sword was engraved at the same time as the phallus/arm, the legs, and the head. Support for this is provided by their similar width and depth. The shorter phallus including testicles was engraved afterwards; it is a somewhat more realistic rendition. For stylistic reasons, the thin arms are assumed to be last in the overall production sequence (Figure 6.5).

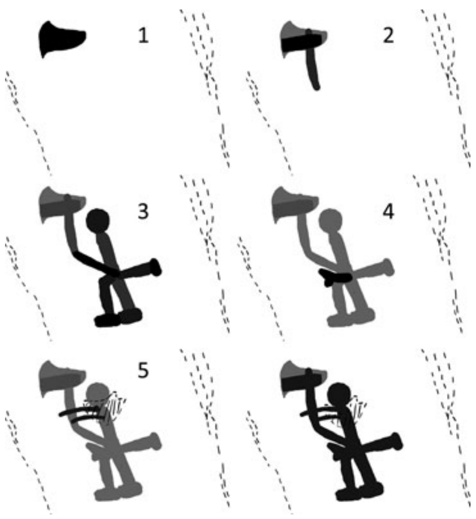

Figure 6. *Engraving sequence of the axe bearer.*

A Pair of Warriors with Bent Legs

Description

The two human figures were engraved to the south of the other figures (see Figure 2), but they are closer to the axe bearer. We carried out RTI once in 2015. The left figure (from the observer's point of view) was 24.7 cm long and the right 26.5 cm (Figure 7). Slight damage occurred to the neck area of the right figure after it was engraved. A recent frottage of these anthropomorphs seems to indicate a nose on the right figure (Figure 2c). In images from the RTI files, we observed that this 'nose' was more likely to be a crack that runs through the head. The fissure does not show up very

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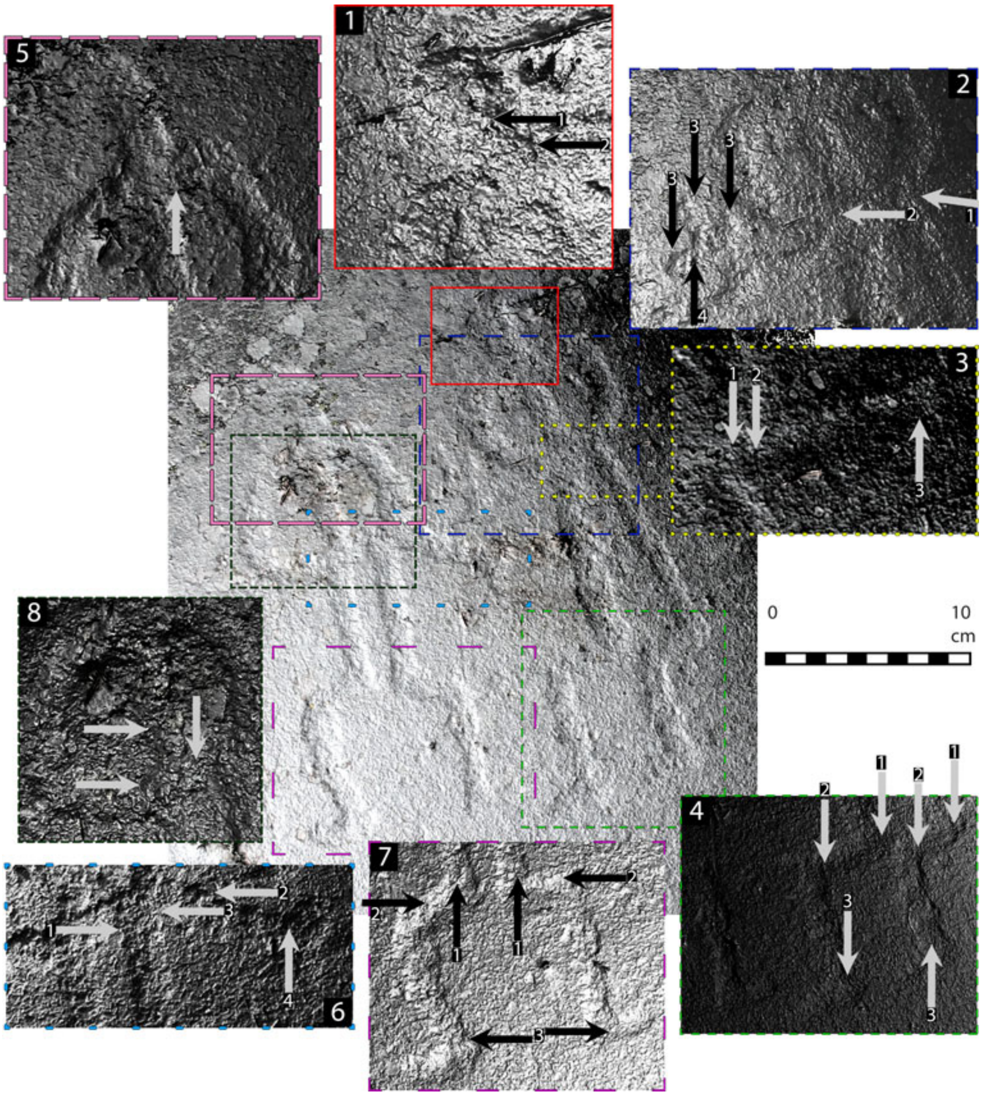

Figure 7. *RTI documentation of the warriors with bent legs (1–4 right warrior, 5–8 left warrior). 1: head and neck; 2: lower body; 3: sword sheath; 4: bent legs; 5: head and neck; 6: lower body and sword sheath; 7: bent legs; 8: upper body.*

well in the frottage, but given its weathered edges, it is probably an old crack.

The following observations could be made about the right figure. The head cuts into the neck (Figure 7.1.1). The neck itself intersects with a ring that may form the arms (Figure 7.1.2). The body/left leg line also bisects the arms (Figure 7.2.1), but is itself superimposed by the phallus (Figure 7.2.2). The genitals may form what could be perceived as a 'flower' with three petals at the tip and a leaf. None of the 'petals' cut into the phallus (Figure 7.2.3). Close to the tip is a circle that cuts into the three surrounding 'petals' (Figure 7.2.4). The right leg also cuts into the arms (Figure 7.3.1). Very weak chipping on the border between the right leg and the

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sheath may indicate that the sheath cuts into the leg (Figure 7.3.2). The sword sheath overlays the arms (Figure 7.3.3). The peculiar shape of the legs is of particular interest. At the 'knee', there is a small oval shape that overlays the upper leg (Figure 7.4.1) which is itself intersected by the lower leg (Figure 7.4.2). The lower leg is cut by another oval shape (Figure 7.4.3).

Unlike the right figure, the head and neck of the left figure seem to consist of one continuous line that then cuts into the ring and forms the arms (Figure 7.5). The right leg and the sword sheath also cut the arm (Figure 7.6.1). The right leg and sword sheath touch each other, and the leg might cut through the sheath (Figure 7.6.3). Again, the chape cuts the sheath (Figure 7.6.4). Both legs show the same pattern as the legs of the right figure (Figure 7.7.1–4). It is possible that the left leg cut the arms as well; however, it is difficult to observe because the phallus, including the testicles, bisects this area (Figure 7.8).

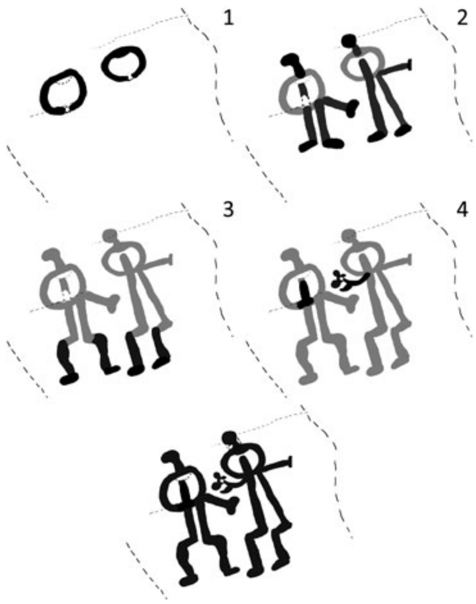

Figure 8. *Engraving sequence of the warriors with bent legs.*

Production sequence

With these observations, we may suggest a possible sequence of production and find an explanation for the legs. Since the arms do not seem to overlap any other feature, they may have been the first feature of the composition (Figure 8.1). Due to the positioning of the body/leg line, it is unclear whether they were engraved as a closed or open ring. Single rings are known on many rocks; for example, Skee in Tanum (RAÄ Skee 602:2). It may be that the carvers of the Finntorp panel chose such individual rings to add human features to them. The rings themselves have a peculiar shape; they are not quite round, but rather oval and sharply curved. The top is thicker than the lower part, and one seems to be slightly curved inwards.

All the lines representing the neck on the right figure, the head and neck of the left human, and the thighs are wider. Therefore, they may have been applied by different carvers (Figure 8.2). If we visually isolate the thighs and the 'knees', it is possible that they originally formed a normal pair of legs with feet (Figure 8.2–3). We think that the production event ended after the application of this initial pair of legs, because we assume that anyone who makes the effort of engraving a complete pair of legs does not immediately go on to amend their work. Nevertheless, it is currently impossible to determine how much time passed before the legs were transformed. The swords were potentially added during this session as well. On the right figure, the sheath cuts very marginally into the right leg, on the left figure both lines are next to each other. This kind of precision may lend support to the thesis that the same individual applied the sheath and the initial legs. A similar width

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and depth of all these lines speaks in favour of their contemporaneity.

We suggest that people visiting this site at a later date added a new pair of legs to both human representations (Figure 8.3). This transformed the old feet into very pronounced knees. The new feet were engraved after the line of the new legs was applied. Since the old feet pre-determined the direction of the knees, the new feet follow the positioning of the old feet. The astonishing similarity of how each transformation was carried out on the two figures suggests that it was done during the same event.

The phalli on both figures were applied after the first legs (Figure 8.4). Both figures show a parallel development until that point, but, after it, one was fitted with a physiologically correct representation of a phallus, while the other was more complex. This may indicate that steps to differentiate the two figures were taken after the addition of the second pairs of legs.

Hypothetical Chronology of the Production Sequences

The relative production sequences outlined above have no specific time depth. The images could have been made within a few hours, weeks, years, or centuries as nothing in the technique used to engrave the lines indicates a chronology. It is only when we are able to date some of the features that we can argue for a chronological separation of engraving events. Dating human representations in southern Scandinavian rock art is notoriously difficult. Typically, associated objects are the best option to narrow the chronology down, because parallel metal objects exist in the archaeological record (Hildebrand, 1869: 425–26; Nordén, 1925; Almgren, 1987: 38). As we shall see, however, there is some doubt that human figures are always contemporary with the object they hold. Shoreline dating has proven successful in establishing a chronology of canoe images (Ling, 2008), but has not yet been used to evaluate anthropomorphic representations. Superimpositions of, or by, canoes have been used, but they are rare (Fredell, 2009). Comparisons of petroglyph style are problematic for anthropomorphic images and can only be used as a first guess. Stylistic approaches have been used for the Scandinavian material only (Almgren, 1987) and by drawing parallels to other regions (Fredell, 2003; Fredell & Quintela, 2010). To get some indicators of the chronology of the figures, we will examine some of the linked objects. Other objects, i.e. the axes and the rings, are too nondescript to attempt dating them.

The spears

The big spearman is best suited to address the chronology of the Finntorp figures because of the objects associated with him. Unfortunately, three later images obstruct the original spear point. The elongated form and the potentially smooth outward swing of the lower part of the blade could suggest a Valsømagle type (Figure 9a). Later spears have different proportions (Figure 9b). This may indicate that the first spear belongs to period Ib (1600–1500 BC) in the Nordic Bronze Age chronological scheme. Other early individual spear petroglyphs have been discovered; for example, on a panel in Himmelstalund (Östergötland; Östra Eneby RAÄ 1:1) or Kalleby (Bohuslän; RAÄ Tanum 248:1). The three subsequent spearheads are very schematic. This may point to a date after period II (1500–1300 BC), because during the initial phase of rock art, carvers seem to have preferred a more realistic style for metal objects (Burenhult, 1973: 45; Ling,

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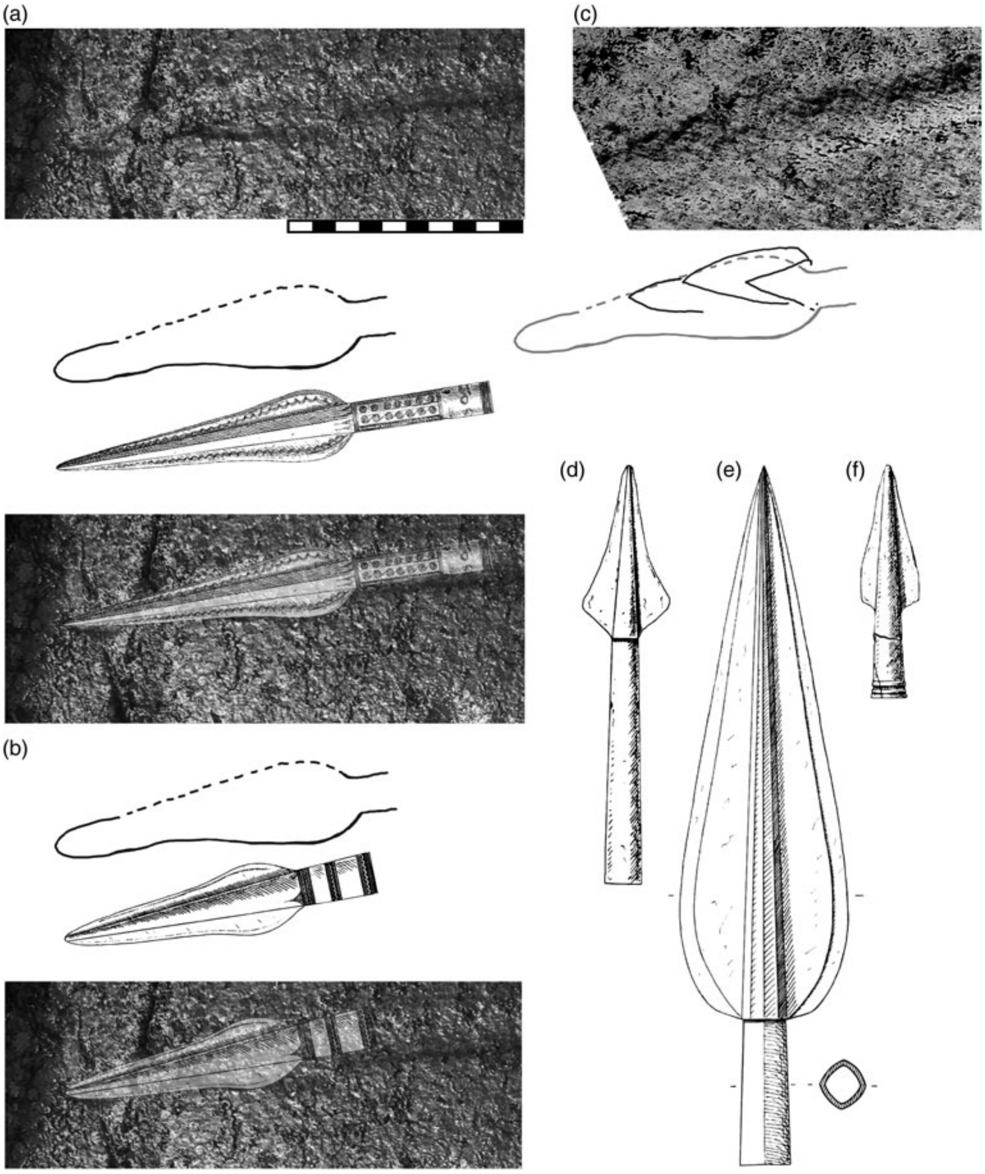

Figure 9. Comparison of the largest spear point with (a) Valsømagle type spear (Falköping, Sweden; original length 37.2 cm; Jacob-Friesen 1967, no. 221.); and with (b) a period II type Smørumøvre spear (Smørumøvre, Denmark; original length 18.8 cm; Jacob-Friesen 1967, no. 365.); (c) later spearheads with possible comparisons for spearhead engraving 3 at Finntorp; (d) Bassen-Tüchten, Germany (18.2 cm; Jacob-Friesen 1967, no. 1217.); (e) Borbjerggård, Denmark (30.4 cm; Jacob-Friesen 1967, no. 589.); and for spearhead engraving 4; (f) Bäk, Germany (10.2 cm; Jacob-Friesen 1967, no. 698.). Spearheads (a)–(b) scaled to the size of the engraving. All images redrawn by Christian Horn.

2008: 53–54). The last two reworkings of the spearhead represent triangular blades with straight or slightly concave edges, the second oldest (spear two) seemingly narrower and longer (see Figure 4.4). Spear three is somewhat larger than the final spear tip (see Figure 4.5–6). Spear three could potentially resemble a Lüneburg type I or III spear (Figure 9d–e). The edges of these Lüneburg type spears sometimes join the socket almost perpendicularly. Spearheads from Bassen-Tüchten (Germany, no. 1217a; this number and all the following numbers refer to Jacob-Friesen, 1967), Ladeburg (Germany, no. 1432), and Bad Oldesloe (Germany, no. 785) are not perfect fits, but they could be seen as the closest available parallels. Other parallels could be the spears from Boerakker (Netherlands, no. 1736), or from the Borbjerggård hoard (Denmark, no. 589). The last spear engraving in the Finntorp spearman's image bears a closer resemblance to a Saxo-Thuringian type spear (Figure 9f), for example those from Bäk (Germany, no. 698), Ahlem (Germany, no. 902) or from the Basland hoard (Denmark, no. 522). Another possibility is that points three and four represent flint spearheads (see for example Montelius, 1917: 450–90).

The coexistence of longer and shorter spearheads, for example in a hoard from Bargfeld (Germany, no. 1120), makes the chronology of spear points three and four complicated. However, reviewing the evidence collected by Jacob-Friesen (1967), we could perhaps suggest that finds of longer spearheads, for example Bassen-Tüchten and Ladeburg, could be dated somewhat earlier, i.e. from period III to the beginning of IV (Jacob-Friesen, 1967: 180) of the Nordic Bronze Age chronology (1300–1000 BC). Assemblages with shorter spearheads of the types that resemble the engraved ones tend to date to period IV–V (1100–720 BC); for example, the hoards from Bäk and Basland (Jacob-Friesen, 1967: 237). This is also true for hoards in which longer and shorter forms of spears are associated, such as the hoard from Bargfeld (Jacob-Friesen, 1967: 182). This dating is consistent with the newer literature (Schmidt, 1993; Maraszek, 2006). However, none of these parallels fit the later spearhead engravings perfectly. If the two triangular points are flint points, then the chronology becomes even more problematic as, to our knowledge, there is no chronological study for this group of finds.

The shield

The second object the spearman carries may be a shield. The shields of the Nipperwiese type (with simple concentric ribs) may represent a good parallel (Figure 10a), which in turn has a parallel in Schiphorst, Northern Germany (Uckelmann, 2012: 21). This shield type spread from Germany and Poland to the British Isles and dates to the transition from Period II to III of the Nordic Bronze Age (1350–1200 BC).

The swords

The style of the human features on the big spearman deviates from both the spear's shaft and the concentric circles; and the figure superimposes the lines of the objects and the cupmarks in all instances. This means that the earliest point in time the image could have been transformed into a fully articulated human representation is after the shield had been engraved. The chape of the sheath may give some indication of its date. Parallels may include the rhombic chapes of Westersode type (stepped, widest at the end; Laux, 2009: 137–38) from oak coffin graves, for example in Debsted (Laux, 2009: no. 413) (Figure 10). The bronze chape is much more delicate than the engraving, but if the engraving represents a general idea it may be an appropriate parallel. These chapes are dated to period III of the Nordic Bronze Age (Aner & Kersten, 2001: 15–16; Laux, 2009: 137–38). Of

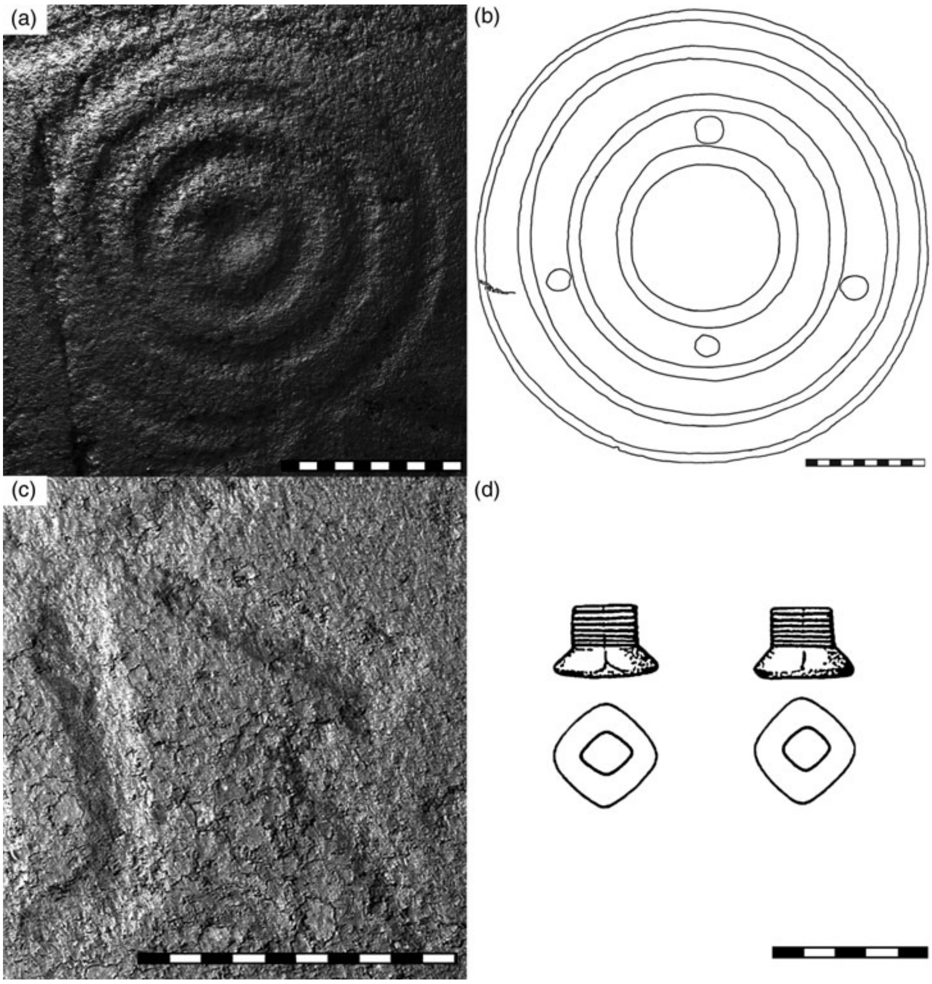

Figure 10. *Comparison of the shield of the big spearman (a) and the shield from Schiphorst (b), drawn by Christian Horn after Uckelmann, 2012: no. 12; comparison of the chape of the big spearman (c) and chapes from Debsted (d), drawn by Christian Horn after Laux 2009: no. 413.*

course, such chapes also occur on figures considered to be much later, like the horned warriors (recently Ling & Rowlands, 2015). It may also be that the horns were added later, but this needs to be tested. All other figures have similar sword chapes.

Ships on the panel

There are more than eleven ships on the panel, ten of which possess enough details to be datable (Kaul, 1998; Ling, 2008, 2013). Many canoes can be dated to periods II–III of the Nordic Bronze Age as shown by inturned, almost semi-circular prows and slightly upturned or oval keel extensions (Figure 11: canoes 1, 4–7). A cluster of these canoes is located between the four figures discussed here. Late Bronze Age canoes are also present and can be recognized by the very detailed animal heads at the prows' ends, by straight or inwardly-angled prows, and by a very sketchy and thin style of engraving that is

Figure 11. *Dating of canoes in Finntorp (RAÄ Tanum 89:1); canoe 1: period II–III; canoe 2: period VI; canoe 3: period IV–V; canoe 4: period II–III; canoe 5: period II–III; canoe 6: period II–III; canoe 7: period II–III; canoe 8: period I–II; canoe 9: period V–VI; canoe 10: period V–VI.*

akin to the arms of the axe bearer (Figure 11: canoes 2–3, 9–10). Most intriguingly, the canoe that is directly above the spear dates to period I–II, as indicated by the long, semi-circular prows and the straight keel extension (Figure 11: canoe 8). Although there is no definitive evidence, the chronology and location of the canoes complements the suggested chronology.

Discussion

For reasons of clarity, we shall summarize the sequence of events for each petroglyph before discussing their implications.

Big spearman

Two cupmarks were the first event, followed by the engraving of the first spear. The shield was then added and the spear point updated. In a fourth event the spearhead was updated again and the first anatomical features were engraved. Afterwards, the spear was renewed a fourth time and the earrings and phallus were added. This was done in one to three further events. In total, it may have taken four to ten separate events to give the composition its final appearance.

Axe bearer

The first event was the image of a single axe. Thereafter, the axe was transformed into a ‘complete’ implement. In a third event, head, body, legs, feet, and the phallus/arm were added to the composition. Later, someone added a realistic phallus. A considerable time after that, the two thin arms were engraved, which partially destroyed the figure. Five different events may have taken place.

Warriors with bent legs

Two rings were engraved during the initial event. Afterwards, they were transformed

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into human figures whose feet were further transformed into legs with pronounced knees. In a potentially final event, the realistic phallus and the 'flower-like' phallus were added. There were up to six different events to complete this composition, assuming the two phalli and the sheaths were engraved in separate events. It seems, however, more likely that there were only four.

Implications

It appears that none of the figures discussed here were originally conceived as human. During the Late Neolithic and Early Bronze Age, cupmarks and individual objects like halberds were engraved (Burenhult, 1980). The spearhead at Finntorp was the focus of considerable attention, with three recuts. Similarly, the axe of the axe bearer was also updated. Although only based on comparison, all sword sheaths seem to have been added in the course of period III of the Nordic Bronze Age. All human features have a very similar style, with each other and with the sword sheaths. This may lend support to the notion that they were engraved close together in time. They may even have been created by the same community or individual. On all figures, phalli may have been added later, because they deviate in style. The phallus/arm of the axe bearer may be the one exception. As opposed to the human features, the phalli are very varied in form and technique. On the engraved burial slab at Sagaholm (Wihlborg, 1978), this has been interpreted as an intentional device for a narrative. This was possible because the different styles were used simultaneously, intentionally creating a difference between the images. The burial was sealed after the interment so we know that the carvings were made at approximately the same time. The possibility of time passing between engraving events in Finntorp should nevertheless be taken into consideration because objects of different periods are depicted. We must at least assume that a different style represents a different individual.

Differences can be found in the kinds of objects connected to the figures and some of the bodily transformations, such as the pronounced knees or the later arms of the axe bearer. Taking all the evidence together, this particular panel in Finntorp may have been revisited periodically. Each of the three compositions was subject to at least four or five separate events, possibly taking place from the Late Neolithic/Early Bronze Age I to Bronze Age III (2200–1100 BC). The phalli may have been added at an even later time. Canoe petroglyphs from several periods on the same panel support this sequence. This indicates a long-term curation of rock art at Finntorp.

We suggest that more than one individual was involved in giving the compositions their final appearance. If we assume that arms, legs, and sword sheaths were engraved during period III, and were indeed engraved by a single individual, then the minimum number of people involved over time would be twelve. However, if different carvers added these anatomical features, such as the two pairs of legs on the warriors with bent legs, then a minimum of fifteen individual carvers may have been involved. This number could be higher if, for example, two separate people engraved the cupmarks on the spearman.

Meeting the Past on the Rocks – Interpretation

Based on these observations, it seems that multiple individuals were engaged in transforming images at Finntorp and, if our chronological suggestions are accepted, then some time may have passed between separate events. Later engagements with petroglyphs have previously been recognized. Recently, Per Nilsson discussed later activities on rock art panels and pointed out that additions were made to Bronze Age petroglyphs (Nilsson, 2012: 87–88). He interprets this as a dialogue with the past in which the meaning of the engravings was transformed. However, he talked about much later additions to panels after the tradition of making figurative rock art had ended. Katherine Hauptman Wahlgren observed that a reactivation of particular features may have taken place by engraving lines repeatedly, since the re-engraved lines show up lighter (Hauptman Wahlgren, 2004; Goldhahn, 2014). At Finntorp, this may only apply to the repeated engraving of the spearheads. All other parts were not re-engraved, but added to pre-existing images. Even the spearheads were not just re-engraved, but also transformed. Australian Wandijna paintings could be cited as an ethno-archaeological parallel. These are paintings of heroic ancestors in caves. Parts of them were re-painted regularly by clans to secure a continuous supply of animals (Layton, 1985). This engagement of people with the rocks to secure outcomes in the real world has been attributed to the secondary agency with which rocks and petroglyphs are imbued (Mowaljarlai 1988; Ling & Cornell, 2010). In Scandinavia, it has been argued that this is directly linked to the depiction of real-life activities and objects (Ling & Cornell, 2010).

This could have been the case at Finntorp. The site still stands out because objects were not just re-engraved, but also transformed. Similarly, there were not only features added to the pre-existing images, but the images themselves were transformed. A notion put forward by Tim Ingold is that landscape 'enfolds the lives and times of predecessors who, over the generations, have moved around in it and played their part in its formation' (Ingold, 2000: 189). In that sense, communities could engage physically with the past and their ancestors or the heroes of their stories with every transforming event. Temporal boundaries are transcended through the materiality of the rocks and the repeated material action of making petroglyphs (Fahlander, 2012). Nonetheless, Ingold goes on to say that individuals contemplated their own socio-environmental setting; they did not anticipate the sensibilities of future observers (Ingold, 2000: 198).

After their initial engravings, the rocks represent a framework anchored in time and space, where people could engage with their forebears. Whether they were heroes, as in the Wandijna example, or other ancestors is open to discussion. Regardless, the images were not stable, but malleable. Every engraver updated what was most important, or brought about change in their own socio-environmental setting. Therefore, every transformation produced a finished product. However, the successors of the initial carvers not only contemplated their own social environment, but something already made that oriented possible transformations. That these transformations were made suggests that these images were not sacrosanct.

Lastly, the potentially long history of some of the images is also a call to modern observers to exercise caution. What appears to us to be a great phallic spearman was only perceived as such relatively late in the existence of this image. Before that, it was purely combat weaponry. What was perhaps once perceived as a pair of (arm-?) rings was transformed into two phallic warriors with pronounced knees, possibly centuries later. In sum, engravings condense the material culture, rituals, and social ideas of many ages, and that should change the way we think about rock art too.

Summary

The application of new recording methods on rock art panels has enabled us to record an already known rock art site in greater detail. By moving to the micro-level of observation, we were able to retrace the sequence of events of individual lines and thus reconstruct specific events separated and distributed in time. The figures follow a similar sequence, from petroglyphs of individual objects to the addition of human features transforming them into warriors; phalli were added even later. We have suggested a tentative chronological sequence, spanning from the Late Neolithic to the Bronze Age.

With this, we could show that several individuals were involved in assembling specific figures in rock art that is usually perceived as a whole by modern observers. Interpreting the rock as a spatio-temporal meeting point, we argue that the rocks not only link individual carvers and their respective societies, but that engraved panels partially break down the barriers of time and space. Older petroglyphs attract, affect, enable, and constrain future transformations. Through their actions on the rocks, the carvers were able to engage almost physically with their ancestors.

Acknowledgements

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Des roches en transformation – art rupestre et temporalité en province de Bohuslän, Suède

Les représentations de figures humaines constituent un des plus importants groupes d'images gravées sur roche en Scandinavie méridionale. On a longtemps considéré ces humains comme des représentations complètes, stables et fixées dans le temps. Les résultats d'un nouveau relevé vont à l'encontre de ce point de vue. Un relevé utilisant l'imagerie par transformation de la réflectance (ITR) sur le site de Finntorp (Tanum, Suède) nous a permis de documenter une séquence de représentations humaines, de parties du corps et d'objets associés. Sur la base des différences dans la taille des lignes gravées, la chronologie des objets représentés et la position des éléments du corps nous estimons que plusieurs individus ont participé à la création de ces figures humaines et que leur apparence finale était due à des transformations successives. Nous pensons que l'art rupestre scandinave est le résultat d'une évolution dans le temps, les communautés qui en étaient responsables créant des images qui leur permettaient de communier avec le passé en transformant les roches. Les résultats et l'interprétation que nous présentons ici pourraient avoir des conséquences importantes pour la recherche en art rupestre scandinave et l'âge du Bronze nordique en général. Translation by Madeleine Hummler

Mots-clés: préhistoire, art rupestre, âge du Bronze nordique, représentations anthropomorphiques, ITR

Die Transformation der Felsen – Zeit und Felsbilder in Bohuslän, Schweden

Menschliche Figuren sind eine der wichtigsten Motive von Felsbildern in Südskandinavien. Darstellungen von Menschen sind lange als vollständig, stabil und zeitgebunden angesehen worden. Die Ergebnisse einer neuen Untersuchung stellt diese Interpretation infrage. Die Dokumentation von Felsbildern in Finntorp (Tanum, Schweden) mittels Reflectance Transformation Imaging (RTI) ermöglichte die Rekonstruktion der Produktionssequenz einzelner menschlicher Figuren und damit verbundener Gegenstände. Die unterschiedlichen Dimensionen der eingeritzten Linien, die chronologische

Abfolge der dargestellten Objekte und in die Lage der Körperteile weisen darauf hin, dass die Figuren erst nach mehrfachen Transformationen ihre endgültige Erscheinungsform als menschliche Darstellungen annahmen und dass über eine lange Zeitspanne hinweg mehrere Individuen an der Produktion beteiligt waren. Wir sind der Meinung, dass solche Figuren von Gemeinschaften im Laufe der Zeit geschaffen und verändert wurden. Wir schlagen vor, dass die Felsbilder eine zeitübergreifende Gemeinschaft kreierten, die es eventuell ermöglichte direkt mit der Vergangenheit in Kontakt zu treten, in dem die Bilder transformiert wurden. Translation by Madeleine Hummler

Stichworte: Urgeschichte, Felskunst, nordische Bronzezeit, anthropomorphische Darstellungen, RTI

4.2. Laser and LiDAR scanning

Laser scanning has had a relatively long history in the documentation of rock art, including projects in Northern England (Trinks et al. 2005), Scotland (Valdez-Tullett and Barnett 2021; Valdez-Tullett et al. 2023), Tanum (Bertilsson 2017, 2018, p. 275; Kucera et al. 2013),[11] Kivik (Bertilsson et al. 2017; Horn et al. 2018), Stonehenge (Abbott and Anderson-Whymark, 2012; Goskar et al. 2003), Kyrgyzstan (Kęsik et al. 2022), France (Jaillet et al. 2017), and Australia (El-Hakim et al. 2004). There are a variety of different types of laser scanners, an evaluation of each is not within the scope of this thesis. However, those that have commonly been used in the documentation of rock art will be presented below along with a discussion about their use.

In the past, laser scanners were large pieces of equipment described as Terrestrial Laser Scanners (TLS) that required tripods, external power sources, and were static during data collection (Barnett et al. 2004, p. 70; Díaz-Andreu et al. 2005; Neubauer et al. 2013; Trinks et al. 2005; Verdiani et al. 2021, p. 428). TLS systems tend to be time of flight scanners, i.e. they calculate the length of time it takes for a pulse to be returned to the scanner (Creaform 2014, pp. 11–12; Davis et al. 2017, p. 2; Jaillet et al. 2017, pp. 6–7). More recently, handheld scanners have become more popular in rock art studies. These have two primary types: structured light– which does not require target points and can obtain textures, and triangulation scanners -which can have different colour lasers (usually red, green, or blue) and require target points to work accurately. While structured light scanners work by projecting a pattern of

11. https://sketchfab.com/SHFA-3D (accessed 20/07/23)

light onto a surface and measuring deformities to capture the surface topography (Creaform 2014, p. 14), triangulation scanners project laser lines onto a surface and their position is detected by two cameras on the scanner (Arias et al. 2022, p. 4; Creaform 2014, p. 13; Jaillet et al. 2017, pp. 6–7; Trinks et al. 2005, p. 132). With the latter, the placement of target points on the surface helps the scanner to orient itself and maintain scale and accuracy (Creaform 2014, p. 16). Other than when targets are required, laser scanning is a non-contact method of documentation (Díaz-Guardamino and Wheatley 2013, pp. 192–193; Barnett et al. 2004, p. 71; Pires et al. 2015, p. 417; Wojcicki et al. 2022, p. 12).

4.2.1. Laser scanners as a documenting method

In 2016, in collaboration with Länstyrelsen[12] (the Swedish heritage authority), the SHFA[13] purchased a Creaform Handyscan 700 triangulation scanner[14] following a series of field tests with both structured light and triangulation scanners. The SHFA's methodology when documenting rock art has been to clear the rock surface of loose debris, and then perform a tactile and visual analysis of the surface to locate the carvings. The area is then prepared using target points, taking care to avoid placing them in areas where carvings are present. A scan is then taken of the surface, and the results are evaluated in the field. If more work is required, the scan is restarted, and more data is collected. The data is then processed and reassessed. Once the scan is complete, the mesh is exported as a .stl file. It is then ready to be post processed (as will be discussed in Chapter 4.4).

12. Overview of Lanstyrelsens project: 3D-scanning av hällristningar i Tanums världsarv - Henrik Zedig, Digikult 2017 - https://www.youtube.com/watch?v=bi5BnguQ4DU&ab_channel=KulturutvecklingVGR (accessed 20/07/23)
13. 3D-teknik kastar nytt ljus över hällristningar - https://www.youtube.com/watch?v=WROLIfYTYhU (accessed 20/07/23)
14. This is no longer available as it has been surpassed by a newer model, and as such a link to a specification sheet cannot be provided.

Figure 21: *Making use of a Creaform Handyscan 700 at Litsleby, Tanum.§*

The accuracy and speed of the scanner are undoubtedly excellent, but there are several issues that arise through its use. Firstly, and most importantly, the placement of target points can obscure the carvings underneath them. While it is often possible to avoid this, some carvings are not visible to the naked eye (especially those which are unknown) and although most of the time a tactile evaluation of the surface is carried out prior to data collection (regardless of the documentation method), it is still easy to miss subtle carvings and obscure them with target points.

Additionally, the target points appear on the final mesh, which to the untrained eye, or to those who did not perform the scan, can lead to misidentification of areas since the software interpolates the points and closes the holes in the mesh without highlighting them. It is also not ideal that it requires stickers to be put onto the rock surface, though they are so mildly sticky that the risk of damage is minimal.

Figure 22: *Target points on a rock surface ready for scanning.*

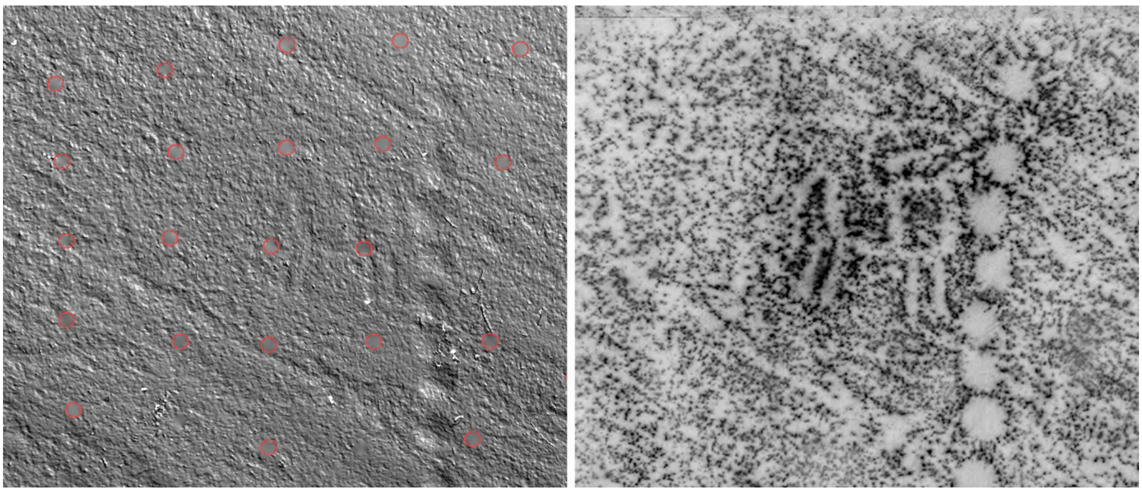

Figure 23: *Section of laser scan from Tanum 506 showing part of the carving detail obscured by target points (Meijer and Dodd 2018). Laser scan: county administrative board Västra Götaland, source SHFA and rubbing: Tanums Hällristningsmuseum Underslös.*

Laser scanners often struggle during daylight, as the bright light prevents the scanner from detecting the laser lines which are essentially washed out (Barnett et al. 2004, p. 70). This is less of an issue with blue light scanners (Personal communication Kristofer Axelsson / Maskin Laser Teknik 15/06/23), but is especially problematic for structured light scanners.

Laser scanners suffer from their huge starting price, which not only includes the scanner, but also the cost of batteries and a field laptop capable of processing the data as it is collected, as well as the cost of the consumable target points (Bryan 2009, p. 3; Díaz-Guardamino and Wheatley 2013, p. 193; Valdez-Tullett and Figueiredo Persson 2023, p. 7).[15] This is also a limiting factor of how long fieldwork can take place, as batteries determine the how long scanning can take place (Barnett et al. 2004, p. 70). Taken together, even though the size of the laser scanner has decreased significantly, it is still a lot of expensive equipment to move around compared to other techniques (Arias et al. 2022, p. 5). The smaller size of modern hand-held laser scanner units means that it is possible to use them in areas where other recording techniques would not be possible (Valdez-Tullett et al. 2023, pp. 291–292). Some laser scanners can collect textures (Trinks et al. 2005, p. 132), but they are often so low-resolution that they are only useable for identification rather than scientific purposes.[16]

Laser scanners work by first creating a high-resolution point cloud, which is then refined into a solid mesh. In contrast to SfM, which is reliant on the quality and spacing of the photographs taken, laser scanners create an evenly laid out mesh, which -depending on what you intend to record and how experienced the data collector is, can be highly beneficial (Morris et al. 2018, p. 52). The size of the files created by triangulation scanners can be quite large, which tends to limit the size of the area that can be scanned (Jaillet et al. 2017, p. 8). More modern scanners can also

15. Boxes of 500 target points cost around 50 euros. While they can be reused to some extent, they are largely single use only.
16. For example see the Artec line of scanners featuring 1.3mp cameras (https://www.artec3d.com/portable-3d-scanners/artec-spider accessed 20/07/23).

actively adjust the amount of detail recorded based on the curvature of the surface (for example the Handyscan Black Elite's smart capture – Personal communication Kristofer Axelsson / Maskin Laser Teknik 15/06/23).

As well as the speed at which the laser scanner can record data (Trinks et al. 2005, p. 138), a unique benefit of laser scanners is that they give immediate feedback of how the recording is going on a laptop screen. Since the data is rapidly collected and often requires little post processing, results can easily be obtained quickly and assessed in the field (Morris et al. 2018, p. 55). This immediate feedback reduces the risk of missing areas, especially since newer software highlights sparse areas in different colours and gives an overview of the carvings on the surface as they are recorded. From an outreach perspective this is a highly engaging experience for those who are not familiar with the process and/or the rock art, since they are able to see everything as it is happening and potentially even see carvings that they cannot see directly on the rock surface.

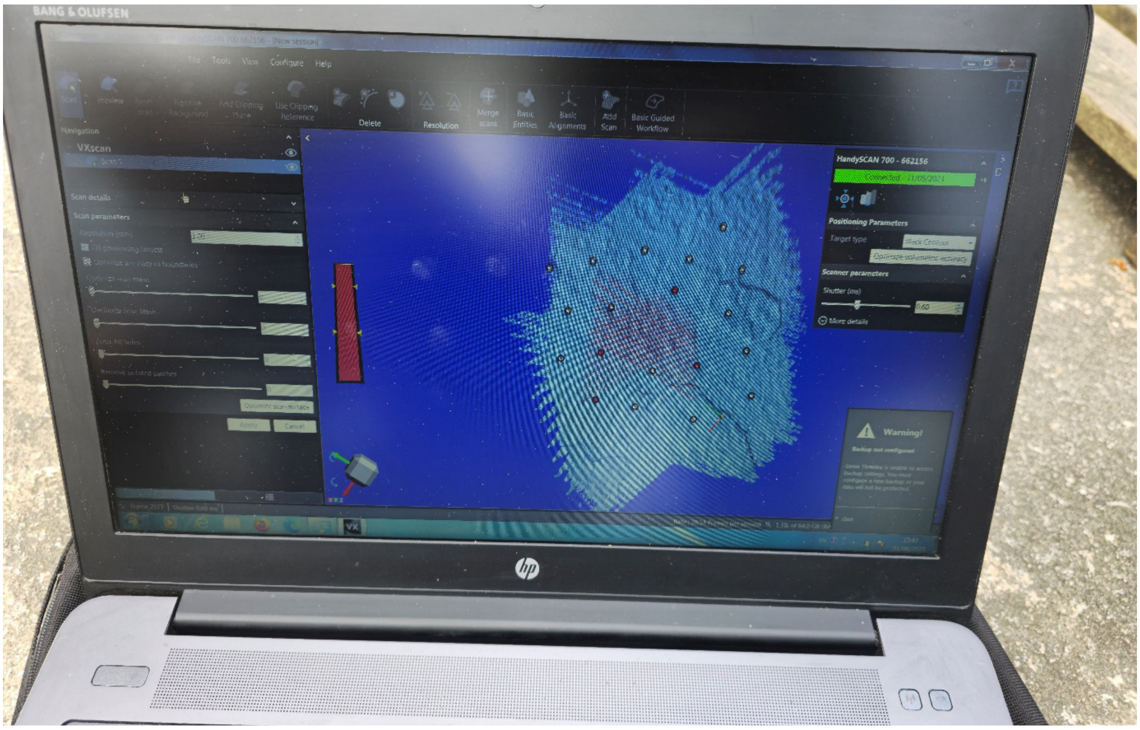

Figure 24: *The live output of laser scanning is very useful both from a recording and outreach perspective.*

As previously mentioned, TLS have also been used for the documentation of rock art (Davis et al. 2017; Kęsik et al. 2022). This includes Leica's MS60, a time-of-flight laser-scanner total-station combination (Axelsson and Fahlander 2023; Maar and Zogg 2017). While the results from this type of scanner are not detailed enough for some of the more focused visualisation methods (see chapter 4.4), they still create a useful overview of the surface of the panel from a topographic perspective. However, since other methods like SfM allow you to generate a similar topographic overview, as well as a higher-resolution model, it is probably a better suited method to use.

Figure 25: *Tony Axelsson from the University of Gothenburg making use of a Leica MS60 at Lövåsen.*

In the past few years, it has become possible to use mobile devices (e.g. Apple iPhones/iPads with LiDAR sensors, RealSense cameras) for the creation of 3D models through a variety of applications.[17] Tests of a number of these devices determined that they are not suitable in most cases for scientific research. They are useful for creating fast scans of objects and surfaces during excavation, which can be used as an informal record, but when it comes to using them for research purposes or anything other than a representative model, they fall hugely short in terms of both quality and mesh density.

Figure 26: *LiDAR scanning with mobile device.*

17. Polycam was the main app we tested with these tools (https://poly.cam/ accessed 20/07/23), but various other apps were also tested with similar or worse results.

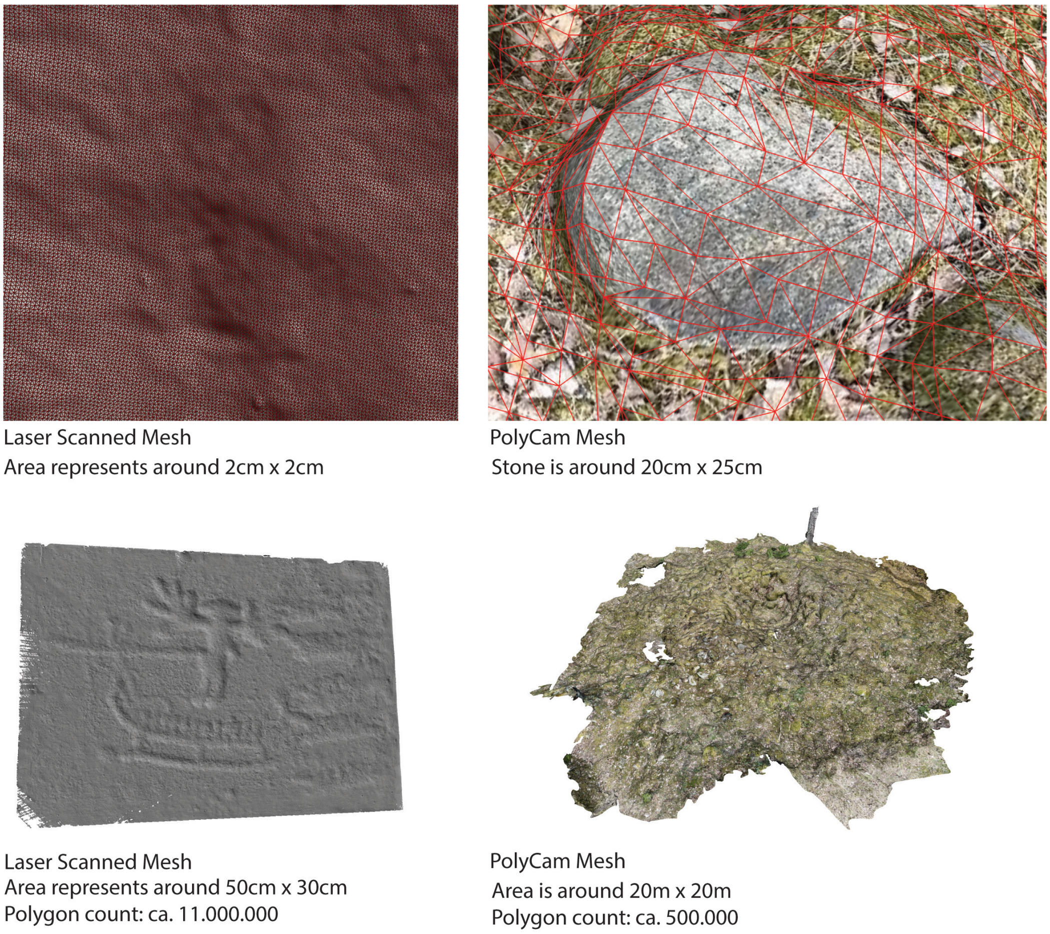

Figure 27: *Comparison between the wireframe from a Handyscan 700 with a PolyCam LiDAR mesh showing the huge difference in mesh density between the two scans. Note that the laser scan represents the tip of the prow of a carved boat, while the PolyCam represents a stone in a cairn.*

A major concern with this method of recording is the lack of understanding about the resolution of the model it creates. While the model can look fairly accurate and is usually even textured -which can further give the impression that the model is of high quality (Davis et al. 2017, p. 3), an inspection of the mesh / wireframe, or any further attempts to evaluate the models always falls short. In cases where a low-resolution model is desired, it would be far better to create a high-resolution model and then decimate it, as at least then there is some possibility to use the higher-resolution data if required.

To sum up, hand-held laser scanning has been beneficial to rock art documentation because it creates extremely accurate high-resolution data which can be assessed on the fly since it is displayed while you are working. This feedback is also highly visually interesting to observers, and is a good outreach tool, as well as being a useful tool for locating hard to find rock art carvings. In general there is very little training required to use hand-held laser scanning approaches, but the cost of the initial investment is extremely high.

4.2.2. Related article

The following presents an article which documents my work with rock art in Tanum and the Kivik tomb using a multitude of methods including laser scanning. The article is summarised in further detail, along with a description of how I contributed to it, below. For a more detailed breakdown of my contribution, see figure 1.

Article four: By All Means Necessary – 2.5D and 3D Recording of Surfaces in the Study of Southern Scandinavian Rock Art

Horn, Christian; Ling, Johan; Bertilsson, Ulf; **Potter, Rich** (2018): By All Means Necessary – 2.5D and 3D Recording of Surfaces in the Study of Southern Scandinavian Rock Art. In *Open Archaeology* 4 (1), pp. 81–96. DOI: 10.1515/opar-2018-0005.

My contribution to this article was predominantly methodological through the production and processing of Reflectance Transformance Imaging (RTI) and Structure from Motion (SfM) datasets. As well as joint analysis of the results, I also wrote elements of the article. **(Overall contribution 30%)**

This article offers an evaluation and presentation of the results from the use of various techniques on examples from within Scandinavian rock art. It presents RTI, SfM and Laser scanning and demonstrates how they can effectively be used within the rock art context. Specifically, the contentious fish motif on one of the standing stones in the Bredarör tomb in Kivik is examined, along with panels at Hoghem and Finntorp in Tanum. It also argues that the presented methods are useful in determining the chronologies of the carvings -something which is returned to in more detail in later articles. A less accurate/precise, but quick and cheap scanner was presented as a method of generating quick test zones in the field to find rock art before more time extensive methods were undertaken. The article argues that the newer digital methodologies should become part of the new standard method of documenting Scandinavian rock art, but not at the exclusion of the traditional methods.

The article also evaluates two common traditional methods, and looks at how digital methodologies improve upon them. In retrospect, the article took a somewhat too negative attitude towards traditional methods than it needed to, partly due to the novelty of the digital methods that we were coming to terms with. We have since understood that the best results come from a combination of both traditional and digital methods (Potter et al. 2022).

Original Study

Christian Horn*, Johan Ling , Ulf Bertilsson, Rich Potter

By All Means Necessary – 2.5D and 3D Recording of Surfaces in the Study of Southern Scandinavian Rock Art

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Abstract: Southern Scandinavia is Europe's richest region in terms of figurative rock art. It is imperative to document this cultural heritage for future generations. To achieve this, researchers need to use the most objective recording methods available in order to eliminate human error and bias in the documentation. The ability to collect more data is better, not only for documentation, but also for research purposes. Recent years have seen the wider introduction of image based 2.5D and 3D modelling of rock art surfaces. These methods are Reflectance Transformation Imaging (RTI), Structure from Motion (SfM), and Optical Laser Scanning (OLS). Importantly, these approaches record depth difference and the structure of engraved lines. Therefore, they have clear advantages over older methods such as frottage (rubbings) and tracing. Based on a number of short case studies, this paper argues that 2.5D and 3D methods should be used as a standard documentation techniques, but not in an exclusionary manner. The best documentation, enabling preservation and high-quality research, should employ all methods. Approaching rock art with all the research tools available we can re-appraise older documentation as well as investigate individual action and the transformation of rock art.

Keywords: rock art, documentation, Reflectance Transformation Imaging, Structure from Motion, Optical Laser Scanning, southern Scandinavia, Tanum, Bronze Age

1 Introduction

When the Norwegian priest Peder Alfsön documented the large "Shoemaker" in 1625 in Backa, Brastad (Sweden), the imagery on Scandinavian rock has fascinated people. Over time documentation efforts have evolved into a more systematic and scientific endeavour with the comprehensive recordings by Carl Georg Brunius and Lauritz Balzer (cf. Bertilsson, 2015b). Oscar Almgren's ground-breaking 'Hällristningar och Kultbruk' made rock art an essential window into Bronze Age life (Almgren, 1927).
With temporal and spatial variations, rocks were engraved throughout the Nordic Bronze Age (1700–550 BC). The corpus of images comprises cupmarks, canoes, human figures, animals, objects and much more. The largest concentration of petroglyphs can be found in Tanum, West Sweden. The region was designated a World Heritage Site in 1994. Many other regions in Scandinavia, such as Uppland, Sweden

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or Stjørdal in Trøndelag, Norway also contain rock art. It is important to preserve this fascinating cultural heritage for future generations (for a recent overview of sites, interpretations and literature see Goldhahn & Ling, 2013). Most of our work concentrates on Tanum; however, some work has been done in other regions. If not indicated differently, the sites mentioned in the following text are in Tanum. The numbers attributed by the Swedish Heritage Board (Riksantikvarieämbetet) are put in brackets when a site is mentioned first. These numbers can then be located in the online database of the Swedish Heritage Board (http://www.raa.se/hitta-information/fornsok-fmis/) and the Swedish Rock Art Research Archive (www.shfa.se).

Period after Montelius	Calendar Dates[1]
Period I	1700/1750–1500 BC
Period II	1500–1300 BC
Period III	1300–1100 BC
Period IV	1100–950/920 BC
Period V	950/920–730/720 BC
Period VI	730/720–550/530 BC

Notably, preservation is not the only aim of documentation. Jarl Nordbladh argued that high-quality documentation is essential for innovative research (Nordbladh, 1981). This also requires methodological innovations to improve the quality. This article highlights work conducted using modern imaging techniques to document rock art in comparison to older methods. Despite criticism of older methods, it should be stressed that all methodologies complement each other and documentation works best when rock art sites are recorded using multiple techniques. Here we demonstrate how our methods can be used to re-assess older documentation. Furthermore, our method is a powerful tool-set to study individual action on the rocks and the transformation of images, enabling us to address rock art biographies.

2 Documentation of Rock Art

Rock art is largely an open-air heritage. Therefore, it is exposed to weathering by the elements such as frost, environmental hazards such as acid rain, and human destruction. A recent incident in Tro (Nordland, Norway) where youths destroyed the famous image of a skier (Orange, 2016), highlights the problem of anthropogenic destruction. The destruction of images can also be seen at other sites, for example, in Finntorp (RAÄ Tanum 89:1) a large chunk of the rock is missing, and the fracture runs through some of the Bronze Age rock art. Photographs from 1935 and 1945 document building activities here, and on a site directly neighbouring this (RAÄ Tanum 90:1), a farmstead partially covered the panel. However, another photo from 1903 indicates that the destruction had already occurred. Both examples vividly demonstrate the need to document rock art. Through recording the images, we are able to preserve them for future generations even if the original should be destroyed. As researchers, we are also interested in the meaning of rock art and what information it contains about past societies. Thus, research is another purpose of documentation (Nordbladh, 1981).

Therefore, it is necessary to record the images on the rocks fully and as close to the original as possible. The aim is to eliminate human error as much as possible. Rock art is mostly very shallow and elusive. Consequently, it can be very hard to discover images with the naked eye. Most steps in the documentation process may require interpretation. This accumulates steps of inference, and thus, introduces potential

1 Montelius' original calendric dating was largely confirmed by newer radiocarbon and dendro-dating, see Kneisel, Hinz, and Rinne (2014); Randsborg and Christensen (2006). Evidence from burials tends to be somewhat older (Olsen et al., 2011).

sources of error. In the best case, documentation techniques can provide a surplus in visibility, record features previously undiscovered, or settle disputes over contentious features. It follows that documentation techniques should be efficient, storage should be manageable, and it should aim to eliminate steps that require interpretation as they are sources of error.

In the past, many techniques have been employed with varying degrees of success ;for example, drawings, oblique light photography and even casts (Bertilsson, 2015b; Nordbladh, 1981). Tracings and frottage were the most prevalent documentation techniques until recently.

2.1 Frottage

First, the rock is examined by feeling for engraved lines. If such lines are discovered, large sheets of paper are fixed on the panel. For large panels, several sheets of paper are necessary. Then carbon paper is wrapped around a soft sponge and rubbed over the paper. The carbon paper leaves more colour on hard surfaces, elevated parts, and edges. Conversely, in depressions such as engraved lines, less pigment is put on the recording paper. Whether a line is natural or anthropogenic must be decided after the frottage. Naturally occurring lines in the rock's morphology usually possess smooth edges. Fractures have irregular edges. Engraved lines should possess relatively sharp edges that are linear, and therefore, should show up clearer in the rubbing. Afterwards, the carbon is fixed by rubbing the frottage with grass. Frottage contains four documentation steps:

1. Feeling lines
2. Putting the paper sheets up
3. Rubbing carbon on them
4. Fixing the carbon.

2.2 Tracings

The initial step in tracing is a tactile technique. The bedrock in Tanum consists of a particularly hard granite called Bohus granite which was smoothed by the ice masses of the Ice Age (Eliasson & Schöberg, 1991). Most ancient engravers sought out such smooth surfaces (Coles, 2004; Goldhahn & Ling, 2013, pp. 275–77). Naturally occurring lines in the morphology of the rock are also smooth. Fractures occur along the boundaries of the rock crystals. Accordingly, the lines are very rough. Engraved lines break the rock's crystals and the originally smooth surface becomes rough, though not as rough as natural fractures. Documenters feel the rock in an attempt to identify these differences in the lines. Other information may aid the decision of whether a line is engraved or natural, such as the lines overall profile. After an interpretation, the engraved lines are painted with a non-permanent colour such as chalk or chalk paint. Clear plastic sheets are then fixed onto the surface of the rock on which the lines are transcribed. Consequently, tracing is a four-step recording process:

1. Feeling lines
2. Painting the lines
3. Putting up the plastic sheets
4. Transferring the lines.

2.3 Problems with Tracing and Frottage

Both methods have clear advantages over other documentation techniques such as drawing or photography. They record more details of larger areas than photography, and they are more objective than just drawing the images from a visual impression. Tracing and frottage have been standard in the documentation of rock art for decades (Toreld & Andersson, 2015; Nordbladh, 1981). However, both also have severe disadvantages:

1. Researchers have to kneel, sit or lie on the rocks for extended periods of time. Intensive and continued contact is made with the rock surface, especially on larger panels. This can cause damage to the images, particularly, if there is a lot of movement required.

2. Both methods are highly manipulative and human bias is a considerable factor (Bertilsson et al., 2017). Feeling lines in tracings is largely a sensual undertaking and depends on the experience of the researchers as much as on their expectations of what images should look like and where to find them. For example, an engraved line in an unexpected place might be interpreted as natural. Rubbings may be carried out intensely where rock art is expected, but only superficially in other areas. Weathering can also cause a background noise obscuring engraved lines.
3. Although the area of documentation is technically not limited, multiple papers or plastic sheets have to be put together to cover large panels. This makes a continuous documentation improbable. The sheets and paper recordings have to be put together afterwards. This can cause offset on the edges. Tracings usually do not record the entire rock face and frottage tends to flatten out the topography causing erroneous spatial relationships between individual images (Nordbladh, 1981).
4. Both methods are time-consuming. The documentation of large panels takes more than one working day (8+ hours) and generally requires a larger number of people to document areas effectively.
5. Frottage is difficult to carry out in relatively cold and wet climates such as Central Norway (Peacock et al., 2015).
6. While both methods do a decent job of recording rock art in two dimensions, they are less well suited to recording depth differences within engraved lines. Therefore, there is one entire dimension missing in the preservation of this heritage. It is problematic for research because depth differences contain valuable information (see below). Sometimes, documenters denote if figures superimpose each other, but again, this is heavily dependent on individual perception and interpretation.
7. One major disadvantage of both of these methods is that they require careful cleaning of the rock art that precedes the documentation. Both chemical and mechanical cleaning increases abrasion of the rock.

3 New Approaches to Rock Art

New method development needs to take these problems into account and if not solve them, minimise their impact. Fortunately, there has been innovative and active research in the field of 2.5D and 3D imaging in the past two decades which has made techniques such as Reflectance Transformation Imaging (RTI), Structure from Motion (SfM) and Optical Laser Scanning (OLS) accessible and easy to use. A range of open source and commercial software aids the calculation of imaging files. Although they vary in user-friendliness, there is no high-level training necessary to get good first results.

Early attempts to computationally record Scandinavian rock art date to the 1990s, but they were not available to a wider audience (Freij, 1993; Lindqvist, 1994, p. 247). Around 2000, the ATOS scanner technology was developed to document the open-air rock art at Tanum for the National Heritage Board's Rock Care Project (Johansson & Magnusson, 2004). The ATOS scanner's already high accuracy is surpassed by modern laser scanners making them much more powerful documentation tools (see section *Optical Laser Scanning (OLS)*). Some 10 years ago, Joakim Goldhahn tested the technique of documenting petroglyphs using laser scanning at the famous Bredarör grave (Kivik, Simrishamn). However, since the documentation made by Goldhahn has unfortunately never been published, the results remain unknown. In the past five years, rock art researchers in Sweden have embraced image-based and range-based modelling approaches to the documentation of rock art by regularly using SfM, OLS and RTI. The results of the case studies (see below) are stored in the Svenskt Hällristnings Forsknings Arkiv (SHFA). OLS is carried out in cooperation with County Administrative Board of Vastra Gotaland. The SHFA uses a Sketchfab Pro account to make OLS files publicly available. Since many contributions in this volume deal with SfM and laser scanning, remarks on these methods are kept very brief, while RTI is discussed in greater detail.

3.1 Reflectance Transformation Imaging (RTI)

RTI was carried out on sites, for example in Tanum, Askum and in the Bredarör tomb, mainly by Rich Potter (RP) and Christian Horn (CH). To avoid damage to the rocks, soft brushes were used to clean the panels before any work (RTI or other documentation) was carried out at the sites. Lichen growth exists variously, but it was minimal and did not affect the engraved lines enough to impair the analysis. Therefore, no attempt to remove lichen was made as it would also risk damaging the panels.

RTI uses Polynomial Texture Maps, invented by Tom Malzbender of Hewlett-Packard in 2000 (c.f. Earl, Martinez, & Malzbender, 2010; Malzbender, Gelb, & Wolters, 2001; Mudge et al., 2006; Mudge et al., 2012). We used the method described as “Highlight RTI” by Mudge (2006). This method computes a pseudo-3D or 2.5D file from the surface reflections. One or two black or red glossy balls record the light direction (Fig. 1a). A remotely controlled static camera set up on a tripod takes a series of images with lighting from oblique angles including raking light (Fig. 1b). Guidelines provided by the Cultural Heritage Imaging group (CHI) describe the appropriate use of the method, with which we complied (Cultural Heritage Imaging 2013). The ideal number of photos is 60–70 (Díaz-Guardamino et al., 2015). However, the weather conditions during our fieldwork seasons necessitated completing the work quickly. We aimed to take as many photos as possible with a Canon 7D DSLR (18 Megapixel), and a Canon Speedlite 430EX flash unit and achieved good results with 40–50 photos. Phottix Stratos 2 triggers were used as the remote control.

The photos were converted into ptm files with RTI Builder Version 2.02 and thereafter analysed with RTI Viewer Version 1.1. Both are open source and can be downloaded from CHI’s website. RTI Viewer computes surface normals from the light reflection and creates an artificial representation of the shape of the surface. The application of filters and the dynamic movement of the lighting enhance the visibility of features. We primarily used the diffuse gain and specular enhancement filters. RTI can only be used on small sections of a panel and it is sometimes difficult to identify the correct spot. However, the advantages of RTI compared to SfM are the shorter computing time (up to 5 minutes), files are less storage-intensive, and the quality of the pictures is usually higher. RTI does not produce a real 3D model that can be turned and spun, though it mathematically enhances the surface shape.

3.2 Structure from Motion (SfM)

For SfM, photographs are taken with a 60–70% overlap (Reu et al., 2013). This guarantees high precision of the calculated 3D models enabling measurements as low as 1mm in a 10m scene. This precision can be significantly increased through the use of targets that aid the model calculation (Sapirstein, 2016). The photos have to be processed to calculate the 3D model, which may take up to a day using Agisoft Photoscan©. Calculation time for the models depends heavily on the number of photographs, the specification of the computer, and the software used. There will be substantial improvements to the processing time in the future due to the development of technology. Testing of a new software (Capturing Reality©) indicates that the processing time can be shortened by up to 80%. SfM has been used in various locations in Tanum, the Bredarör tomb and in Nämforsen, Sollefteå, mainly by Johan Ling (JL), Ulf Bertilsson (UB) and Rich Potter (RP).

3.3 Optical Laser Scanning (OLS)

Two qualitatively and very different scanners have been used to record rock art. A project-scanning petroglyphs using advanced digital technology took place in early 2015, when the County Administrative Board of Västra Götaland started to record many engravings at the Tanum World Heritage site. The scanner used in this project was a Handyscan 700 with red lasers provided by the Maskin och Laser Teknik (MLT) Company in Gothenburg. The Handyscan 700 sends out about 480,000 measurement points per second which reproduce the panels with an resolution of 0.05 mm. Thus, the main objective with the Handyscan is to detect “mechanical” impact at 0.05 mm. The other scanner is a 3DSystems Sense scanner. Compared to the Handyscan 700 this is a low-tech, cheap scanner (ca. 300€) providing a spatial x/y resolution of 0.9 mm and a depth resolution of 1.0 mm.

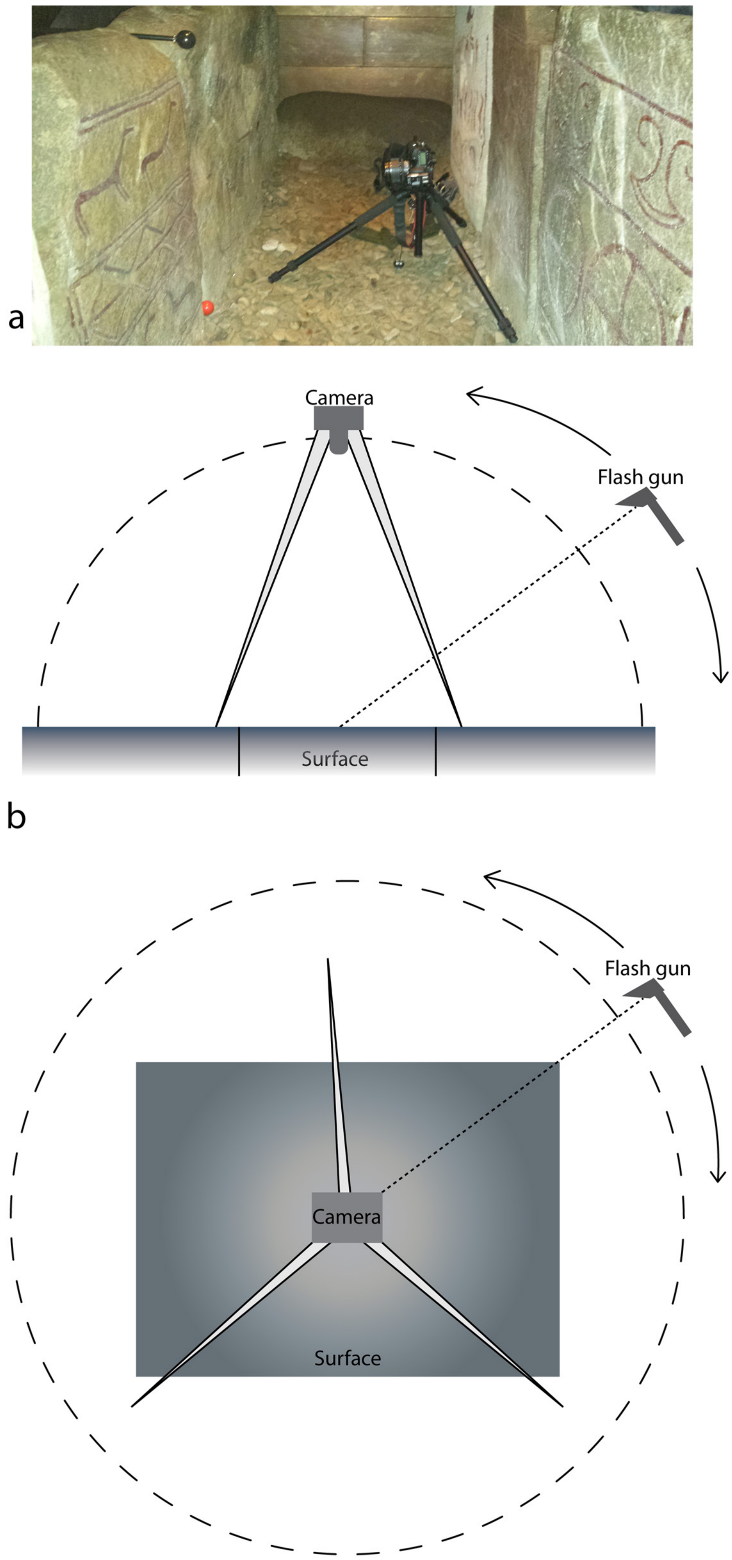

Figure 1. a. camera setup in the Bredarör tomb in Kivik, Sweden; b. schematic camera setup and process to record non-vertical rock art panels.

3.4 Mixed Approaches

As mentioned before, it can be difficult to identify the precise location of images on panels to conduct RTI or close up SfM. This was experienced through the attempt to document a scene in Finntorp (RAÄ Tanum 89:1), which may show a couple engaged in intercourse (Fig. 2a). The scene is very shallow and was not discovered in a previous attempt to record it. To counter this problem a protocol was developed. First, we recorded the area in question with the Sense 3D scanner. This can be done within seconds and the model can be reviewed on a laptop in real-time. The model is of low quality, but it is enough to identify the area of interest. The model of the Finntorp couple shows the basic, blurry outline, but as expected did not record any details (Fig. 2b). Afterwards, the area was marked using string or tape. Then the camera equipment is set up above the marked-out section in a way that captures the markers in the shot for RTI or photographs for SfM which are taken in that area. This ensured that we captured a high-quality model of the intercourse scene in Finntorp (Fig. 2c).

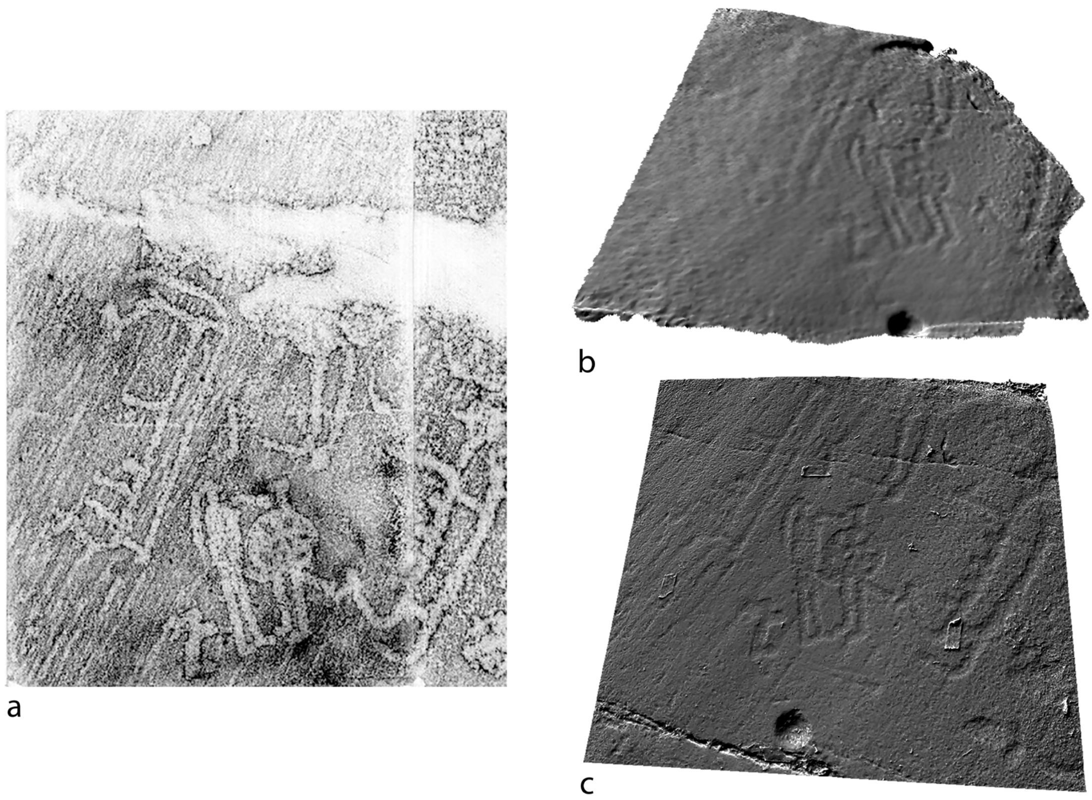

Figure 2. a. Frottage by RockCare of the intercourse scene in Finntorp, RAÄ Tanum 89:1; b. Sense laser scan of the couple by CH; c. SfM of the couple by RP.

4 Advantages in the Documentation of Rock Art Using RTI, SfM and OLS

Before any advantages are described it should be acknowledged that documenting with RTI, SfM and OLS has some disadvantages. The calculation, especially of larger SfM files, takes a very long time and requires high-end computers. The files can be very large, exceeding 1GB on high quality with high-density point clouds. This presents a problem for the storage of high-quality files, so there is usually a trade-off between model quality and size. The area that can be recorded using RTI is limited. RTI and OLS can be difficult in open air environments. Direct sunlight is detrimental to both techniques. It is also not possible to conduct RTI during strong winds as this causes the camera to shake and makes the images blurry. Finally, laser scanners can be too expensive, especially for smaller projects. However, none of this affects the quality of the documentation directly.

There are some clear advantages of RTI, SfM and OLS compared to tracing and rubbings:

1. There is minimal impact on the engravings and a reduced potential of damaging them during the recording. It is, of course, necessary to step on the rocks as in the older methods, but wearing shoes with soft soles and avoiding stepping on images makes damage less-likely. The tripod for RTI can be set up in a way that does not affect any petroglyphs and plastic or rubber caps on the legs protect unrecognised engravings.
2. Human bias in the recording is minimised because the methods do not rely on experience or perception. They simply record everything including a three-dimensional representation of the topography of the lines. From this, it is easier to judge whether lines are natural depressions, fractures, or were made by humans. The files and models are obviously in need of interpretation. However, they do not leave out features that are within their capability to record, just because they are considered unimportant or are perceived as natural. This increases the visibility of engravings even in largely eroded areas (see Fig. 3a–c).
3. All these new techniques are essentially one or two step processes of documentation, none of which includes interpretation before the final analysis. This further reduces human error, and therefore, potential sources for an incomplete or erroneous documentation.

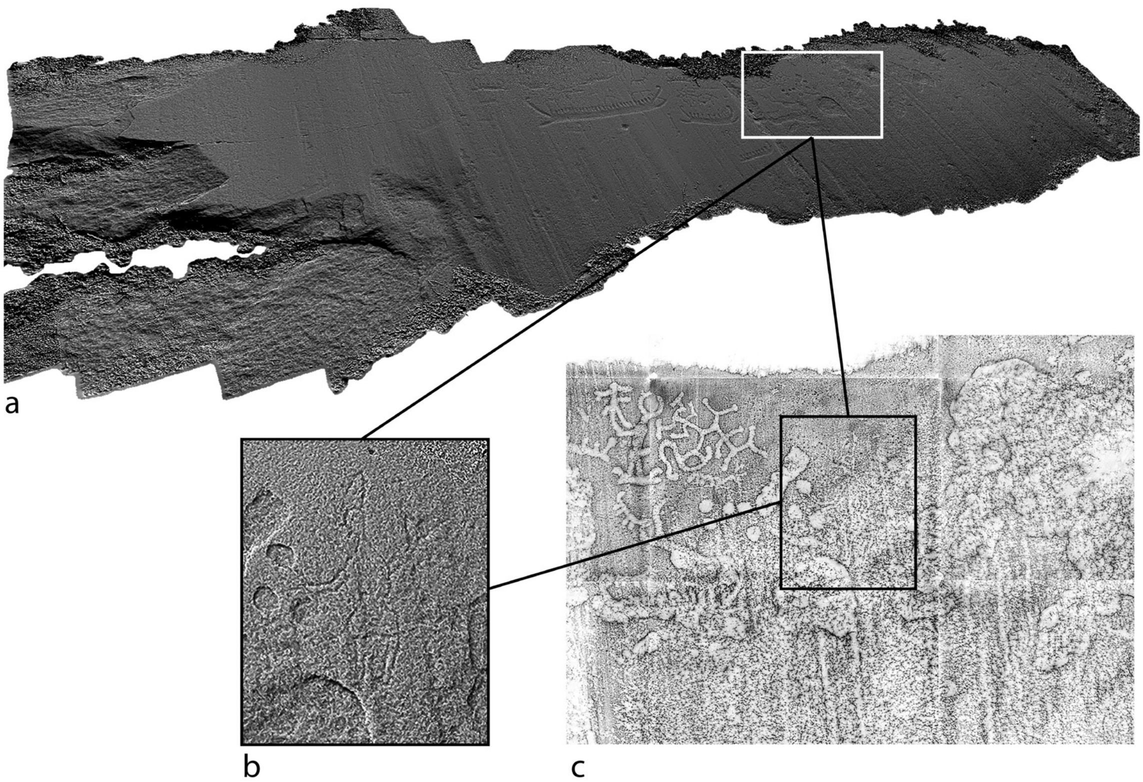

Figure 3. a. SfM of the entire Hoghem, RAÄ Tanum 160:1 panel by RP; b. Anthropomorphic figure in eroded zone, SfM with radiance scaling filter (80%) by RP & CH; c. Frottage by Tanums Hällristningsmuseum Underslös.

4. Given sufficiently powerful hardware, SfM and OLS enable the continuous documentation of large areas in a relatively short time of up to an hour, even for very large panels such as Aspeberget (RAÄ Tanum

12:1) at 10.8 x 8 m (https://tinyurl.com/k953f83). Since the rock's overall topography is recorded, spatial relationships between images are easier to observe and can be a more central part of the interpretation.

5. The methods allow fast documentation in small teams. The teams that conduct fieldwork usually consist of two people. The process can be completed in 30–40 minutes. Including camera setup and shooting a set of images for RTI. Using the Sense 3D scanner enables the survey of a rock face, depending on its size, in a couple of minutes up to an hour. Usually, the approximate area of the scene that needs to be documented is known so that scanning can take around 5–10 minutes. The necessary images for SfM, even of a large panel of several meters in length such as Hoghem (Sweden, RAÄ Tanum 160:1), can be taken in under an hour. The calculation of the model may take much longer, but during this time, other work can be conducted while the computer calculates.
6. The results of the OLS recording are visible on the laptop in real-time in the field. Therefore, errors can be readily adjusted. The scans are automatically calibrated, a process that takes 5–10 minutes.
7. As their biggest advantage, these methods enable us to observe depth differences in the engraved lines. Marking intersections and superimpositions in tracings inscribes the bias directly into the documentation. Conversely, RTI, SfM and OLS record an unbiased documentation that is later interpreted. This means that even if the scientific interpretation of documentation made with RTI, SfM or OLS contains bias or error, there is a chance for other researchers to correct them without having to re-document the rock art.

After detailing the advantages of the documentation of rock art with RTI, SfM and OLS, several case studies are described below to demonstrate how multi-method approaches enable high quality research and the investigation of rock art biographies.

5 Is the Fish not a Fish? – Dietrich Evers and the Documentation of the Rock Art in the Bredarör Tomb, Kivik (RAÄ Stora Melby 42:1)

Dietrich Evers documented rock art at many European sites including Italy and France. In the 1970s he also used his frottage technique in Sweden, amongst other sites, in the Bredarör tomb, Kivik (Fig. 4a). Here he documented a figure that has been interpreted as fish, owing to its form and the many fins or barbels (Fig. 4b). He experimented with the frottage method using several paper formats and ways to apply graphite. Through this he produced several rubbings of the same motif. Recently, his work has been criticised by Andreas Toreld and Tommy Andersson (2015, 2016). Together they re-documented the slabs in the tomb using tracings (Fig. 4c). Their approach was to feel lines in turns and if they both agreed that a line was human made it was drawn; as such if one disagreed then the line was marked as questionable, and finally, lines which both felt were not human made were dismissed or drawn as natural features. Using their documentation, they harshly challenged the results of the frottage done by Dietrich Evers. For example, they denied the existence of multiple lines on the fish that have been interpreted as fins or barbels stating the following:

> *"Evers has imaginatively created his own motifs on the frottage paper by retouching it using a pencil and eraser. A clear example of this is the two completely different versions that are published of the fish-like figure and a four-legged animal on the slab 7 (Figure 3). Evers' frottage cannot be said to have any greater scientific value"* (Toreld & Andersson, 2015, p. 12, translated here).

From 2015 to early in 2016, the slabs of the stone cist in the Bredarör burial were re-documented on three separate occasions. The methods used were OLS (JL, UB and RP), SfM (UB and Catarina Bertilsson) and RTI (CH and RP). The fins were visible in images produced by all three techniques and all four researchers involved agreed on their presence (Fig. 4d–e; cf. Bertilsson et al., 2017). Thus, Evers recording was validated. If any criticism could be levelled it is that there are potentially even more fins or barbels (Fig. 4d–e). Finally, it was possible to detect some information on how the individual that applied the fish approached the task.

The oval shaped body was made first and the barbels were then added. The tail fin was perhaps engraved last because it seems that it cuts across the body and one of the barbels (Fig. 4d). Similar observations were made for other figures on the slabs (c.f. Bertilsson et al., 2017). These detailed observations introduce the next case study.

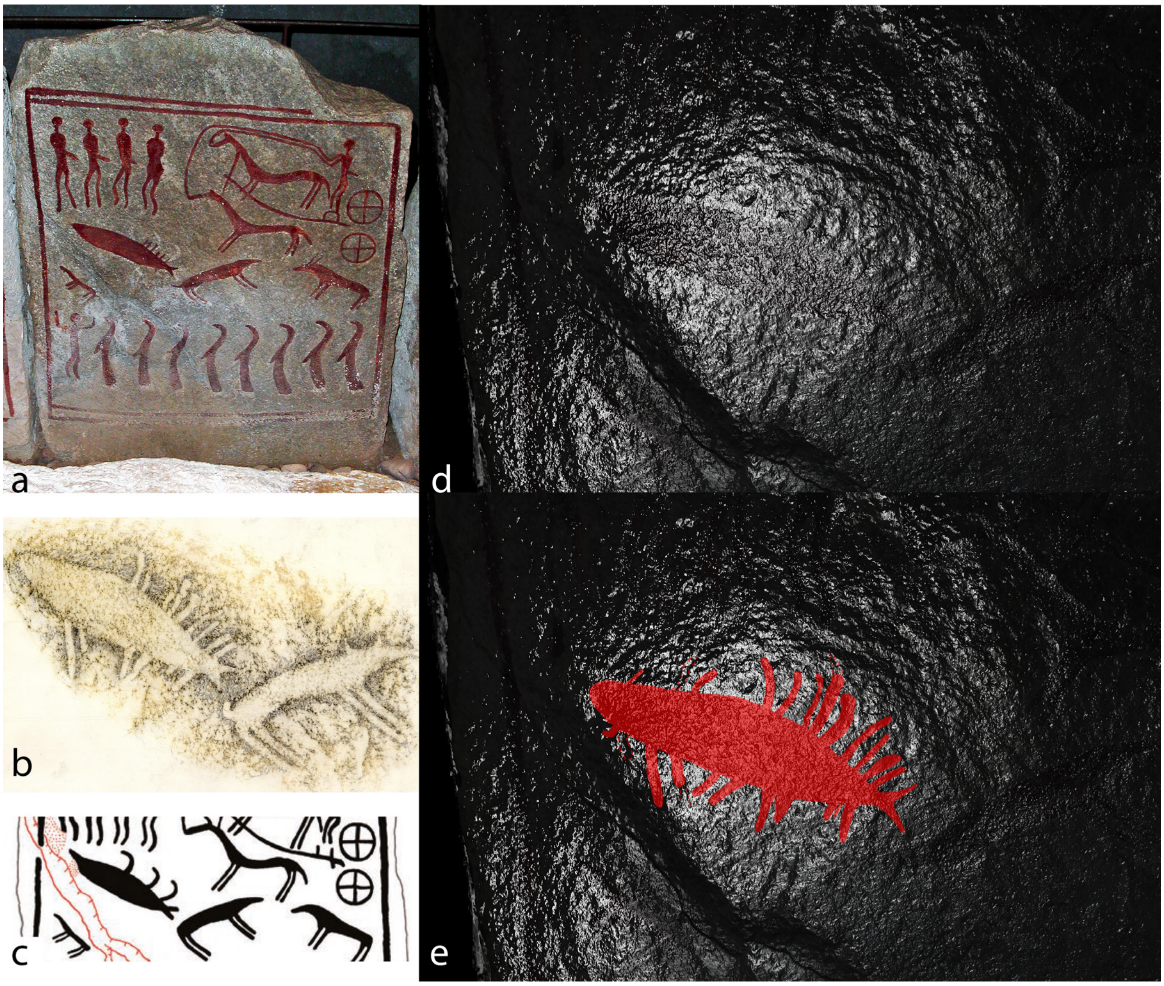

Figure 4. a. Photography of slab 6 in the Bredarör tomb, Kivik by Catarina Bertilsson (the red paint is applied by the heritage service to make the engravings better visible to the public); b. Frottage of the fish by Dietrich Evers; c. Result of the tracing by Andreas Toreld and Tommy Andersson (2015); d. RTI of the fish; e. Fish indicated; Figures 4d–e by RP & CH.

6 At the End of the Longest Line – Individual Action and Transformation of Rock Art

With the capabilities of the various software used for 3D models and RTI files, rock art can be subjected to very detailed analysis by means not available to the human eye alone. The topography of the panel and individual lines gives a sense of the spatial and relative chronological relations of the images. It provides an opportunity to investigate intersections and superimpositions. This allows establishing a relative sequence of transformations on individual figures. The comparison of the production techniques, line depth and width on all kinds of documentation allows for the possibility that different individuals added these lines. Discussing the differences in engraving techniques used on the picture stones in the burial in Sagaholm, Goldhahn suggested that these were used to emphasise aspects of the engraving in the construction of a narrative (Goldhahn, 2016). However, in the following case study, it is argued that the open context of the panels and the dating of depicted objects supports the notion that several individuals throughout time contributed to the images and scenes final appearance.

On a scenic level, this can be demonstrated with the OLS and SfM documentation of a panel in Finntorp (RAÄ Tanum 184:1). On the frottage of the panel a particular setup of two canoes can be observed (Fig. 5a). The two canoes sit on an axis mirroring each other. Such a position has been interpreted as one canoe representing the living, while the other is the canoe of the dead (Fuglestvedt, 1999). The argument rests on the observation that one canoe contains humans and the other seems to be empty combined with the perception of both being "mirrored" reflecting the two sides of the human existence: life and death.

We approached the documentation first using the Sense scanner to gain an understanding of the topography (Fig. 5b). We discovered a wide natural depression close to one of the canoes. This first result seemed promising and it was decided that we should document the entire panel using SfM (Fig. 5c). It was discovered by turning the model from a top-down view to an isometric view that the canoes were sitting on opposite sides of the natural depression (Fig. 5d). After sorting through the photographs taken for SfM it was discovered that a black layer runs along the depression (Fig. 5e). This finding indicates that water was frequently flowing through the depression forming a natural water channel.

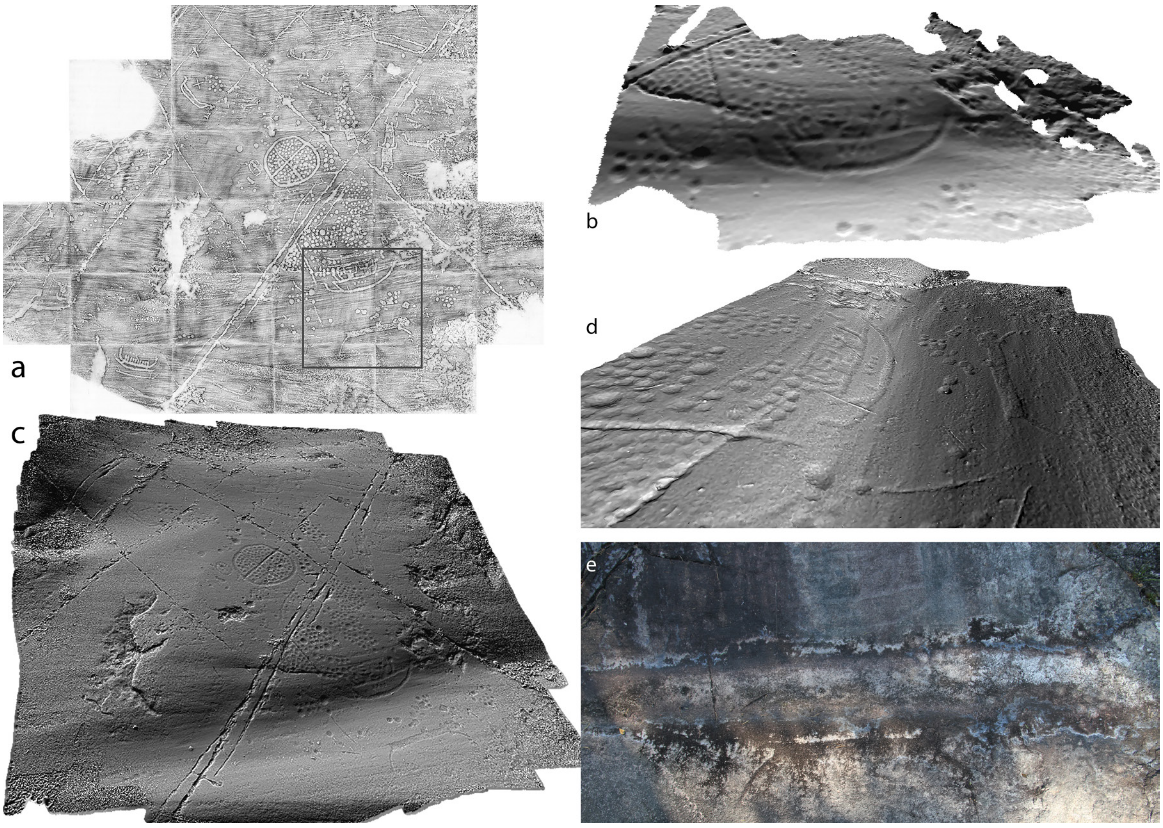

Figure 5. a. Frottage of Finntorp, RAÄ Tanum 184:1 by Tanums Hällristningsmuseum Underslös; b. Sense laser scan of the boat with the spearman by CH; c. SfM of the full site by RP; d. Section with the channel turned, applied radiance scaling filter (80%) taken from the model by RP; e. Photo of the discolored rock in the channel by RP.

This allows for a more elaborate interpretation of the two canoes. Leaving aside whether these are canoes of the living and the dead for the moment, it can be suggested that these canoes do not mirror each other; rather they are depicted as being on either side of a stream, a river, or a fjord. Given that one canoe includes two humans armed with spears this could be interpreted as a canoe crew threatening another crew. The canoe without crew possibly dates to Period III and the canoe with the two spearmen aboard could have been added in Period V (see Ling, 2008, pp. 102–5). This means both were separated by at least 250 years. The later addition could have turned the scene of a canoe travelling along a fjord into an antagonistic scene emphasised by the raised spears. However, the other canoe does not contain any indication of the crew. This means it could have been perceived as some kind of ethereal or ghost ship to fend off. Alternatively, the raised spears could be a form of greeting and depict a meeting of living warrior crew with their ancestral predecessors. Rock art is a very open medium and more than a single reading of it may have been held by different individuals at different times. Still, the scene was transformed from depicting travel to an engagement of some kind.

That individual figures may have extended chronologies involving many engravers is also demonstrated by, for example the large spearman in Litsleby (RAÄ Tanum 75:1). The warrior's arm, for example, was engraved over some canoe images. The SfM reveals that the hand of the figure is cut across the handle of the spear which indicates that the spear was applied before the hand. The spearhead is morphologically similar to Valsømagle type spears and was perhaps reworked 2–3 times (Fig. 6a–b; Bertilsson, 2015a). The thighs of the figure cut across a Period III canoe (Ling, 2008, pp. 102–5). That could mean that 2–400 years passed between the engraving of the spear and the addition of the human figure. This means several individuals were involved in shaping the scene (see also https://tinyurl.com/leo8ueg).

In some instances, the process is more complex and difficult to differentiate. A panel in Fossum (RAÄ Tanum 255:1) was documented using SfM (Fig. 6c) and OLS (Fig. 6d; see for details Ling & Bertilsson, 2016). One figure usually seen as an axeman shows an interesting setup. The figure superimposes a line that forms the phallus and the sword of the figure. An animal superimposes the sword, presumably a dog (Fig. 6d). There are three relative sequence instances, but these cannot be dated because they lack chronological markers. The arm of the human was applied after the body and the hand cuts across something that has been interpreted as an axe (Fig. 6c). This feature superimposes another line that is also superimposed by another human figure. For the second human, this line serves as a sheathed sword. The specific setup of the hand of the first human cutting across it and the attached line make it more likely that this is the representation of a sword (Fig. 6c). In this case, the feature formerly identified as an axehead is more likely a hilt (Fig. 6e). This hilt's form can be compared to period II types.

Lastly, such a build-up has also been observed using RTI on four human figures on another panel in Finntorp (RAÄ Tanum 89:1). A tall warrior (40 cm) carrying a spear was documented three times in two field seasons. The Sense 3D scanner was used to mark the exact extent of the figure. The two other warriors have been documented twice with RTI and the axeman once (cf. Horn & Potter, 2017). In the following, the emphasis is on the spearman and the two warriors.

The pair of warriors displays very pronounced knees (Fig. 6f). These knees have previously been interpreted as representing a connection to posturing and the body image of warriors (Fredell & Quintela, 2010). The documentation results suggest that this may not always have been the case. The lower legs and feet were added after the knees and the thigh indicating that they are later. The thigh and the presumed knee could have regular legs with feet. Similar observations can be made, for example on OLS scans from panels in Aspeberget (RAÄ Tanum 29:1) where one frontal figure to the left has feet that consist of a long line. Two other figures in a central group of three show the similar lines at knee level (see https://tinyurl.com/l2j7mz6). There is currently no way of dating the later addition.

This is different for the large spearman. The overall elongated form and the potentially smooth outward swing of the lower part of the blade could suggest a Valsømagle type spear parallel to the discovery in Litsleby (Fig. 6h–i; Horn & Potter, 2017). The shield could be of type Watensted and would date this addition into the transition from Period II to III 2–300 years later (see Uckelmann, 2012). The analysis of the RTI file also indicated that the spear tip was reworked 3–4 times. It also showed that the cup mark used as the head was made in a different style and is marginally superimposed by the spear's handle (Horn & Potter, 2017; Horn, 2016). All this demonstrates that there may be a considerable time-depth for all the discussed case studies.

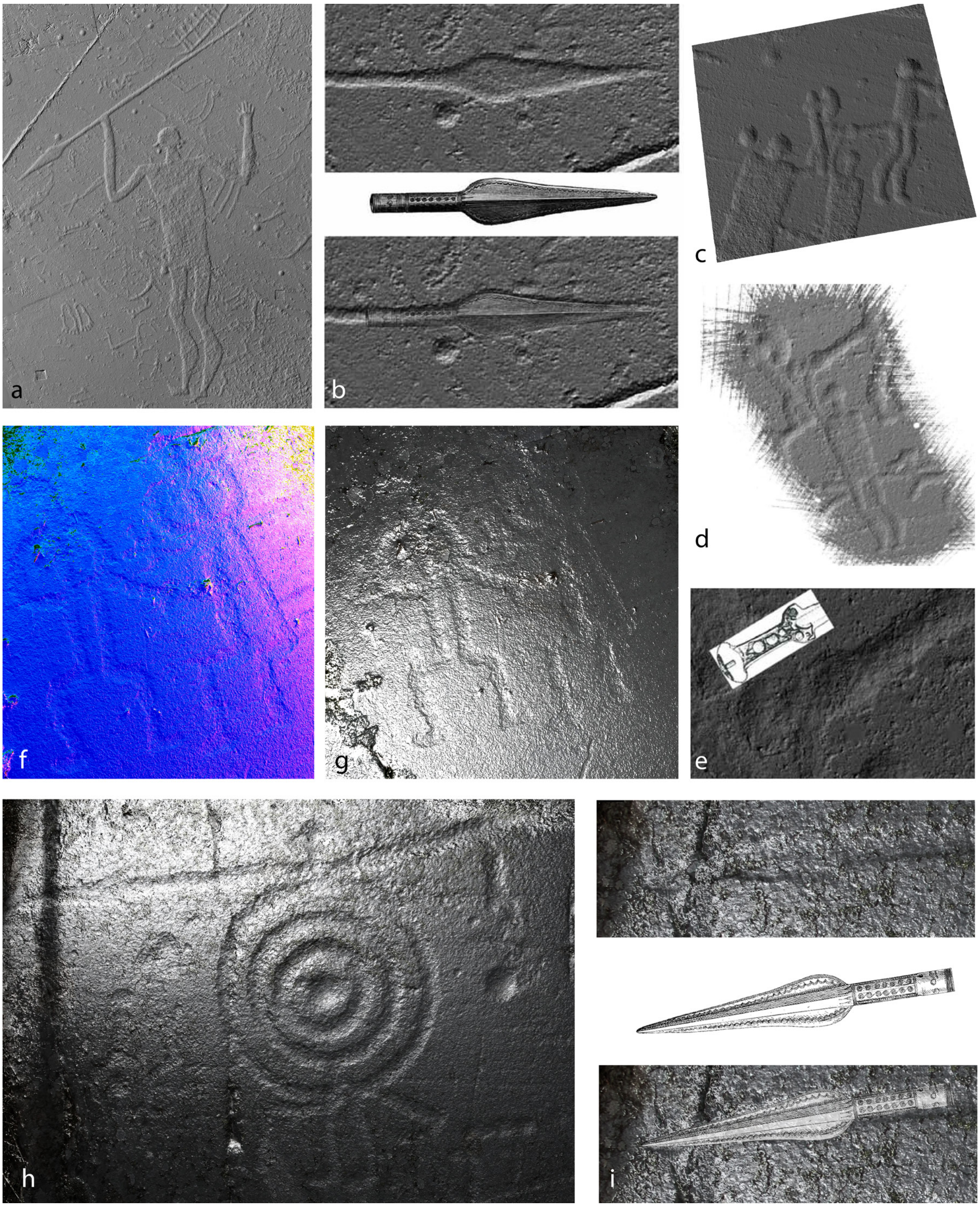

Figure 6. a. SfM of the spearman in Litsleby, RAÄ Tanum 75:1 by SHFA; b. Comparison of the spear point in Litsleby with a Valsømagle spear from Falköping (Bertilsson, 2015); c. SfM of warriors on the Fossum, RAÄ Tanum 255:1 by RP; d. Handyscan 700 scan by Länstyrelsen i Västra Götland; e. comparison with a flange hilted sword (Ling & Bertilsson, 2016); f. RTI of the two warriors with knees in Finntorp by RP & CH, normals visualized in RTIViewer and enhanced using the DStretch in ImageJ; g. RTI of the two warriors with knees, lighting adjusted to make the feet that form the knees visible on the right figure, specular enhancement filter; h. RTI of the spear man in Finntorp by RP & CH; i. Comparison of the spear point in Finntorp with a Valsø-magle spear from Falköping by CH.

7 The Past is Alive – Rock Art Biographies

Identifying transformations and additions in Litsleby, Fossum, and Finntorp has further implications. For example, the spearman on panel RAÄ Tanum 89:1 in Finntorp was transformed at least on five separate occasions. The scene in Litsleby involved at least four transformative events. Rock art research has previously established that images were added on the panels over a long period of time (Bengtsson, 2004; Ling, 2008; Fredell, 2003; Nilsson, 2012). However, this only pertains to the panel level. The results of the new documentation effort indicate that individual figures accrued engraving events. On the example of the Sarsen stones in Stonehenge, it has been argued that repeated human-object interaction provides the stones with a biography (Gillings & Pollard, 1999). This biography provides the stones, or in the Scandinavian case the images, with the power to have an influence on future engagements. We see this for example in Litsleby, where the direction of the handle predetermines the direction of a potentially Late Bronze Age rider. The Period III canoe on the channel in Finntorp influenced the location of the canoe from Period V. The spear and the cup mark on the other panel in Finntorp may have evoked the impression of a human to later prehistoric observers which may have "completed" the figure.

A valid interpretation of the process is perhaps that the presence of rock art allowed humans to engage directly with their predecessors or ancestors on the rocks. That would mean that rock art provided a nexus for whatever rituals the making of rock art was enmeshed in to shrink temporal distance and maybe even break down the barrier between the living and the dead for those who engraved the rocks. This complements other interpretations of rock such as its relation to the dead world (Fuglestvedt, 1999) or more agency centred interpretations of rock art as intended to change the real world (Ling & Cornell, 2010). Prehistoric communities may have even recognised the age of the images, linked them to certain myths, and imagined engaging with their ancestors or heroes of the past by transforming the images. This could explain why rock art would have been important because it represented a link to the past.

The presented results also have an implication directly impacting archaeological thinking. Figures and scenes are much less stable than previously thought. Most interpretations focus on the completed scene (cf. Goldhahn & Ling, 2013), but they were not finished in one engraving instance. Instead, they evolved over time potentially changing their meaning. That means that interpretations may only apply to the latest phase in the biography of the image or scene. In the future, more biographies should be reconstructed to recognise all variations, the time-scales of transformations and potential common trends.

8 Summary

The wider introduction of RTI, SfM and OLS in combination with each other and older techniques has enhanced our ability to record, store and investigate rock art. Image based 2.5D and 3D modelling should become the new standard of documenting rock art in southern Scandinavia complementing existing methods like frottage and tracing. That way, we can best ensure the preservation of the world heritage in Tanum.

By employing all means necessary it was possible to demonstrate that rock art figures and scenes were transformed and constructed over time involving many individuals. It is an indication that a singular interpretation of rock art, or even a singular figure, are problematic. Researching more rock art biographies will add more complexity to the study and interpretation of Scandinavian rock art.

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4.3 Structure from Motion (SfM)

Structure from Motion is a method that is both relatively affordable and easy to learn. The output from SfM documentation is extremely versatile as it creates a point cloud, a mesh, textures, a Digital Elevation Map (DEM) and an orthophoto, and as such it generally offers a significant amount more flexibility than the previously mentioned methods.

SfM is a photogrammetric method which works on the principle that structural (3D) shapes are conceived by the brain through movement (Alonso et al. 2021, p. 49; Green 2018, p. 1; Hixon et al. 2018, p. 43). SfM works by first analysing a set of overlapping photographs, from which a software determines tie points -elements of the photographs that can potentially be linked to similar tie points in other photographs, and then aligns the photograph set based on these (Ducke 2018, p. 2; Espinosa et al. 2021, pp. 167–168). From this alignment a point cloud is formed which is then used to create a denser cloud by creating depth maps from the photographs. A solid 3D mesh can then be created. Additionally, since the main source of information is photographs, a high-quality texture can be created and applied to the models. SfM is capable of capturing extremely high resolution and accurate models (Jones et al. 2015, p. 1086).

Although the end result is similar, SfM differs from laser and range-based modelling as it does not take direct measurements, but relies on algorithms to reconstruct surfaces from photographs (Carrero-Pazos et al. 2016, p. 108; 2018, pp. 37–39; Green 2018, p. 2). The models it creates are not inherently scaled, and it is therefore necessary to include a scale during recording.

4.3.1. Description of method

SfM Is a versatile method which can be used to document the small, e.g. pottery and other mid-sized artefacts, teeth, coins, and macro photographs of rock art (Emmitt et al. 2021; Göttlich et al. 2021; Molloy et al. 2016; Morris et al. 2022; Vaïopoulou et al. 2022), the medium, e.g. rock art panels, cenotaphs, standing stones, buildings (Brandolini et al. 2020; Fioretti et al. 2020; Plets et al. 2012a; Rivera Jiménez et al. 2021; Strasser et al. 2018), and the large scale, e.g. drone surveys of landscapes (Potter et al. 2023a). SfM of smaller targets can be taken terrestrially, via a camera, or and it can be taken via a drone (Bertilsson 2023; Wiseman et al. 2020). In some instances it is used as a method of creating high-resolution orthophotographs which can be used to make tracings (Wang et al. 2019). For an overview of the method's history and current uses see (Marín-Buzón et al. 2021).

While there have been a number of articles presenting the methodology of creating an SfM model (Agisoft LLC 2023; Meijer 2015; Scotland's Rock Art Project 2018a, 2018b), the methodology differs slightly in terms of settings used and how the photographs are taken depending on what is being documented. While a full and detailed description of the SfM methodology is out of the scope of this thesis, an abridged overview of the method of documenting a rock art panel is presented below. Although there are differing opinions about the order of the steps, with one of the most commonly used software, Agisoft Metashape,[18] now seeming to favour skipping some of the steps presented below, this is a method that I have found to work best for rock art documentation.

Before any photography takes place, the panel must be cleared with long grass and overhanging branches etc. being removed and the surface swept. GPS points of obvious carvings or reference points should be taken so that the surface can be georectified, and a scale bar should be added (Koenig et al. 2021, p. 212).

18. Other SfM processing software exist (see e.g. Jaillet et al. 2017, p. 5; Scotland's Rock Art Project 2018b). However, since this is an industry standard it will primarily be used as the main example of software for SfM.

Next, a series of photographs, typically overlapping around 60% and covering the entire surface of the rock art panel that is to be documented, are taken. The first set of photographs is taken working from the bottom of the panel up to the top, and then a second series of photographs is taken from left to right. All photos are taken at the same distance from the surface and using the same focal length. Where possible there should be no shadows in the pictures.

The photographs are then assessed for camera shake, depth of field, and other issues, with unusable photos being discarded. Photographs with areas that should not be included in the final model are masked, i.e. the areas are marked as not to be included in the calculation. The photographs are then aligned to create a sparse point cloud. The calculation area in the software is adjusted to remove any extraneous areas that are present, and a dense cloud is created. From the dense cloud the point confidence (a colour coded signifier of how accurate the model is) is checked and values that are below three[19] are removed. The remaining points in the dense cloud are then converted into a 3D mesh, and the mesh is textured. From here the georeference points are added, a scale is added from the scale bar, and the photos are updated so that the coordinate system is applied to the model. Subsequently a digital elevation map (DEM) is created alongside an orthomosaic.

The outputs from this method are a textured 3D mesh, a DEM and an orthomosiac. There is also the possibility to export the dense point cloud if necessary. While it is possible to add target points for additional accuracy (Sapirstein 2016), for rock it is often unnecessary, and can lead to loss of data as the targets are placed on the surface of the panel.

19. This is at the discretion of the processor, but generally the points below three are untrustworthy.

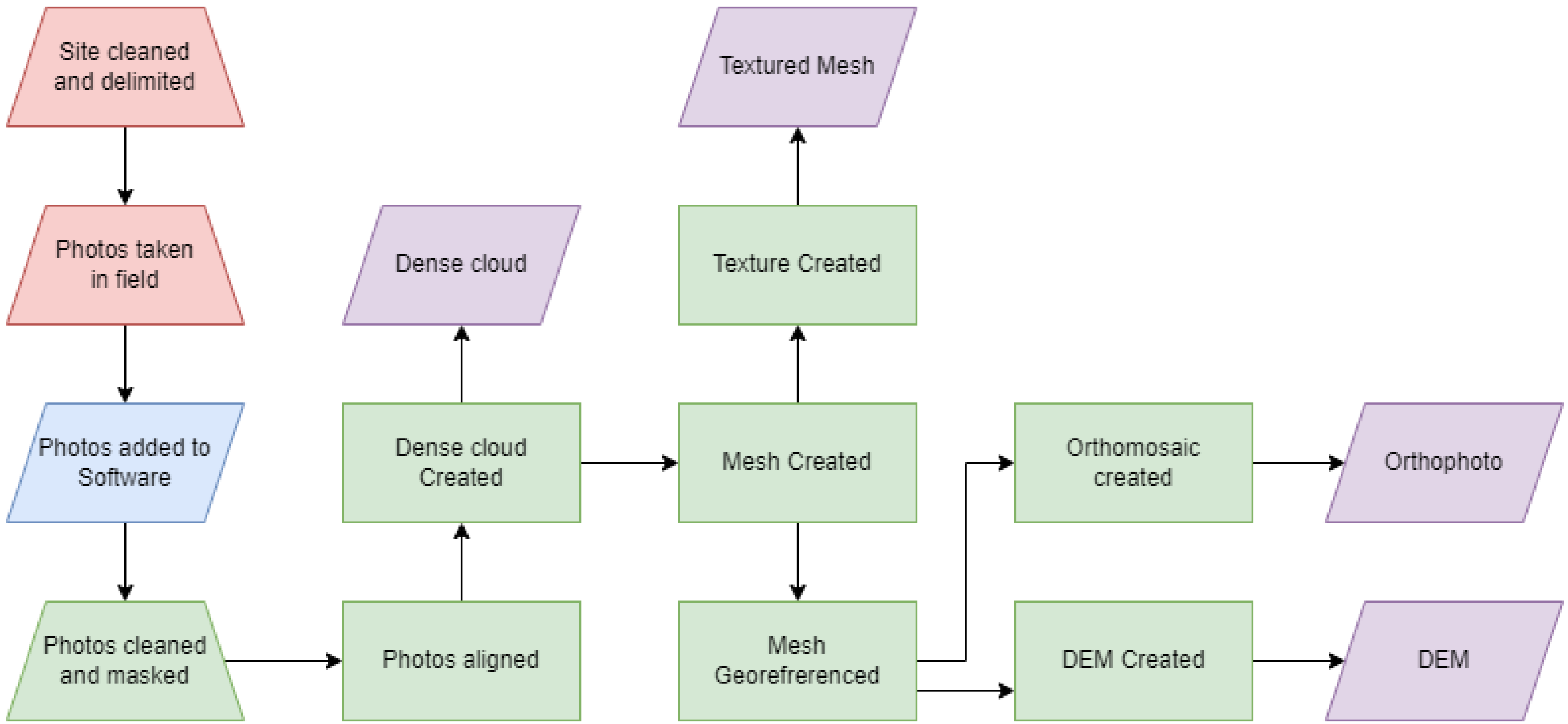

Figure 28: *Overview of the basic process of capturing and processing a rock art panel using Agisoft Metashape.*

Structure from Motion (SfM).

4.3.2. Projects that use Structure from Motion

SfM has proven extremely useful in the documentation, collection, and analysis of carvings and epigraphy (García and Aláez 2021, p. 85; Marquet et al. 2023; Pintado and Basterra 2021, p. 28; Tolosa 2021, p. 139). Along with the SHFA (Bertilsson 2017, 2021, 2023; Bertilsson et al. 2014, 2017; Horn et al. 2018; 2019; 2022d; Horn and Potter 2019; Meijer 2015; Meijer and Dodd 2018; Potter et al. 2022), a prominent promoter of SfM within fieldwork has been Scotland's Rock Art Project (ScARP). ScARP have successfully worked with community groups, and created user guides for beginners to follow when documenting rock art (Scotland's Rock Art Project 2018a, 2018b), which has led to the discovery of new carvings (Valdez-Tullett and Barnett 2021; Valdez-Tullett et al. 2023).

SfM is also useful on a larger scale, as has been demonstrated by various studies which use SfM as an archaeological recording method for fieldwork (Dell'Unto and Landeschi 2022; Derudas and Berggren 2021; Plets et al. 2012a; Scott et al. 2021). It can also be used on a landscape scale, both in terms of recording areas for orthophotos (Wang et al. 2019), estimating scales/volumes (Parizzi and Beltrame 2020), and also as a prospecting technique for ancient remains (Potter et al. 2023a). The models, which can be georeferenced (i.e. have coordinates that relate to specific places on a map), can also be used in software like ArcGIS to generate somewhat interactive documentation of sites, with layers that can be turned on and off to show how excavations have progressed (Dell'Unto & Landeschi 2022).

One of the most useful aspects of using SfM is that the data that can be processed further using other methods and software (See Potter et al. 2023b and the chapter 4.4. for an overview, Green 2018, p. 3). Because the output is essentially a 3D model and a 2.5D representation of the same model, it is possible to use both 3D and 2D spatial tools to analyse the surface.

4.3.3. Structure from Motion as a method

There are a lot of benefits to using SfM in the workflow of analysing carvings, the primary being that there are a multitude of methods that you can apply to the various outputs, as described in chapter 4.4. SfM is easy to teach: for the past few years the University of Gothenburg has developed a series of video tutorials[20] demonstrating how to create models using SfM. Throughout this time, it has been apparent that students pick up the method very quickly through the classes and tutorials. They were able to produce high-quality textured models within a very short period of teaching, using a variety of quality levels of photographic equipment.

Scientific rigour dictates that we must obtain the best possible documentation for the best possible analysis (Nordbladh 1981), but it is very possible to get a useable result from SfM with imperfect raw data, or low-quality equipment, as it is a fairly forgiving method (Espinosa et al. 2021, p. 168; Green 2018, p. 1; García and Aláez 2021, pp. 86–87). The result is of course only as good as the images taken, so there can be issues caused by photographs not being perfect leading to holes or issues in the mesh and texture (Ducke 2018, p. 2). Fortunately, there are a number of options within the software that allow the user to determine where there are issues with quality (e.g. the point cloud confidence tool and the photograph quality value in Agisoft Metashape), and it is possible to return and take more photographs of the object if necessary (Pintado and Basterra 2021, p. 36). It is usually fairly easy to determine the quality of the data based on the output and the photographs.

20. The video tutorials created for the University of Gothenburg: https://www.youtube.com/playlist?list=PLOKjUngLFMc3An0O-7kSJDwtwh6T4e8Sc (accessed 20/07/23)

Structure from Motion (SfM).

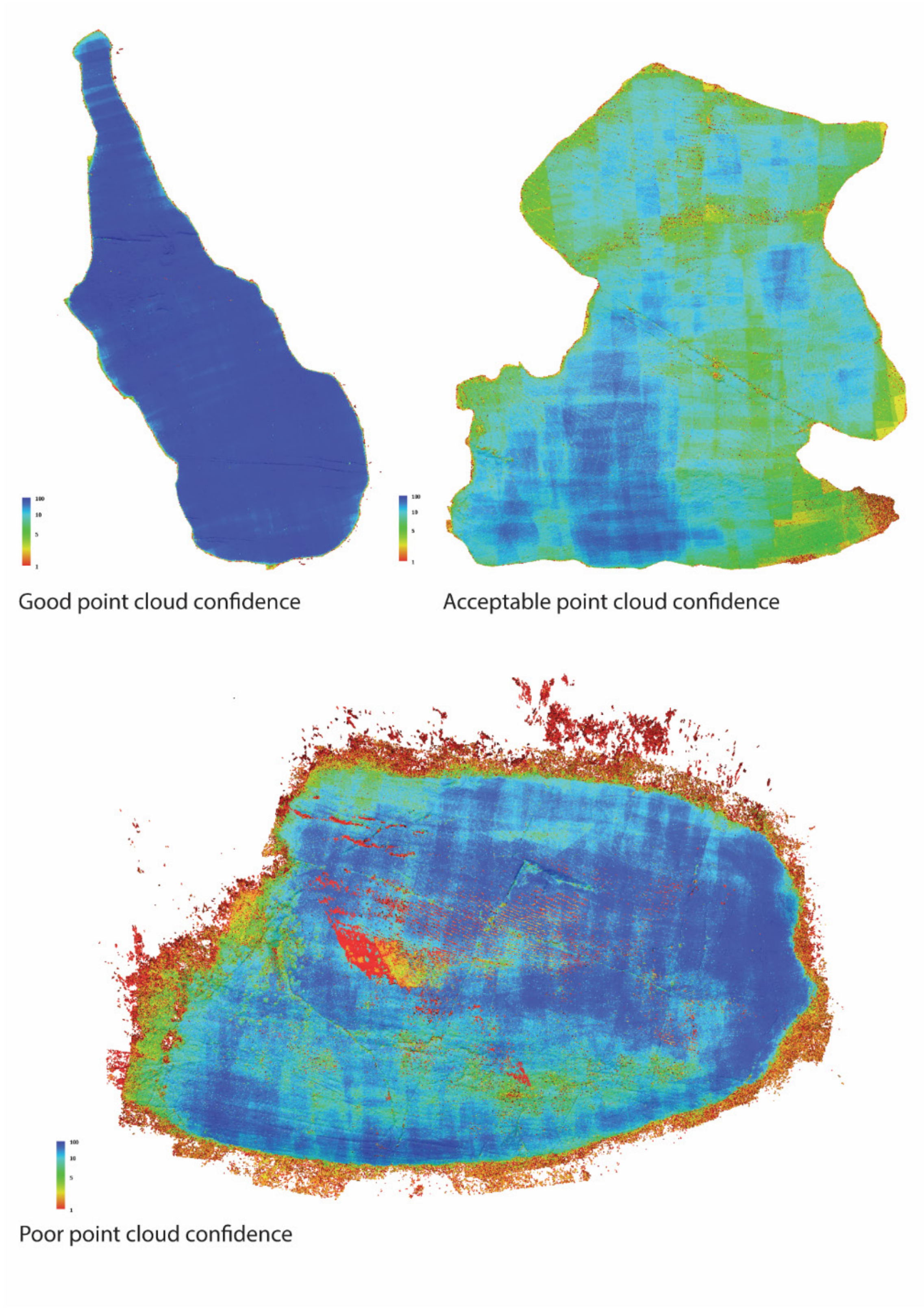

Figure 29: *The various levels of point cloud confidence*

SfM makes it possible to generate high-quality textures for objects, something which is not possible using laser scanning.[21] This is beneficial as it allows for analysis using both textured and untextured models (Molloy and Milić 2018, p. 104). While the models created by SfM are generally instantly understandable and readable because of their shape, textures allow for even greater orientation on larger surfaces. They also allow for an additional determination of whether something is damage, natural, or a carving if there is uncertainty. Untextured models offer the possibility to see a greater definition of shapes unhindered by colour (Hammer and Spocova 2013).

In the past, there has been discussion about the high start-up cost of SfM due to the necessity of specialists and high-powered equipment (Brady et al. 2017, p. 19; Bryan 2009, p. 3). While this is still somewhat true, the cost, both in terms of physical hardware required and time spent processing, has come down significantly due to the increase in power of computing (specifically graphics cards have improved exponentially, and are now used to compute models). Although there is an initial startup cost, for example for the camera and software, it is cost-effective in the long term (Ducke 2018, p. 1; García and Aláez 2021, p. 83; Hixon et al. 2018, pp. 42–43; Seidl 2016, p. 2). With the recent addition of low-cost and even open-source SfM software options (Scotland's Rock Art Project 2018a),[22] and given that it is quite possible to use lower-price cameras for data collection (Espinosa et al. 2021, p. 168), this has reduced the initial outlay even further. Though it must be re-stated that better cameras tend to take better photographs, and better photographs lead to the possibility of better results as the quality of the model scales with the quality of the photographs (Ducke 2018, p. 2).

SfM documentation is fairly quick in the field, which means that information which might otherwise be lost during archaeological excavations can be rapidly collected and help direct the excavations (Green 2018, p. 2; Scott et al. 2021, p. 575). However,

21. It is possible to get textures using some laser scanners, but the quality of the images is generally sub-par.
22. For example Meshroom (https://alicevision.org/ accessed 20/07/23)

Structure from Motion (SfM).

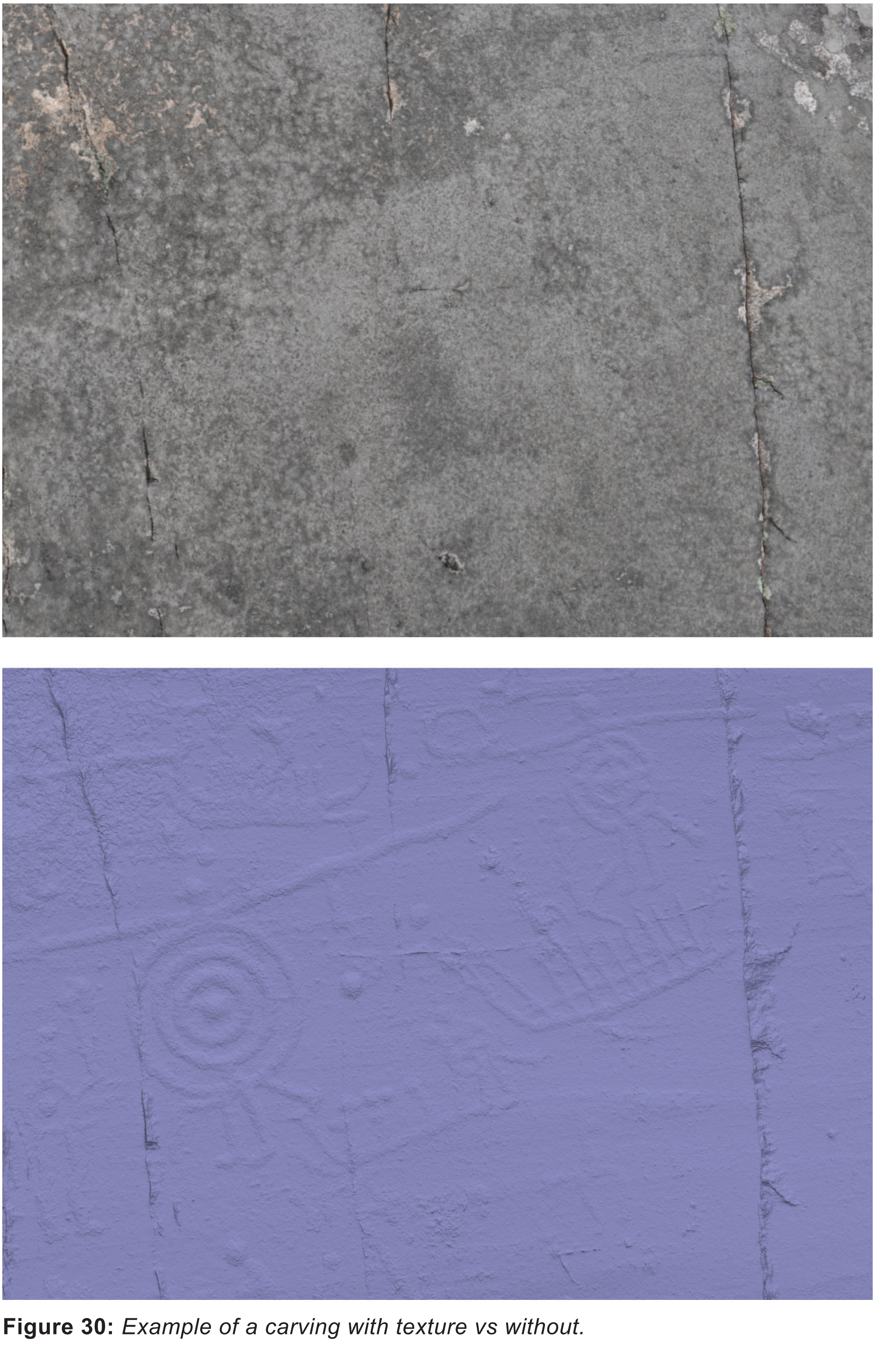

Figure 30: *Example of a carving with texture vs without.*

storage of data from SfM can become problematic as with larger projects the number of photographs -preferably both in .jpg and RAW formats (Molloy et al. 2016, p. 83; Valdez-Tullett and Figueiredo Persson 2023, p. 22), can quickly become sizeable. Additionally, the files created by SfM software tend to be fairly large as they consist of multiple point cloud datasets (Bertilsson 2017, p. 66). This issue will be looked at further in the discussion.

SfM has proven beneficial for rock art research because it is possible to cover large panels, while retaining the same high level of detail across the surface that you would get from a small area. The large number of possible outputs from the processing offers greater analysis, which is also possible to integrate into other methods, like RTI (Green 2018, p. 3). The raw data is essentially photographs, which makes it possible for other researchers to use the material as they please. Additionally, little equipment is required, which means it can be used in smaller spaces than other methods (Strasser et al. 2018). Software costs can be high, there are also free options available, although they often suffer from a lack of user-friendliness (Scotland's Rock Art Project 2018a).

Structure from Motion (SfM).

4.3.4. Related articles

The following presents three articles that are related to my work with SfM. The first documents the development of an accessible visualisation method using ArcGIS, and the second covers the use of the method at a rock art site in Tanum, demonstrating the suitability of the digital frottage method. The third article is more theoretical, but covers the documentation and analysis of a rock art panel in Finntorp, Sweden, and discusses the updating and continued use of rock art panels. Each article is described in further detail below, along with an overview of how I contributed to them. For a more detailed breakdown of my contribution, see figure 1.

Article five: An evaluation of the visualisation and interpretive potential of applying GIS data processing techniques to 3D rock art data.

Horn, Christian; Pitman, Derek; **Potter, Rich** (2019): An evaluation of the visualisation and interpretive potential of applying GIS data processing techniques to 3D rock art data. In *Journal of Archaeological Science: Reports* 27, pp. 1–13. DOI: 10.1016/j.jasrep.2019.101971.

I contributed to this article by developing and testing the proposed method on a number of rock art panels that I documented using SFM. Through this I developed a set of values that worked consistently with varied surfaces. I also wrote and edited sections of the article. **(overall contribution 40%)**

This article details a new accessible method for creating "Digital Frottages" adapted from an approach originally proposed for use with landscapes by Hesse in 2010 (Hesse 2010). The method uses a highly detailed SfM model of a rock art panel from which a Digital Elevation Map (DEM) is generated in Agisoft Metashape. This DEM is then imported into ArcGIS and processed firstly using focal statistics to create an image of the larger variations in the panel. This is then subtracted from the original DEM, leaving behind the small details of the panel. The characteristics of the resulting image were then manipulated to create a result that is very similar to the output from an analogue frottage taken at the rock face, but with a number of advantages including being able to zoom in easily, the ability to change parameters on the fly, and the removal of seams and stretching that can cause issues with traditional rock art methods. The article presented a number of results from panels documented in the Bohuslän area, and presented new discoveries and improvements in the documentation compared to the traditional methods, chiefly that it was easier to see superimpositions in more detail, and that it made it possible to visualise rock carvings that were not possible to capture with traditional methods. The method is advantageous over only using 3D models as it is more accessible both in terms of being able to share data due to the smaller file sizes of the DEM maps, and because it uses ArcGIS, a software that the majority of archaeologists have some familiarity with.

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An evaluation of the visualisation and interpretive potential of applying GIS data processing techniques to 3D rock art data

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Local relief modelling

ABSTRACT

Rock art provides a tangible visual link to past communities and has significant value in building our understanding of prehistoric societies. Its recording and interpretation has long provided a window to intangible aspects of society, such as belief systems and folk narratives. Petroglyphic rock art has traditionally been recorded through simple rubbing, or frottage, and the majority of interpretations and narratives to date have been based on this work. Recently, three-dimensional capture techniques have become readily available and they replace traditional approaches to rock art recording. These techniques are valuable, but the data-heavy outputs lack the interpretive clarity of traditional methods. This paper explores these issues through a novel approach that employs topographic landscape analysis techniques, initially developed for LiDAR processing, to produce clear images that have the precision and dimensional accuracy of 3D captured data, but the visual clarity of traditional methods. Specifically, this paper outlines an approach based on local relief modelling (a technique that highlights subtle topographic features) and explores its efficacy through case studies of Bronze Age Scandinavian petroglyphs. This method was developed to aid the analysis of 3D models and to improve visualising the results based on such investigations. This work offers a significant impact on rock art studies as it facilitates the identification of previously unidentified motifs, and allows a clearer sense of petroglyphic world views. The technique can be applied to models of other archaeological surfaces.

1. Introduction

This paper outlines a method for the visualisation and interpretation of petroglyph data using a case study from Bronze Age Scandinavia. Rock art can be seen as a tangible way in which past human communities 'socialised landscapes', leaving a mark visible through pigment or, in this case, through petroglyphs, which gives a long lasting glimpse into aspects of society that are often lost to archaeology (Chippindale and Taçon, 1998). Its record and analysis are a vital component for understanding past social dynamics, organisation, and character. The methodological refinement of recording, analytical techniques, and the presentation of accurate and precise graphical reproductions is a fundamental field of research.

Within the context of Scandinavian rock art study, documentation techniques have been developed and refined over the last 150 years in an attempt to produce graphic representations of incised rock art that best represent the original work. These developments went through various imaging techniques from Indian ink graphics, drawings using measurement grids, tracings, and rubbings (frottage). Recently, the Swedish Rock Art Research Archive (SHFA), which is concerned with the documentation and research of Scandinavian rock art, has advocated the use of 3D models as a new, complimentary documentation standard (Horn et al., 2018). Bertilsson and others have argued that 3D models based on image-based and range-based modelling techniques are a way to minimize bias and improve the quality of documentation (Bertilsson, 2015; Bertilsson et al., 2017; Horn et al., 2018; Rondini, 2018). The research using 3D documentation has demonstrated the veracity of Nordbladh's, 1981 argument that high-quality rock art research requires high-quality documentation (Nordbladh, 1981), through new discoveries and a reinvigorated debate about rock art documentation (Díaz-Andreu et al., 2006; Díaz-Guardamino Uribe and Wheatley, 2013; Fahlander, 2017; Ling and Bertilsson, 2017; Rondini, 2018).

Central to the development of this field has been the shrinking size/cost of laser scanners and the development of multi-image photogrammetry (using software like Agisoft Photoscan©; now

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Metashape©). This has greatly facilitated accessible and versatile use of 3D documentation of rock art research. Precise and accurate data capture of rock art is significant, but it is vital to be able to interrogate the data and show the results of the analysis of 3D data to the public in a readable, understandable format (see Reu et al., 2013). Typically, traditional techniques like rubbing or tracing documentations provide a visibly clear and understandable image, despite their clear shortcomings. Similarly, journals are increasingly offering the ability to upload models, and 3D hosting sites such as sketchfab.com enable the curation and distribution of rock art documentation.

It is essential then, that data resulting from the capture of three dimensional rock art can be processed, curated, and distributed in a visually clear and accessible manner. However, file size restrictions, necessary computer power, and technical knowhow limit these opportunities and the impact of such digital dissemination. Consequently, it is of significant value to replicate the positive aspects of traditional documentation with the advantages of digital data capture. This paper proposes a relatively straightforward method for the transformation of 3D data into easily discernible and distributable visualizations of complex 3D datasets. The images exhibit the clarity of rubbings (also termed frottage), but retain the accuracy of the 3D recording. This creates visually clear and accessible images that show topographic characteristics of engraved rock art, as well as potentially highlighting previously unidentified imagery. In this article, various tentative interpretations will be given when discussing the advantages of this visualisation method. A fuller argument to sustain such interpretations requires more than one example and a much deeper discussion. This would distract from the main issue of this article, i.e. the method. Some cases have been discussed in detail, and the published or in print contributions will be referenced appropriately.

This work has been conducted for the purpose of finding a better way to visualise the carvings for a later study using an Artificial Intelligence approach within the project "Rock Art in three Dimensions" granted by the Swedish National Bank's Jubileefond (Riksbankens Jubileumsfond; Ref.nr. IN18-0557:1). The purpose is to further the systematic digital documentation of the UNESCO World Heritage Area in Tanum using holistic, less biased methods. The sites for this study were the first that were documented using either photogrammetry or laser scanning. They were chosen to show that both methods of acquiring 3D models could be used.

2. Incised rock art

A study in the production techniques of petroglyphs conducted by G. Burenhult demonstrated that they typically occur from the following actions: carving, incision, grinding, and through percussive actions. The latter is the most prevalent for of rock art, while true carvings and incisions usually only occur from the Iron Age onwards and are most frequent during the Viking Age (Burenhult, 1980). Percussive techniques were mostly used to apply petroglyphs during prehistory in Scandinavia, but they are also found on the Iberian Peninsula, the British Isles, and the Alpine rock art regions. The most common form of rock art is cupmarks, which are half-spherical depressions in the rock (Horn, 2016). Apart from such abstract motifs, there are figurative petroglyphs, most of which depict canoes, anthropomorphs, metalwork, and animals (Goldhahn and Ling, 2013; Nimura, 2015). Many other motifs such as footsoles, sun discs, wagons, aards, etc. also exist (Bertilsson, 1987; Malmer, 1981; Skoglund, 2013). In the majority of cases Scandinavian petroglyphs are applied to exposed bedrock outcrops, so called panels. Petroglyphs were also made on loose boulders, especially in Denmark and Northern Germany, but also in Sweden and Norway. In this form, they most often occur in burial contexts such as the famous barrows from Kivik and Sagaholm in Sweden (Capelle, 1972, 2008; Glob, 1969; Goldhahn, 1999, 2009, 2016). Scandinavian rock art is the biggest source of pictorial evidence for Bronze Age life, society, and belief systems. Beyond Scandinavia the petroglyphs may have wider implications for the European Bronze Age.

3. Rock art documentation

3.1. Traditional recording techniques

Most rock art in Scandinavia is so shallow that it is difficult to identify visually. Therefore, depth is a crucial aspect of any documentation of petroglyphs; traditional methods make use of this dimension to document rock art. Rubbing, for example, only works because less graphite is applied to the paper over carved depressions. Their advantages and disadvantages have been described in detail elsewhere (Horn et al., 2018; Nordbladh, 1981; Rondini, 2018) so only a brief outline will be presented here. The main methods used were night photography, tracing, and rubbing (frottage). In night photography an artificial light source is taken to the petroglyph panel and shone at an oblique angle during evenings and nights when there is no sunlight. This creates sharp shadows even from small irregularities in the rock, and thus makes petroglyphs visible. Tracing involves a tactile examination of the rock's surface searching for depressions. Each find is interpreted either as artificial, natural, or damage based on the experience of the documenter. Afterwards, the appropriate lines are painted using chalk paint. Following this step, large plastic sheets are fixed to the rock and the lines are transferred. For rubbings, large sheets of paper are fixed to a panel, which in many cases had been pre-examined with a tactile survey. This paper is rubbed using a sponge and graphite. Where the paper lies over depressions in the rock, less pigments are deposited. These areas show up lighter in colour on the paper.

All three methods are long-standing methods in rock art documentation, and the critical comments raised here and elsewhere do not deny their usefulness or that they are able to convey important information. However, to be able to include rock art documentation into research in a scientific manner and assess its relevance, it is necessary to understand the methods shortcomings. None of the techniques described are reductive as they do not record the third dimension of rock art. Many steps of inference are necessary to document petroglyphs using tracings and rubbings; as such, recorder bias is inherent to the documentation process (Bertilsson et al., 2017; Horn et al., 2018). Rubbings and tracings pose a risk to the panels due to the extended periods of time that the documenters spend on the rock. All three methods create problems with spatial relationships. The various angles from which photos are taken skew motifs and make the outcome unusable for measurements of dimensions and distances. The paper or plastic sheet of both other methods are stretched out over the curvature of the rock, but are later flattened out which distorts the real-world position of motifs (Nordbladh, 1981).

3.2. Three-dimensional rock art documentation

The capture of three dimensional data is of significant value within archaeology and heritage (Alexander et al., 2015; Ioannides and Quak, 2014; Molloy, 2018). From landscape survey to artefact analysis, the ability to digitally capture three-dimensional data on a range of scales has facilitated a rapid increase in the ability to share and disseminate information. Projects such as the facial reconstruction of the Cheddar Man have successfully shared 3D scans of skeletal material among research teams to great effect (Lotzof, 2018). The rapid uptake has led to significant epistemological leaps in the way in which data can be captured, used, and disseminated (Karasik and Smilansky, 2008; Molloy, 2018). In broad terms, there are two types of 3D data capture; image base and range based modelling. Image based modelling uses multiple static images and pixel recognition to generate three-dimensional point clouds, range based modelling uses 'time of flight' principles to establish point clouds in relation to a laser source and receiver (Skarlatos and Kiparissi, 2012). The accuracy and level of detail achievable through these techniques is far beyond that of non-digital documentation. In recent years, the cost reduction in computing power and better accessibility to software has lowered the barrier against using them considerably. As a result, these techniques have become increasingly important for the documentation of rock art in many regions since the 2000s (Alexander et al., 2015; Barnett et al., 2005; Díaz-Guardamino Uribe and Wheatley, 2013; Lerma et al., 2010; Lerma et al., 2013; Meijer, 2016; Reu et al., 2013).

These digital capture techniques are central to the case study presented here which focuses on the UNESCO world heritage area in Tanum, Sweden (Horn et al., 2018). Photogrammetric documentation is achieved through a combination of Structure from Motion with subsequent dense Multi-Stereo View (Bertilsson et al., 2014; Bertilsson, 2015; Bertilsson et al., 2017; Meijer, 2016; Sevara and Goldhahn, 2011). For range-based modelling, the SHFA uses a Handyscan 700™ red-light laser scanner with a maximum resolution of 0.05 mm.

The biggest advantage of image-based and range-based modelling is their capability to record, and thus, preserve all three dimensions of petroglyphs. The possibility to turn and adjust the viewing angle as well as the lighting in the 3D models is a great advantage for researchers, because it offers opportunities to study the panels in ways unavailable in the field. Everything on the panel that is within the technical capacity of the chosen method is recorded. No human decision is necessary, and the documentation cannot be intensified on some parts of the panel and lacklustre in others. Thus, bias in capture is reduced by a considerable degree, although it certainly still exists in the interpretation of the 3D data.

3.3. Problems encountered with 3D documentation

All 3D data requires visualisation to convey its content for investigation, interpretation, and dissemination. In archaeology, visualisation is rarely discussed explicitly beyond practical concerns, and is considerably less theorized (Reilly, 1989). Green (1998) discusses the need for the proper visualisation of complex data such as 3D models, and highlights the need to integrate theories of computer graphics and human perception. Jacques Bertin's (1983) 'image theory' is, to date, the most advanced theoretical framework as it considers human cognition to be an element of visual interpretation. He identifies the problem that the human eye can only represent two dimensions in the retinal image, which means that our brains make a 2D image out of 3D reality. To perceive 3D shapes, humans need multiple combined cues (Welchman et al., 2005). Therefore, observations of a 3D model are aided to a considerable degree by the motion of the model and lighting across the surface as this provides the visual cues needed to perceive its shape. As soon as the model is static, perception of its dimensions becomes problematic. For example, screenshots used in the majority of publications lose many subtle differences in shape and depth. It is therefore difficult to show all of the details in one screenshot.

The lighting example of the model of panel 184:1 in Finntorp, from the south-east, conceals parts of a boat in the right top corner (Fig. 1a) and lighting it from the south makes some of the humans and upper boats problematic to recognize (Fig. 1b). Given the limited number of illustrations most journals allow, it is not possible to demonstrate all lighting positions and configurations.

Publishing 3D models directly may remedy that, but their file sizes make this problematic. Professional accounts, for example, on the 3D model hosting website Sketchfab©, currently only allow models up to 500 MB. While this may change in the future, larger models (1GB+) still require more computing power to load and move the model, making them not available to everyone. Most full site documentations prepared by the SHFA exceed the limit of 500 MB, and most are even larger than 1GB (Table 1). Additionally, hosting larger file sizes in the future will likely merit considerable costs which many projects may struggle to bear. These constraints mean that models must often be decimated, which carries the risk of losing important details. Lastly, using software like Meshlab© for viewing, rotating, and lighting models requires technical skill which potentially restricts their non-specialist use.

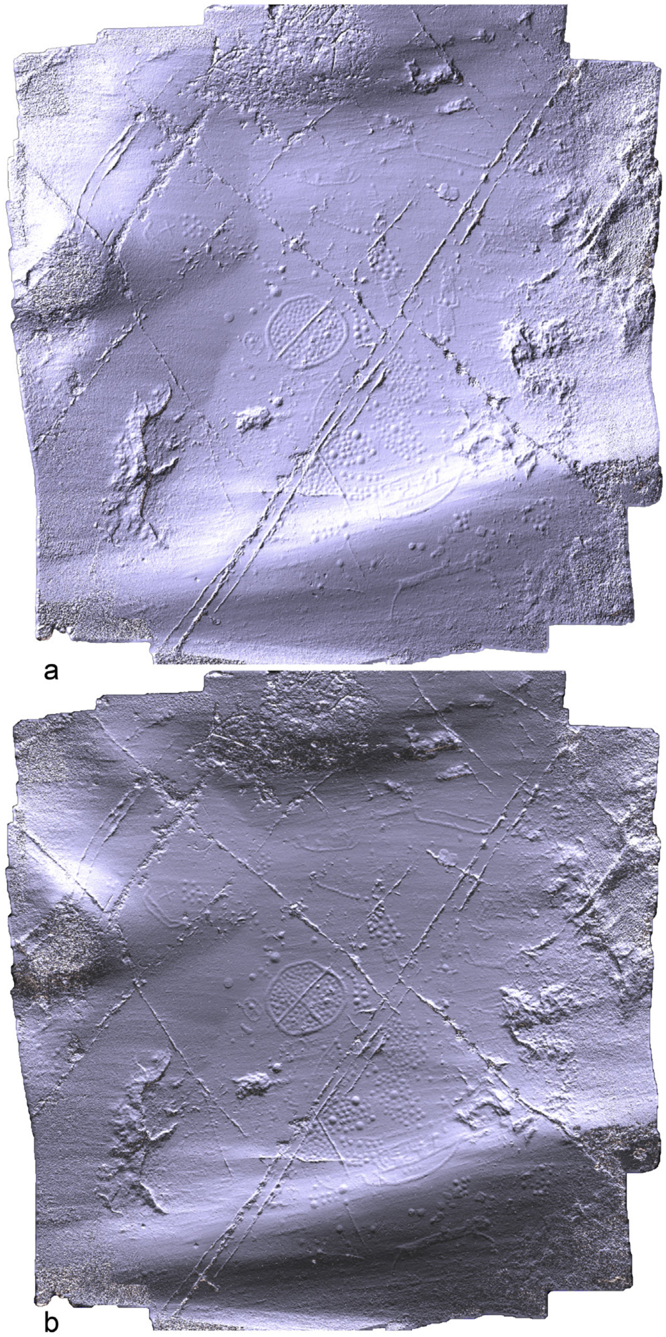

Fig. 1. Snapshots taken in Meshlab from a 3D model (photogrammetry) of a rock art panel in Finntorp, Sweden (RAÄ Tanum 184:1) with lighting from the south-east (a) and the south (b). The extend of the engraved surface is 480 × 400 cm.

3.4. Digital decision making: interpretation versus curation of rock art panels

The interpretation of rock art panels inevitably requires the use of human knowledge and understanding. However, the curatorial process of digital rock art representations should strive to present as little human bias as possible. There are a suite of tools for "highlighting" the images on panels, but we argue here that there is a difference between

Table 1
Summary of the extent of the panels and the file sizes in MB for the 3D model, the geotiff, and as output.

	Finntorp 95:1	Finntorp 184:1	Hoghem 160:1	Gryt 1:1	Tanum 311:1	Fossum 255:1	Tanum 198:1
Extent (cm)	250x120	480x400	880x250	830x320	900x600	1300x500	1400x500
Sqm.	3	19,2	22	26,6	54	65	70
3D model file size (MB)	602	510	721	1010	1620	2800	3860
ArcGIS as .tiff (600 dpi; MB)	27,1	32,4	19,3	10,9	19,1	20,5	24,1
Output saved as .png	20,1	23,3	12,7	5	10,3		16,3

enhancing the topographic features of the panel and superimposing what the researcher wants to be shown. The latter is essential in interpretive discussion, but of less value in the presentation and curation of raw data. Tools like Meshlab are useful, especially for smaller panels without a strong global curvature and sections of larger panels where rendering options such as Radiance Scaling have been used with some success (for example Carrero-Pazos et al., 2018). It has been proposed that Radiance Scaling output should be used further in raster graphic editors such as Adobe Photoshop© with the "dodge and burn tool" and overexposure options (Carrero-Pazos et al., 2018) to better highlight images. Since the proposed Meshlab options work across the entire surface of the 3D model the stronger curvature of some complete panels or strong ridges present a stronger signal that in a sense "cloaks" the weaker signals of the local variations, i.e. the petroglyphs. It would be possible to make a selection to use these tools, but that would reintroduce the problem of bias in human decision making. Furthermore, the steps needed to increase visibility in this method do not directly process height values, but rely on pixel manipulation in image processing applications where some loss of control over the variables may be expected.

Another approach that has been proposed is the use of LIDAR visualisation technique in a method called "AsTrend" (Carrero-Pazos et al., 2016). This method delivers a compelling visualisation. However, it may be problematic since it uses yet another application LiDAR Visualisation Toolbox that was last updated in 2014 (https://sourceforge.net/projects/livt/) and uses unfamiliar file formats. It may in the future also prove problematic for rock art because it causes distortions on slopes (Hesse, 2010) which would especially effect carved lines. Carrero-Pazos et al. (2016) also propose the use of Adobe Photoshop's© toolset to enhance the outcome of their visualisation approach (Carrero-Pazos et al., 2018). This is problematic because the data is manipulated unevenly and without control. This reintroduces documenter bias, because the colour does not represent existing differences in depth anymore, and are more akin to tracings.

These approaches all have their uses, but could also be characterised as digital versions of manually traced rock art images. In the following, the authors describe a simple method to generate images with the compelling clarity of traced drawings or frottage images without further manipulation through raster graphic editors. The images generated in the final output are reduced to two-dimensions, but they preserve the objective, bias free advantages of 3D based documentation which provides a surplus of information for research, i.e. the correct spatial relation of petroglyphs and superimpositions. Lastly, the considerably reduced file size of digital frottage images makes them perfectly usable on every computer and in the creation of mobile apps for rock art museums and centres. The resultant images, similar in appearance to traditional rubbings, maintain their authenticity while significantly improving the visual contrast of the petroglyphs.

Before explaining our method, Reflectance Transformation Imaging (RTI) should be mentioned because it has already had a significant impact in the documentation of rock art (Díaz-Guardamino Uribe and Wheatley, 2013; Horn and Potter, 2018). This photogrammetric method alleviates the problem of large file sizes and produces excellent, high-resolution images. However, RTI cannot be used to create full 3D models, and is affected by directional lighting obscuring carved elements (as described above). For these reasons, we will not discuss RTI further here.

3.5. Landscape approaches to 3D data processing

Landscape analysis within heritage and archaeology has become increasingly reliant on complex three-dimensional datasets. The advent and wide scale capture of LiDAR data has facilitated this development, which has been utilised by a variety of disciplines from ecology, geography, and archaeology (Bewley and Rączkowski, 2002). The latter has enthusiastically embraced LiDAR as a revolutionary tool for site prospection and analysis (Bennett et al., 2012). The need to identify very specific topographic signatures has led to significant innovation within 3D Data processing and visualisation techniques (Bennett et al., 2011; Crutchley, 2010) that are now routinely housed within geographic information systems (GIS). On a landscape scale, archaeological features are typically present as micro-topography which is much subtler than the geographic background. Therefore, techniques that filter the natural from the anthropogenic are essential in landscape analysis. These issues are clearly similar to those outlined above, albeit on a significantly difference spatial scale. The need to highlight faint topographic features and remove macro-topographic structures, however, remains the same. The breadth of visualisation and analysis techniques for landscapes has been summarised elsewhere (Bennett et al., 2012) but some, most notably local relief modelling (LRM), have significant potential for the visualisation and analysis of petroglyphic imagery as it highlights micro-topographic features by removing macro-topography. The basic underlining principal is to defocus a topographic raster image (in ArcGIS using the focal statistics tool or in QGIS using the GRASS r.neighbours plugin) to a radius that is appropriate to the scale of the features you wish to highlight (Fig. 2a). Through this process small scale variation is removed by averaging cells to the surrounding pixel values. The values of the original raster are then subtracted (minus tool in the raster calculator for both ArcGIS and QGIS) from the defocused image revealing only the features smaller than the focal radius. This process is effective on both shallow subtle pictographs and deep incisions. Fig. 2 shows an example of the effects of this workflow. The size of features revealed relies on appropriate parameters, specifically the extent to which the topographic image is defocused (Fig. 2b–e). The typical workflow used in this paper involved the use of ArcGIS, using the focal statistics tool, initially with default values, before adjusting the cell radius in increasing increments until the image was defocused just beyond the point that the desired features

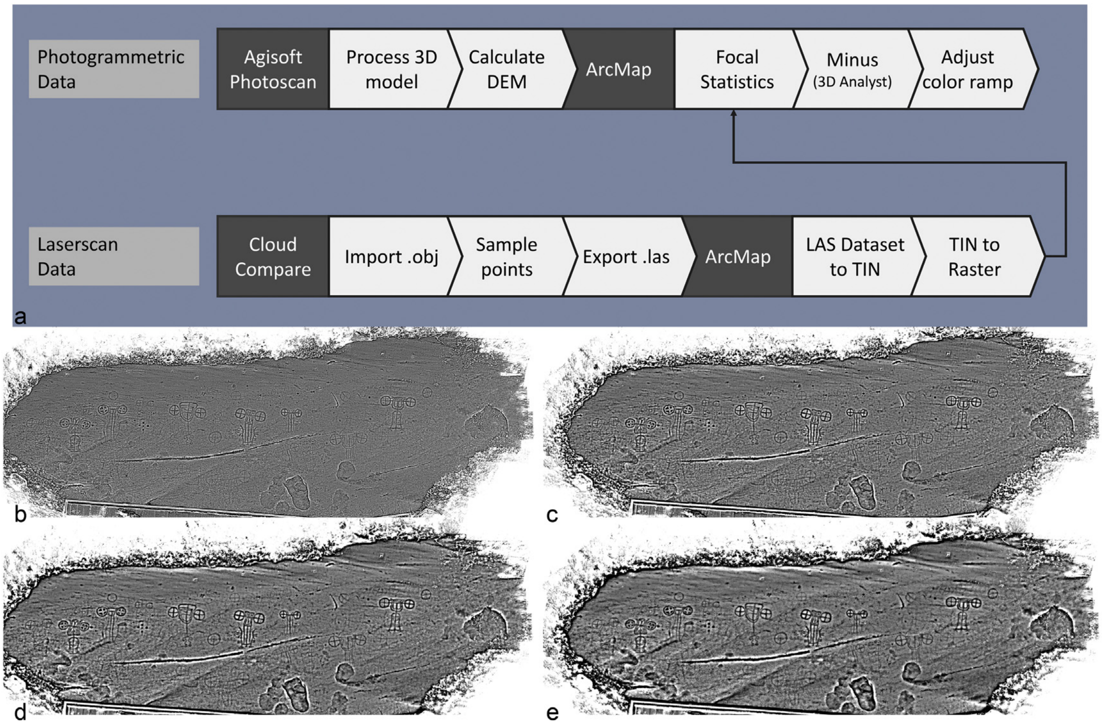

Fig. 2. Workflow of the data processing. The output in this example is produced in ArcMAP (a). Examples of different defocussing values (Focal Statistics tool): b.) 60 × 60, c.) 120 × 120, d.) 320 × 320, and e.) 640 × 640.

lose visibility. This allows the maximum highlight upon subtraction from the original raster data. In addition to the steps above, both ArcGIS and QGIS have dedicated, open source, local relief model plugins that can produce similar effects (the plugins take the workflow a step further, computing a 'true' LRM, however, these steps are more pertinent to landscape studies, Novák, 2014).

The output of the process requires an adjustment to the colour distribution to enhance the contrast of the image. This can be achieved by setting the standard deviation of the colour ramp to values ranging between 0.2 and 2.0 depending on the recorded surface. There is also a range of different colour gradients available. However, in this paper no improvement could be observed by choosing anything other than black and white gradients.

4. Evaluating visualisation techniques using the SHFA archive

4.1. The rock art panels

The dataset used within this paper results from fieldwork conducted in Tanum (Vitlycke (RAÄ 1:1), Finntorp (RAÄ 89:1, 95:1, 184:1), Hoghem (RAÄ 160:1), Bro (RAÄ 198:1), Fossum (RAÄ 255:1), and Gerum (RAÄ 311:1)), Gothenburg (RAÄ Askim 27:1), Scania (Frännarp (Gryt 1:1)) and the National Museum in Copenhagen (Engelstrup). The fieldwork was conducted in seasons between 2014 and 2018 (Horn, 2016; Horn et al., 2018; Horn and Potter, 2018). We will use the numbering system designated by the National Swedish Heritage Board (Riksantikvarieämbete).

All panels have a similar documentation history (Table 2) available through the SHFA. The earliest documentations, from the middle of the 19th century, were drawings and graphics of Gerum, Vitlycke, and Fossum. These are also the panels that have been documented the most. The first comprehensive documentation effort was made by Lauritz Baltzer during the 1880s recording almost all panels except Finntorp 95:1. Modern frottage exists for all sites conducted by Tanum's Hällristningsmuseum Underslös (THU), which record the known extents of each site. Only on panel Finntorp 95:1 were entirely new petroglyphs discovered during laser scanning by the Administrative Board of Västra Götaland (Henrik Zedig). Two additional anthropomorphic figures were discovered. These figures are only partially visible in our own recording as we avoided removing soil.

4.2. Advantages of GIS data processing of 3D rock art data

The following sections outline the key advantages observed when applying this technique to the SHFA dataset. Thus far, the process has produced results that heavily complimented the dataset and greatly facilitated interpretation and dissemination.

4.2.1. File size

For the storage and dissemination of the produced visualizations, the proposed method has a much reduced resource impact. The Tagged Image files (.tiff) produced through exporting the image from ArcMAP for full site models ranges between 12 and 32 MB. The exported images have a resolution of 600 DPI and a size of ca. 6900 × 5600 pixel. With the loss free compression of image formats such as .tiff or .png this can be improved further. Even for large sites like Gerum 311:1 or Bro 198:1 the.png files did not exceed 24 MB (Table 1). This results in more than a 90% reduction in file size, although, it must be kept in mind that these are no longer 3D models.

4.2.2. Visualisation of small details

This approach has the capacity to visualise very subtle details as small as the resolution of the 3D model permits. The panel Finntorp 89:1 is a large panel of ca. 6 × 5 m including at least 17 human figures (Horn and Potter, 2018). Two of these anthropomorphs are depicted engaged in intercourse. In the upper body of the female figure on the panel Finntorp 89:1, an outward swinging line could indicate female breasts. Directly below is a straight line angled upwards towards the back, while a similar second line is lower on the body and is a prolongation of the phallus (Fig. 3b, red arrows). Both lines could indicate a garment pulled aside for intercourse. The long hair seems slightly detached on the traditional rubbing (Fig. 3a). However, the new image

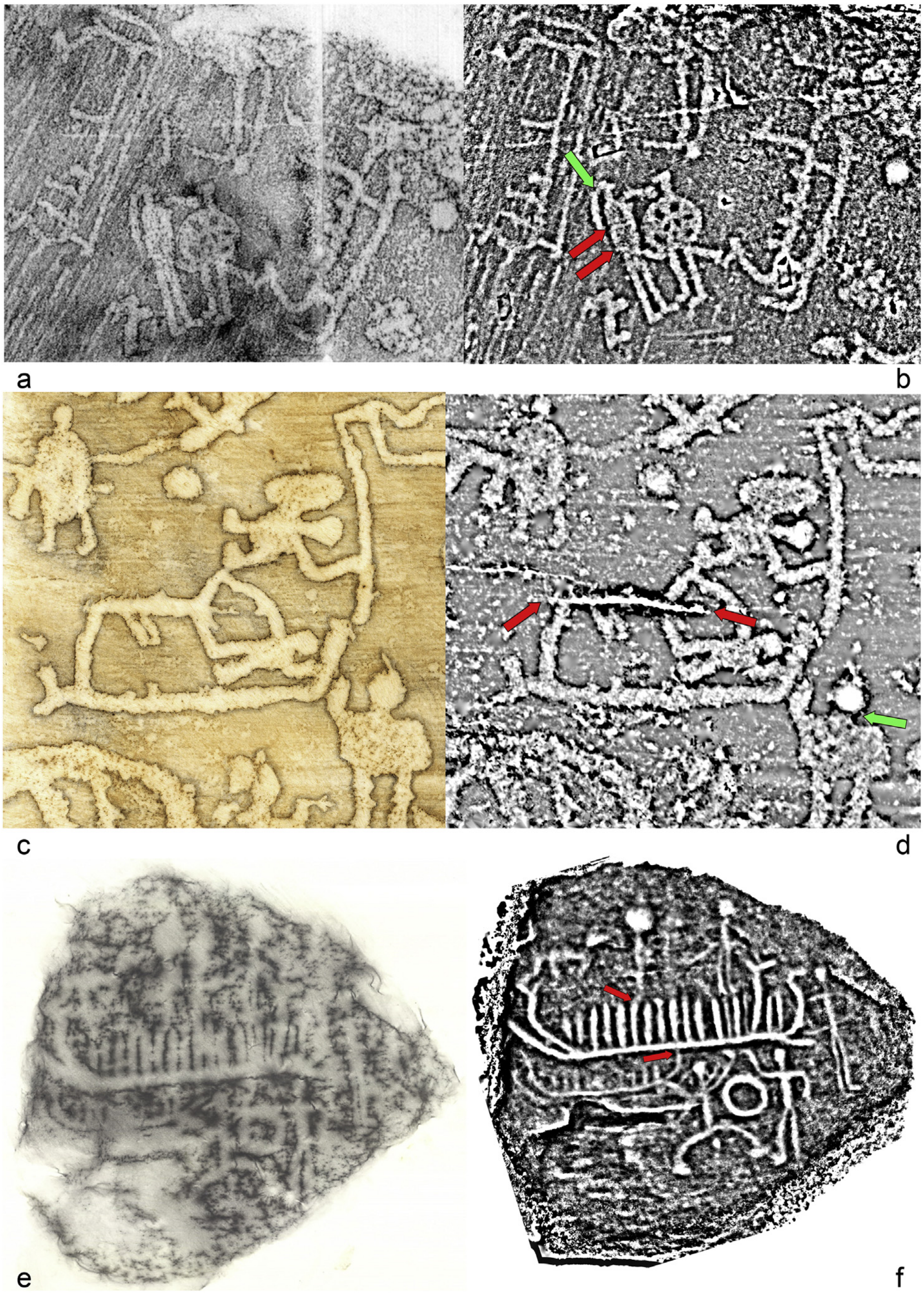

Fig. 3. Comparison between rubbings of images at various sites and the GIS processed output following the proposed methodology (if not mentioned differently based on Structure from Motion data): RAÄ Tanum 89:1 documented by the RockCare project using rubbing in 1999 (a) and the GIS processed output (b). Both figures ca. 20 cm. RAÄ Tanum 90:1 documented by Dietrich Evers using rubbing in 1970 (c) and the GIS processed output based on laser scan data (d). Human figures ca. 15 cm. Boulder from Engelstrup documented by Tanums Hällristningsmuseum Underslös using rubbing in 2014 (e) and the GIS processed output (f). The slab is 58 × 65 cm large.

shows that it is connected to the head by a thinner line which could represent a binding (Fig. 3b, green arrow).

On the neighbouring panel in Finntorp (90:1) there is a figure hunting with a spear. The spearhead is ca. 7 cm long, but shows surprising detail in the digital LRM (Fig. 4). The edges follow from the point of the concave trajectory before sharply curving back towards the socket (Fig. 4, red arrows). Without going into detail, spears with such sharply breaking edges are known from the Early Nordic Bronze Age and belong to the types Bagterp and Hulterstad (see also Bertilsson, 2015; Horn and Potter, 2018; Jacob-Friesen, 1967).

4.2.3. *Equal colour distribution*

When compared to traditional rubbing, digital data files possess an equal distribution of colour whose variation depends only on the structure of the recorded surface. In Finntorp 89:1, for example, the conventional rubbing has a lot of graphite surrounding the male figure because it is a very shallow carving and the documenter wanted to make sure every detail was captured (Fig. 3a). However, these efforts obscured the nose-like shape on the figures head as well as the outline of the shield. The processed digital image shows the nose and full extent of the shield on the male figure in Finntorp 89:1 (Fig. 3b).

A highly detailed rubbing of human figures and a ship on the panel Finntorp 90:1 was prepared in the 1970s by Dietrich Evers (1991). There is an animal on the panel that could be a bull or another animal. The rubbing fails to indicate that the line which seemingly forms the body of the animal is in fact a natural crack in the rock surface (Fig. 3c). The processed LRMs indicate that this is not an engraved line, but instead damage that obscures the original engraving (Fig. 3d, red arrows). Presumably, Evers did not apply graphite vigorously enough in that part to visualise the difference, perhaps because he believed that an engraved figure had to be there.

Rubbing paper is difficult to fix onto small boulders like the one

Fig. 4. GIS processed output from laser scan data of a hunting scene on RAÄ Tanum 90:1. The human is ca. 20 cm large. In situ 1904 with painted figures (a), rubbing by Tanums Hällristningsmuseum Underslös (b), and the GIS processed output (c).

from Engelstrup, Denmark. As a result, the graphite is distributed very unevenly and weakly in some places. Even the strongly carved central ship is not visible on the engraving in full detail because the rubbing left less pigment towards the border of the carved surface (Fig. 3e). Conversely, every figure is clearly visible in the digital LRM, with many details and other information addressed below (Fig. 3f).

Since the colour in the LRM only depends on the carved features and not the documenter, it is possible to estimate depth differences between engraved features. Depending on the colour ramp chosen, the lighter or darker a feature is, the greater its depth. It is possible to recognize immediately that the figure holding the boat in the scene on panel Finntorp 90:1 has a cupmark as head (Fig. 3d, green arrow). In Finntorp 89:1, the mid-section of both partners is engraved shallower than the head and the feet (Fig. 3b). On the boulder from Engelstrup it is possible to observe that the large ship and the ring are the features which are most deeply engraved (Fig. 3f).

4.2.4. *Superimposition*

The possibility of judging depth differences based on colour in the visualisation allows us to investigate a particularly important feature for the relative engraving sequence: superimpositions. This can be demonstrated on the boat with the spearmen on the panel Finntorp 184:1 (Fig. 5a–c). The upper body of both figures cuts into the upper line of the boat (Fig. 5a, red arrows). This line ends in a stem that curves upward from what seems to be an older line that runs longer (Fig. 5a, green arrows). At the aft end the line overlays a stem or prow that curves upwards, but ends shortly afterwards (Fig. 5a, violet arrow). Underneath, the older line reappears slightly askew and is also superimposed by the keel line of the larger boat at its terminus (Fig. 5a, violet arrow). This keel line reaches in an oval curve from the stern where its terminus curves outward. Here the keel line superimposes the older line. At the aft end, a younger line forms another stem, and is also curved outward at its terminus superimposing the keel line (Fig. 5a, orange arrow). Another superimposition can be observed on the left warrior of the spear fighting scene on panel Finntorp 95:1 (Fig. 5d–e). The warrior's knees seem to extend in front of the shin. The lower legs cut across, but are a weaker engraving, i.e. they show more of the irregularities of the original rock surface (Fig. 5d, red arrows). This means that a second pair of legs was possibly added to the original pair of legs. This is a feature that has also been observed on panel 89:1 in Finntorp (Horn and Potter, 2018). Other superimpositions can be observed on the couple in Finntorp 89:1. The line of the sword's sheath cuts into the lower outer line of the shield, but is itself intersected by the left leg. There is no great difference between these lines. Here, digital frottage provides information on the production sequence, and not about transformative events (Fig. 3b).

Other examples of the visibility of superimpositions come from the famous couple on the Vitlycke panel (Tanum 1:1) (Fig. 6a-b). The mouth of the warrior overlays the figure with long hair (Fig. 6a, red arrow). The phallus also superimposes that figure, and in fact, only stops at the petroglyph's back (Fig. 6a, green arrow). The sword's sheath cuts into the hind leg of the warrior (Fig. 6a, violet arrow). The line that seems to connect both figures at the knee has been interpreted as a binding, symbolizing some kind of union (Fredell and Quintela, 2010). Both the legs of the warrior and the front leg of the long-haired figure cut across this line. Only the hind knee of the warrior is directly connected. From there the line angles downward and is situated below the other knees (Fig. 6a, orange arrows). There are two simpler explanations for the line. It could have been an older line that was not recognized and the couple were accidentally placed over it. Alternatively, it could be a reference line to help achieving the proper distance between both figures as their closeness would make placing them a difficult task.

Vitlycke 1:1, is a scene with a warrior seemingly having sexual intercourse with an animal (Fig. 6c-d). In the rubbing it appears as if the animal has four legs, and penetration is indicated by a short line approximately at the anthropomorphic warrior's centre. In the digital frottage, the complexity of the scene becomes visible in greater detail

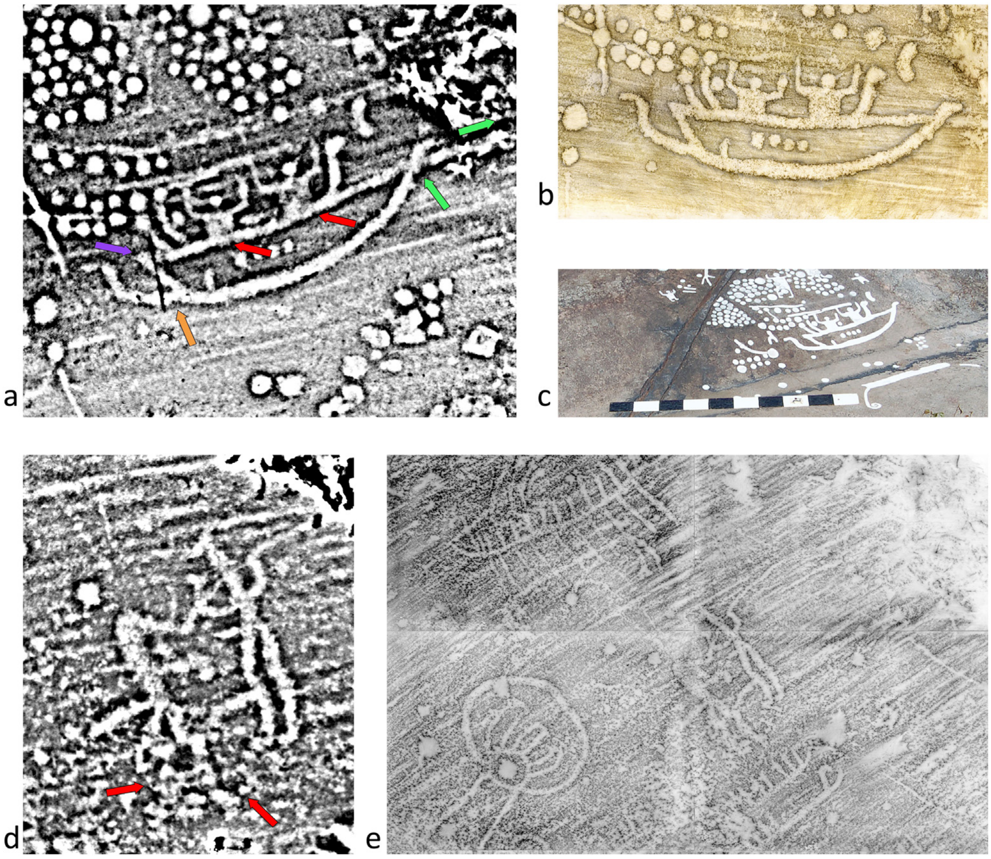

Fig. 5. Examples of superimpositions in rock art (if not indicated differently based on Structure from Motion data): a.) scene with boat and crew on RAÄ Tanum 184:1 with comparative images from a rubbing by Dietrich Evers (b) and an in-situ photo by the Tanums Hällristningsmuseum Underslös with the figures chalked in (c). The boat is ca. 40 cm wide. d.) two fighters on RAÄ Tanum 95:1 with a comparative rubbing by Tanums Hällristningsmuseum Underslös. The taller figure is ca. 25 cm large.

(Fig. 6d). The presumed animal leg is in fact a half circle superimposing the human figure and continuing shortly above the animal's tail (Fig. 6d, red arrows). This potentially indicates the phallus of the warrior, although there are several other possibilities. The tail may cut the half circle (Fig. 6d, green arrow). Therefore, the animal was potentially applied to the scene last, indicating that this scene was not always a warrior-animal-intercourse scene. The overly-long limb is slightly misaligned with the body-leg-line of the warrior and somewhat thicker showing another superimposition (Fig. 6d, violet arrow).

On the rubbing of the stone from Engelstrup, the larger ship merely seems to be placed above the smaller (Fig. 3e). In the digital frottage, one of the stems of the smaller boat is clearly cut by the keel line of the larger boat (Fig. 3f, red arrows). Additionally, other details become clearer, for example the feet of the central figure above the boat are superimposed by the crew-strokes (Fig. 3f, red arrows).

In all the presented cases, GIS data processing can visualise multiple superimpositions. This would require many differently angled and lit snapshots if the 3D model would have been used directly. One point, however, remains problematic. When the engraved feature is very deep then there is no indication of structure in the image, for example, cup marks are usually very deep and they only show up in white, meaning that any internal structure is lost, and with that potential further information about the sequence of superimposition.

4.2.5. *New discoveries*

In a sense, observing superimpositions and very fine details are all new discoveries. However, by themselves they do not necessarily change our view of an image or a scene fundamentally. The base for the following case is of course the 3D model itself. Describing the scene here only serves to highlight the amount of information processed raster datasets can convey in a single image. The following also demonstrates that new discoveries are even possible on panels that have been documented for over 150 years.

One such example is the Gerum panel which was first documented by Axel Emanuel Holmberg in 1848 (Fig. 7a). The panel in Gerum is a large site with a currently known extent of 9 × 6 m. The last published overview over the region puts the number and identification of petroglyphs as follows (Bengtsson and Olsson, 2000): 82 boats, 36 anthropomorphic figures, 23 animals, 14 foot soles, 3 ring crosses, 2 circles, 1 cross, 1 mast-like figure, 3 obscure figures, 119 cup-marks, and several lines (Fig. 7b). The site was re-documented in July 2018 using multi-image photogrammetry. The subsequent analysis is based on observations in the field, the 3D model (Fig. 7c), and to a greater degree on the GIS processed DEM, since the latter was able to visualise most figures without the necessity of shifting the lighting angle continuously (Fig. 7a) (Horn and Potter, accepted).

During this investigation more figures than previously published were discovered even though some parts of the upper panel, which also bears motifs, could not be documented since long, heavy sandbags had been put in place to guide water flows around the panel. The increase in figures compared to the last published documentation is in brackets (Bengtsson and Olsson, 2000). According to this count, there are 95 boats (+13), 43 anthropomorphic figures (+7), 28 animals (+5), 16 foot- or shoe-soles (+2), and 187 cup-marks (+68). In addition, there are 13 potential boats, one potential animal, and one potential foot- or shoe-sole (Fig. 8). The cup-mark count includes cup-marks that have been used as heads of anthropomorphic figures (Horn, 2016) which may explain some of the discrepancy. Another explanation for the difference is that the latest publication did not record the lowest section of the panel (Bengtsson and Olsson, 2000), but older documentations did not identify all of the motifs, i.e. Axel Emanuel Holmberg (in 1848) and Lauritz Baltzer (in 1886). Some of the motifs may be so faint that they escape visual and tactile detection, and could only be made visible with the sensitive and visually enhancing digital methods used here (Horn et al., 2018; Horn and Potter, accepted).

New discoveries have also been made on a smaller scale. One scene

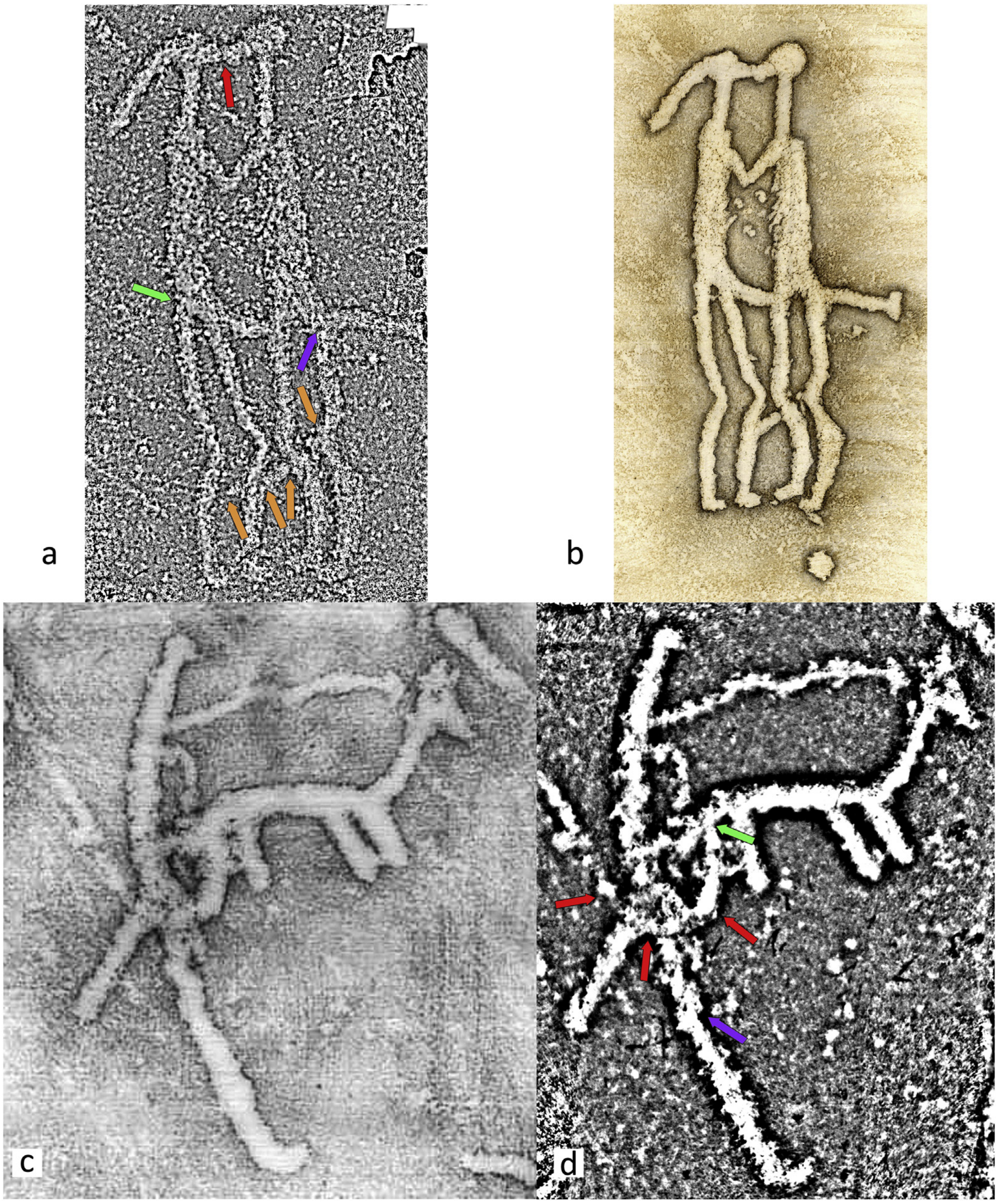

Fig. 6. Examples of superimpositions in rock art (if not indicated differently GIS processed 3D data): a.) intercourse scene on RAÄ Tanum 1:1 with a comparative image from a rubbing by Dietrich Evers (b). c.) zoophilia scene on RAÄ Tanum 1:1 (rubbing by the RockCare project) and the GIS processed output (d).

on the Vitlycke panel shows two warriors engaged in a spear fight. Currently the scene is painted in red for the presumed benefit of visitors (Fig. 9a). The paint presents both warriors with a sword sheath and a phallus. The larger warrior possesses exaggerated calves, two horns, and a phallus. On the upper body, a cupmark is placed right next to the body under the armpit. The processed image shows that the cup mark is not beside the upper body, but that both intersect (Fig. 9b, red arrow). Furthermore, around the horns there are 3–4 more lines engraved which are not indicated by the current paint (Fig. 9b, green arrows). In fact, an older painted version of the figure shows the head much more precisely with this "hairstyle" (Horn, 2018).

The smaller warrior has both arms on the spear and carries a sword sheath without any indication of a chape. In the painted version, the figure seems to possess a phallus and exaggerated calves comparable to warrior 1. However, no horns are indicated, and the phallus is larger. Phallic warriors are common in Scandinavian rock art, so it was a great surprise that the 3D model and the processed raster image showed the engraved feature as what may instead be an animal intersecting the warrior. The back of the animal is placed at belt height so that the head, neck, and front part of the body replace the phallus, with the tail forming the sword sheath. The first front leg substitutes the testicles, the next two legs are part of the front leg of the warrior, and the last hind leg is perhaps indicated in the back leg of the warrior. The placement is so precise that we may rule out accidental placement (Fig. 9b, violet arrows).

This is not simply another phallic warrior, but a case of the transformation of Scandinavian rock art motifs; a topic which has recently received more attention in research and has been interpreted in a number of ways (Bertilsson, 2015; Horn et al., 2018; Horn and Potter, 2018; Ling and Bertilsson, 2017). The main point here is that the output generated by the LRM processed 3D data comprises the complexity of the scene into one readable image. Conveying a similar amount of information would require several screenshots from the 3D model itself.

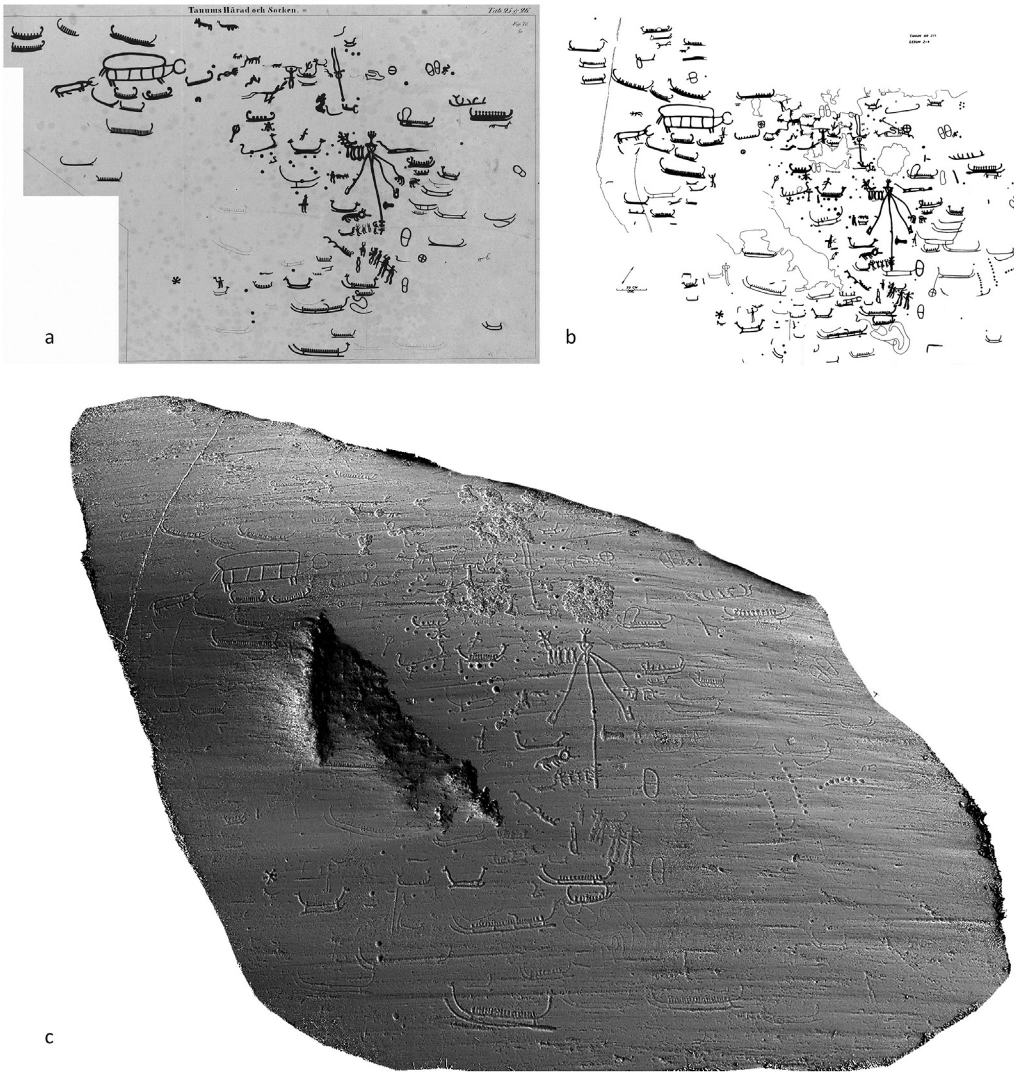

Fig. 7. Documentations of the panel in Gerum (RAÄ Tanum 311:1). The panel is 900 × 600 cm large: a.) Indian ink drawing by Axel Holmerg, 1848; b.) tracing by Tanums Hällristnings Museum, Underslös, no date; c.) Snapshot of the 3D model (Structure from Motion) taken in Meshlab, 2019.

5. Conclusion

This paper has highlighted some of the problematic aspects of three-dimensional and older documentation techniques for rock art, i.e. colour distribution, visualising depth, file size including storage and processability, and the dependency on multiple interchanging lighting angles. It has been proposed that GIS processing of DEMs from 3D models can remedy some of the problematic issues. The GIS processed output produces high quality images with small file sizes that are capable of visualising large panels and small details including depth differences in an equal colour distribution. This provides an excellent visualisation of the chronological and spatial relationships of motifs making complex panels understandable in a single image. However, investigations should not depend on such images alone, but should instead combine observations in the field, 3D models, older documentation, and the GIS processed DEM images to approach rock art as holistically as possible. This complimentary approach to rock art documentation can facilitate both the wide-ranging dissemination of results and a greater clarity of interpretation.

The article argued that beyond being a good tool for visualisation, the proposed method also provides a potent approach to researching petroglyphs. Some of the superimpositions imply a longer chronology in which the images and scenes in Scandinavian rock art were transformed. Therefore, there must have been a temporality to their meaning. The changing face of the panels may imply a change in the narrative structure and the stories and myths linked to the images. This opens new opportunities for research into the relative chronology and the changing social meaning of rock art that future projects will have to address.

The dataset presented here demonstrates just a sample of potential applications. While the method was developed using Scandinavian petroglyphs it does not depend on this data. It could be applied to other 3D models with small depth difference on larger surfaces. This could be petroglyph panels from other sites, carved menhirs, incised script, coins, reliefs, plaques, decoration on metalwork, etc. This means there is no reason the method cannot be used with Late Bronze Age stelea in Spain, Viking Age rune and picture stones, situlae dating to the Early Iron Age, sigilata stamps from antiquity, etc. The applicability of the method to each of these materials would of course require testing. Since the method is free and does not have any high knowledge barriers, these tests can be conducted quickly if the 3D data has already been acquired. For petroglyphs or any other material, increasing volumes of three-dimensional data and the widening adoption of photogrammetric and laser scanning based techniques will only serve to increase the importance of innovative, comparative data processing techniques.

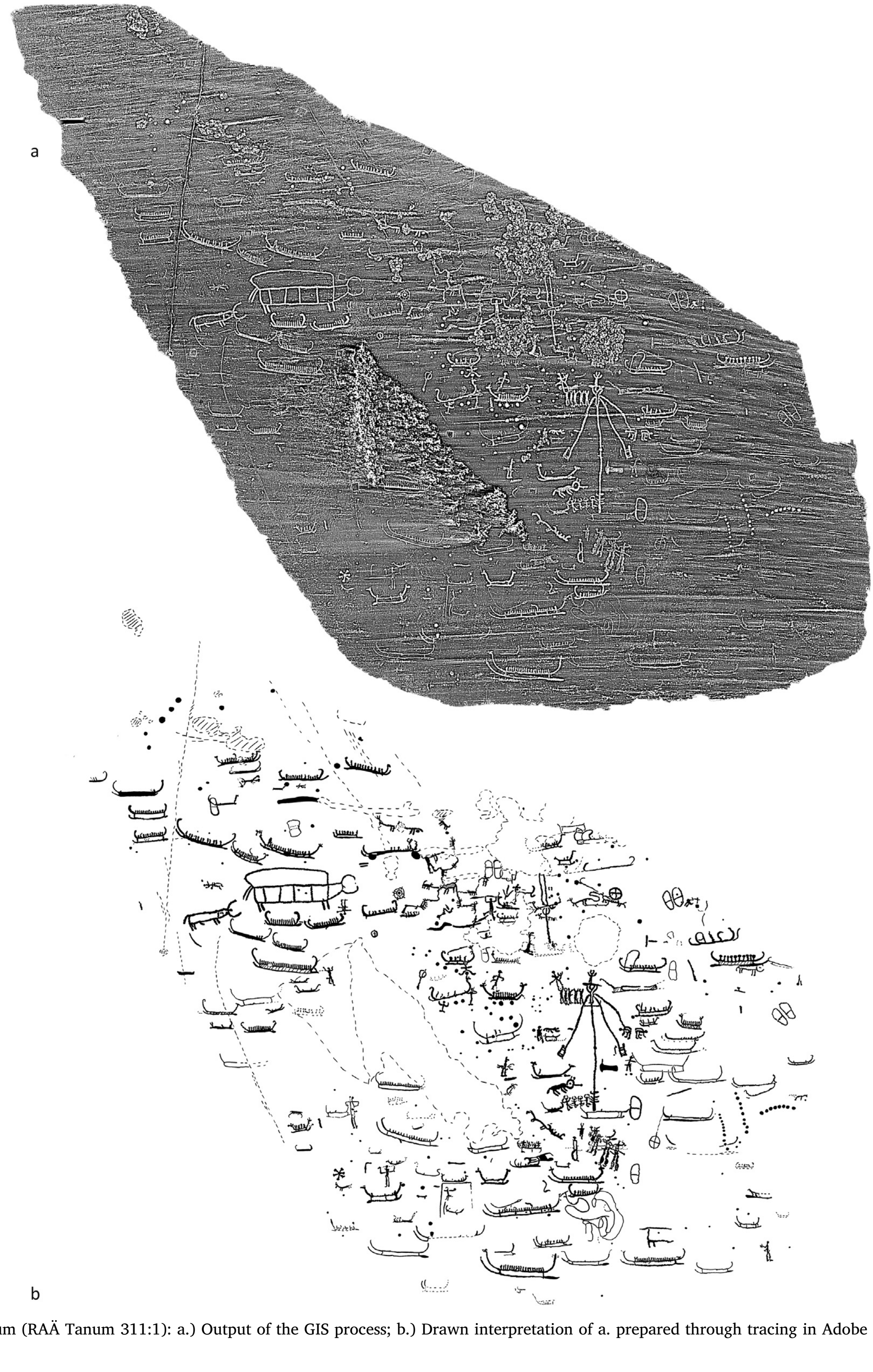

Fig. 8. Gerum (RAÄ Tanum 311:1): a.) Output of the GIS process; b.) Drawn interpretation of a. prepared through tracing in Adobe Photoshop©.

Declaration of competing interest

None.

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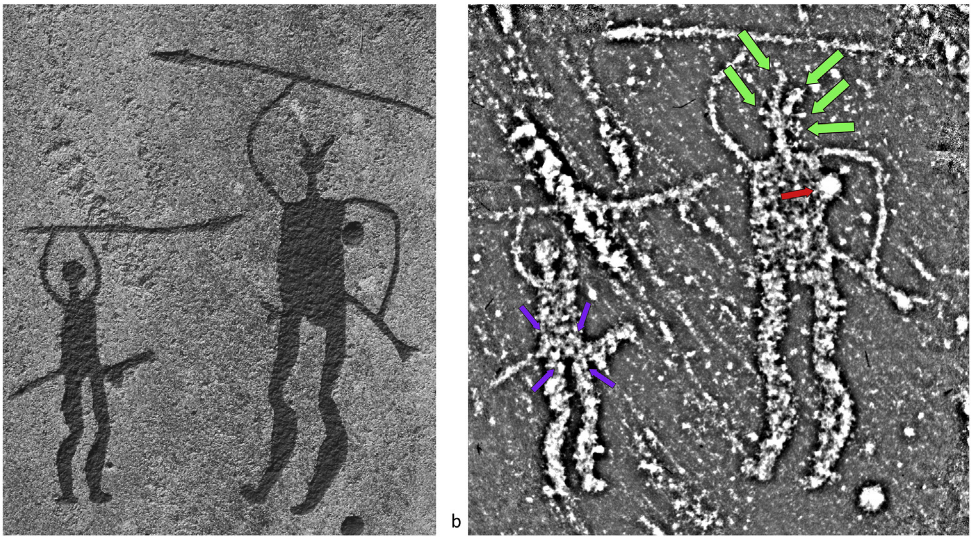

Fig. 9. a.) Photo of the current, painted state of the spear-fighting scene on RAÄ Tanum 1:1 and the GIS processed output (b). The larger figure is ca. 30 cm large.

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Article six: A new documentation of “Runohällen” (Gerum, Tanum)

Horn, Christian; **Potter, Rich** (2019): A new documentation of “Runohällen” (Gerum, Tanum). In *Fornvännen* 114 (3), pp. 129–141.

I contributed to this article by writing sections of the publication, and through the creation, processing, and joint analysis of the SfM of the rock art panel. **(overall contribution 50%)**

This article documents a new digital recording of the rock art panel Tanum 311:1 at a place called Gerum, situated by a small stream of water, in the fields of Bohuslän. Within this article we further-evaluated the digital frottage method outlined in Horn, Potter & Pitman (2019) with the intention of demonstrating its use as a tool in rock art documentation. Tanum 311:1 is a medium sized rock art panel with a large quantity of carvings including boats, human figures, cup marks, footsoles, and animals. There is also a large multi-limbed figure in the middle, the meaning of which is unknown. As a direct result of the analysis of the panel we were able to add a significant amount of unknown data to the corpus including an additional thirteen boats, seven anthropomorphic figures, five animals, four footsoles, and sixty-eight cup marks to the previous count. Several new potential carvings were also found. A deeper analysis of one of the carved axes was also undertaken, enabling us to look further into the potential type of axe that was being represented.

A new documentation of "Runohällen" (Gerum, Tanum)

By Christian Horn and Rich Potter

Horn, C. & Potter, R., 2019. A new documentation of "Runohällen" (Gerum, Tanum). *Fornvännen* 114. Stockholm.

This paper presents the results of a recent documentation of the rock art panel called "Runohällen" in Gerum, Bohuslän (RAÄ Tanum 311:1). The documentation was conducted using photogrammetry and analysed using a new documentation method. It was possible to identify several new motifs, updating the record from previous documentations. During this work a petroglyph previously identified as an axe stood out through an elongated and as of yet unexplained feature. It is argued that this motif is indeed an axe, but converse to the older interpretation, it is suggested that the motif is turned "upside-down" when compared to the majority of petroglyphs on the panel. Several interpretations are considered, but it is thought most likely that the carving had an antagonistic purpose.

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Introduction

In recent years, the depiction of metalwork in rock art has garnered renewed interest as a chronological proxy to date rock art panels (Bertilsson 2015; Bengtsson 2013; Horn & Potter 2017; Ling & Bertilsson 2017; Skoglund 2016). Beyond this, petroglyphs of metalwork recently granted insights into Bronze Age social hierarchies (Kristiansen 2012; 2014), long-distance contacts (Ling & Rowlands 2013; 2015), narratives (Rédei et al. 2018), and beliefs (Horn 2016). This makes the identification of new types of metalwork an important aim for rock art research as it not only allows us to situate engraving actions on the rocks in time, but also enriches the potential to interpret metalwork petroglyphs and thereby investigate the social role of new types of objects. This requires, and even merits, a detailed (re-)investigation and discussion of petroglyphs that could represent Bronze Age metalwork.

This contribution aims to expand the knowledge of metalwork petroglyphs in the Scandinavian rock art record by discussing the possible interpretations of a specific petroglyph carved into the surface of a rock art panel called "Runohällen" in Gerum (figs. 1–2; RAÄ Tanum 311:1). Following a re-documentation of the panel using photogrammetry, we combined our observations in the field with the results of the new and older documentations. We here present a possible interpretation of the petroglyph as the inverted depiction of a socketed axe.

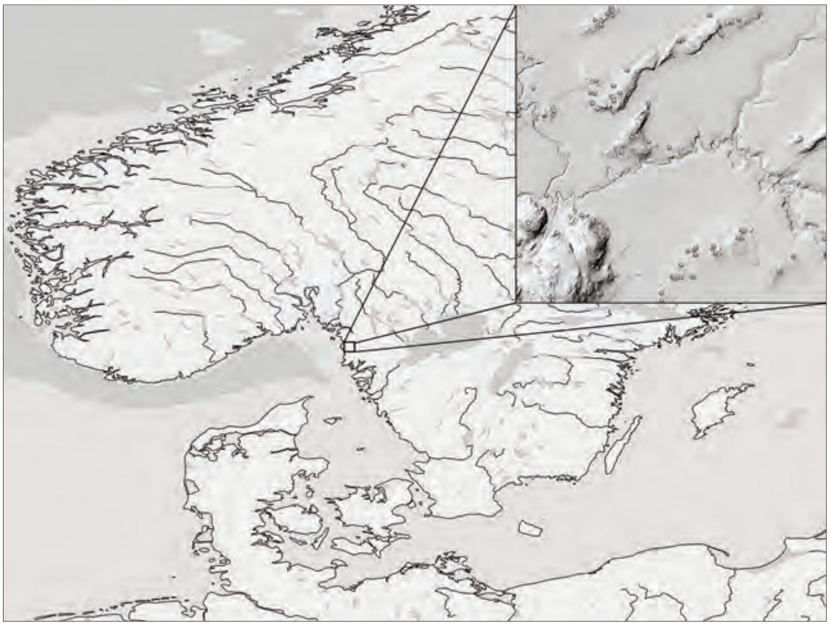

Fig. 1. Location of the Gerum panel (RAÄ Tanum 311:1) in southern Scandinavia and the local context.

Documentation method

In the past decade, Image-based Modelling techniques to create 3D models of individual petroglyphs and rock art panels have generated a breakthrough in Scandinavian and European rock art research (Díaz-Guardamino Uribe & Wheatley 2013; Horn et al. 2018; Lerma et al. 2013; Meijer 2016; Mudge et al. 2012).

The method used to document Tanum 311:1 is commonly called Structure from Motion and was developed in the key fields of photogrammetry and Computer Vision (Micheletti et al. 2015; Sevara & Goldhahn 2011). The process is adept at recovering 3D information from 2D photographs (Cobaz & Jagersand 2003). The photographs are termed cameras in the process. The algorithm finds and matches a number of points occurring in multiple cameras to determine both their interior and exterior orientation parameters (Micheletti et al. 2015). Subsequently, the position of the matched points is triangulated to produce a sparse point cloud that represents the geometry of the scene. Based on the geometry of the sparse point cloud, the software package (Agisoft PhotoScan) calculates a dense point cloud using Multi-View Stereo. Finally, algorithms including Poisson surface reconstruction are used to create a surface mesh from the orientation of the points in the dense point cloud (Kazhdan et al. 2006).

In the field we take photographs in accordance with the best-practice recommendation. That means the photos have a 60–70% overlap (Reu et al. 2013; Meijer 2016). This guarantees a high precision of the 3D models enabling measurements as precise as 1 mm in a 10 m scene. To increase this precision even further, target points aided the calculation of the model (Sapirstein 2016). The placement of the target points was guided by a visible and a tactile investigation of the panel surface, as well as referencing older documentations of the panel in Gerum to ensure that no engraved part of the rock's surface was covered. A total of 1115 photos were taken to build a model of the full uncovered extents of the rock art panel.

The open source software Meshlab, which allows us to view and light the scene from all possible angles, was used for analysis. Other possibilities to visualize details on the model available in Meshlab include the enhancement of the surface (ambient occlusion), rendering (radiance scaling), and curvature colorization. As a further step, we used a technique we have termed "digital frottage". A Digital Elevation Model produced in PhotoScan and processed in ArcGIS 10. This helps to ameliorate visualization problems by making the petroglyphs visible, regardless of any lighting in the scene.

For each newly introduced rock art panel, the Riksantikvarieämbetet identification will be listed upon its first mention in the text.

Site description and previous research

"Runohällen" in Gerum (RAÄ Tanum 311:1) is located on the edge of a plane between 16–14 m above sea level facing SSE. It slopes down at a 50–60 angle to the stream Gerum at the bottom of a crevice ca. 27 m away. Johan Ling (2014, pp. 87–91) studied the canoe petroglyphs, the effects of the land uplift on the panel, and its chronology extensively. According to Ling, the panel was part of a fjord during the Bronze Age. Water still

Fig. 2. a) Drawing of the Gerum panel after Bengtsson & Olsson 2000 (after a tracing by T. Högsberg), b) Still-image of the 3D model.

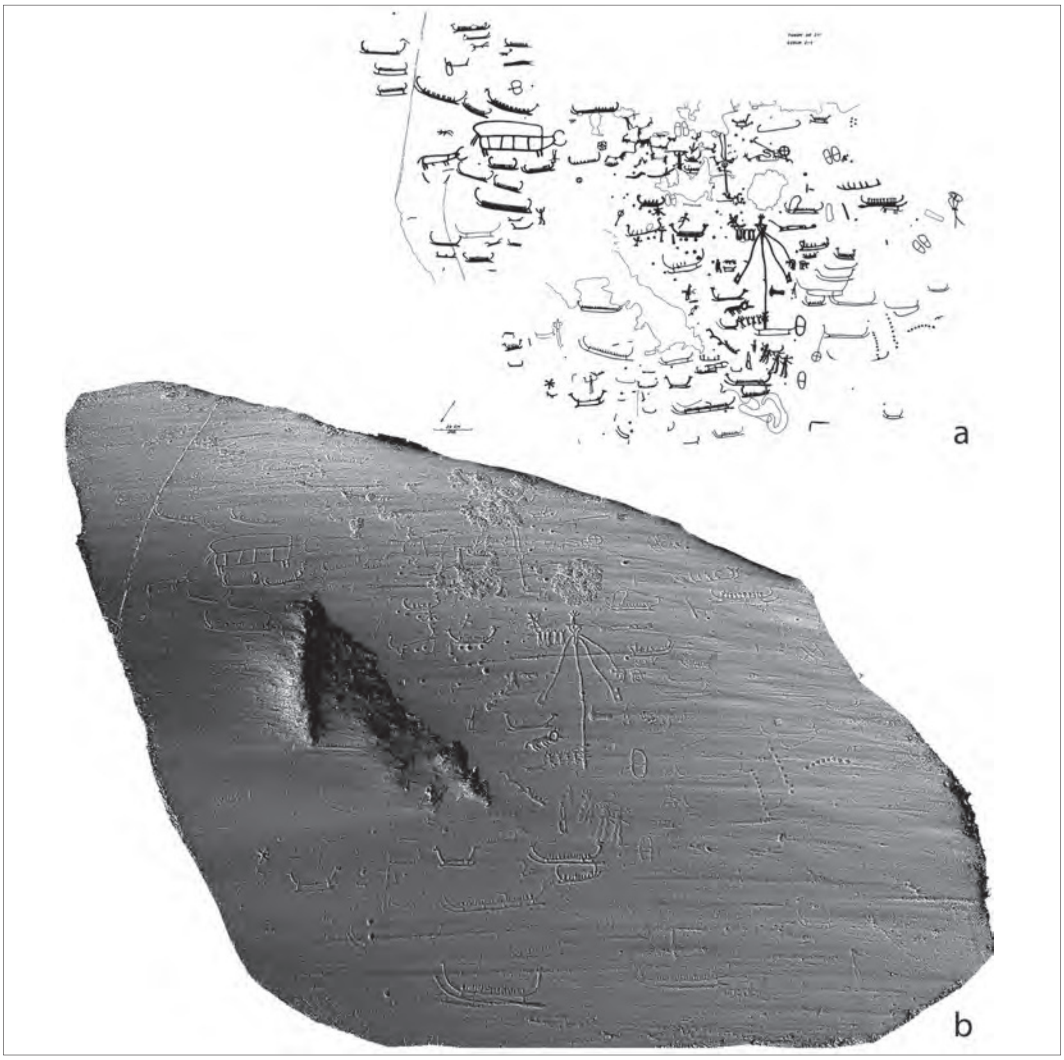

Fig. 3. Digital frottage prepared from the photogrammetry documentation of the Gerum panel.

covered the entire panel during the Late Neolithic and it potentially emerged during period IB of the Bronze Age. In the subsequent period II, the water retreated further allowing images to be carved into the upper half of the panel. The entire panel became dry over the course of period III.

The panel in Gerum is a large site with a currently known extent of 9 x 6 m. The last published overview of the region puts the number and identification of petroglyphs as follows (Bengtsson &

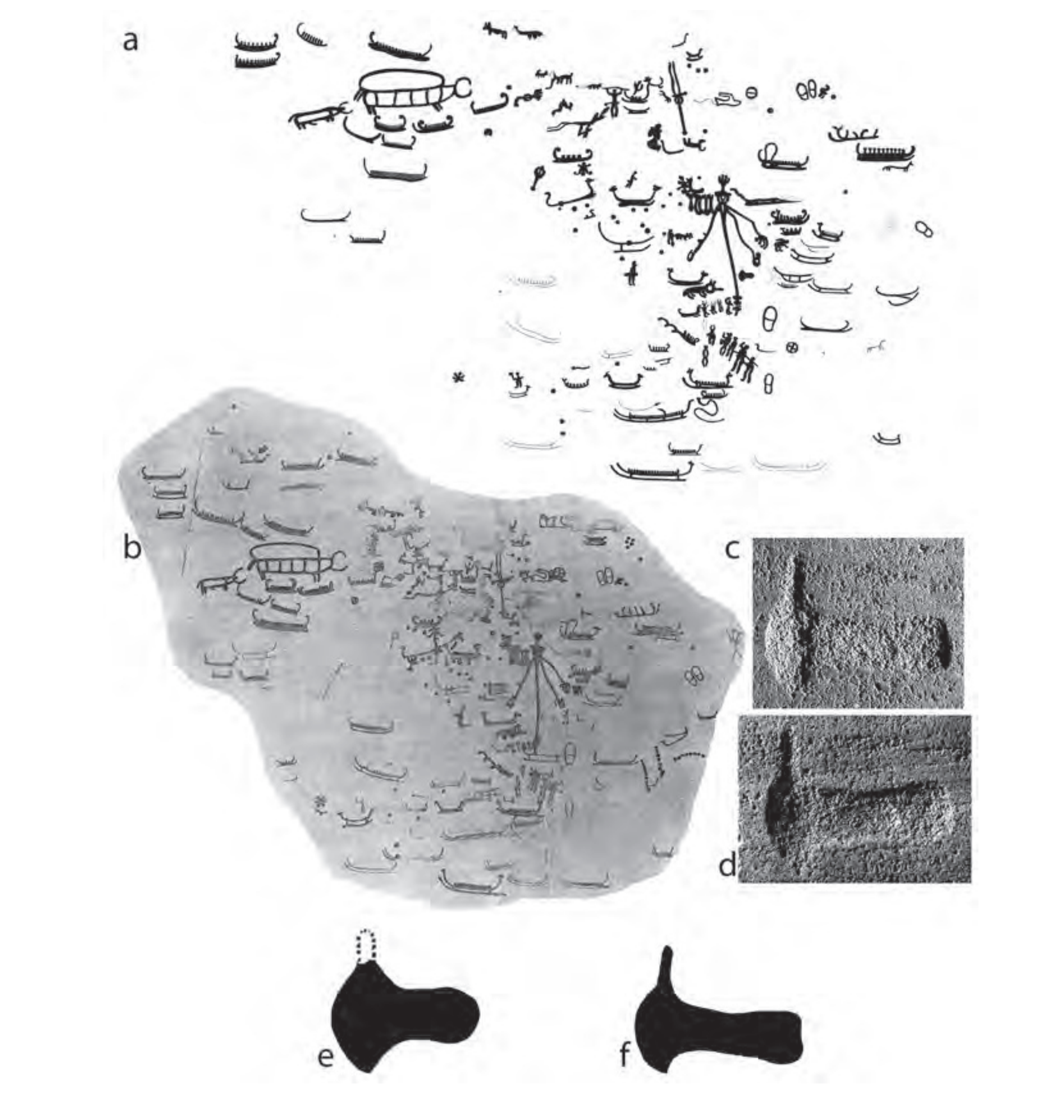

Fig. 4. a) Graphic of the Gerum panel by Axel Emanuel Holmberg in 1848, b) Graphic by Lauritz Baltzer in 1886, c) Night photography by Bertil Almgren in 1955, d) Night photography by Ellen Meijer in 2014, e) Enlarged drawing of the axe after Holmberg, and f) after Högsberg.

Olsson 2000, p. 36): 82 boats, 36 anthropomorphic figures, 23 animals, 14 foot soles, 3 ring crosses, 2 circles, 1 cross, 1 mast-like figure, 3 obscure figures, 119 cup-marks, and several lines (fig. 2).

The new documentation has been fully analysed to account for the number of the major motifs (figs. 3 and 4 a–b). According to this count, there are 95 boats, 43 anthropomorphic figures, 28 animals, 16 foot- or shoe-soles, and 187 cup-marks. In addition, there are 13 potential boats, one potential animal, and one potential foot- or shoe-sole. The cup-mark count includes cup-marks that have been used as heads of anthropomorphic figures (Horn 2016) which may explain some of the discrepancy. Another explanation for the difference is that the latest publication did not record the lowest section of the panel (Bengtsson & Olsson 2000, p. 36). Two older graphics by Axel Emanuel Holmberg (in 1848) and Lauritz Baltzer (in 1886) of the panel are, in many respects, more precise (fig. 4 a–b). However, even here not all engravings on the panel have been recognized. The most likely explanation is that some of them are so faint that they escape visual and tactile detection, and could only be visualised with the aid of sensitive and visually enhancing digital methods (Horn et al. 2018).

The petroglyph discussed here is situated to the right of the mast-like figure, viewed from the lower edge of the panel at the spot visitors are directed to view the panel from today (figs. 3 and 4 a–b). It was engraved only 4 cm away from the lower third of the mast, which has traditionally been interpreted as a "maypole", a carousel, or a similar object (Almgren, O. 1927; Almgren, B. 1987; Bertilsson 1987; Hygen et al. 1999; Fredell 2003; Kaul 2004). Baltzer indicated it as a very faint petroglyph which is confirmed by rubbings made by Dietrich Evers and Torsten Högberg in 1970 and 1983, respectively.

All older documentations notice a line going up from the left side. None of the previous documentations based on rubbing and drawing record a detailed internal structure of the petroglyph. However, some internal features are visible in raking light night photographs taken by Bertil Almgren (1955) and Ellen Meijer (2014), which we will discuss in the next section (fig. 4 c–d). The motif's interpretation seems to have been an axe, with Holmberg and Högberg tweaking the appearance to resemble such an object by making the lower edge of the left side more pointed and sharper than the rubbings reveal it to be (fig. 4 e–f). Conversely, the right-hand side is presented as more rounded.

The shape of the axe as represented by Holmberg is rather stout with a length-width ratio of almost 1:1 (fig. 4 e). The blade is rounded and swings widely outward with sharp breaks at each end of the cutting edge. The body is waisted and the butt end rounded in a semi-circular fashion. Högberg's depiction is roughly similar with a few important differences (fig. 4 f). The upper end of the cutting edge is obscured because he fully acknowledges the line going upwards. The axe body is more elongated, and the butt end is flat with a slight inward curve.

This depiction does not conform to other depictions of axes without a shaft, for example, in Simrishamn 16:1 which have been compared to the axes from Lilla Beddinge (Skoglund 2016, fig. 2.28a). The axes have a clear break between the end of the cutting edge and the body. Instead the shape is more reminiscent of shorter waisted axes including (pseudo-) Anglo-Irish axe or Unetice types dating to the Late Neolithic and Early Bronze Age period Ia (2000–1600 BC) (Vandkilde 1996, pp. 78–91; see Oldeberg 1974, no. 94, 152, 349 & 1550). In younger axe types, the rounded butt is rarer and overall they are more slender. For that reason, the elongated shape and flat butt depicted by Högberg could be parallel to the axes from the hoards in Torsted and Virringe (Becker 1964; Vandkilde 1996, pp. 97–103) but also to somewhat later axes, especially those of the Smörumövre type (Vandkilde 1996, pp. 128 – 129). The Torsted and Virringe axes date to period Ia and Ib respectively (1700–1500 BC). The later palstaves are more slender and/or have less wide blades (Laux 2000; Oldeberg 1976).

While such comparisons are possible, they are problematic since the panel was still largely submerged under water at that time. Engraving them would have been impossible. Therefore, a fresh look at the axe petroglyph from Gerum is necessary.

Result of the documentation of the axe petroglyph

The new documentation confirms that the depicted object narrows towards the middle, where it is only 5 cm wide (fig. 5 a–b). Towards the sides, the figure widens with the widest point at the extended line measuring 14.4 cm. The widest point on the other side is 6.2 cm. The petroglyph is ca. 18 cm long. While the aforementioned interpretation as an axe is palpable, the problematic aspects remain.

Several other petroglyphs were engraved in an orientation other than the majority of motifs. Two anthropomorphic figures and one boat are depicted at a 90° angle to the other images. One human figure and another boat are seemingly en-

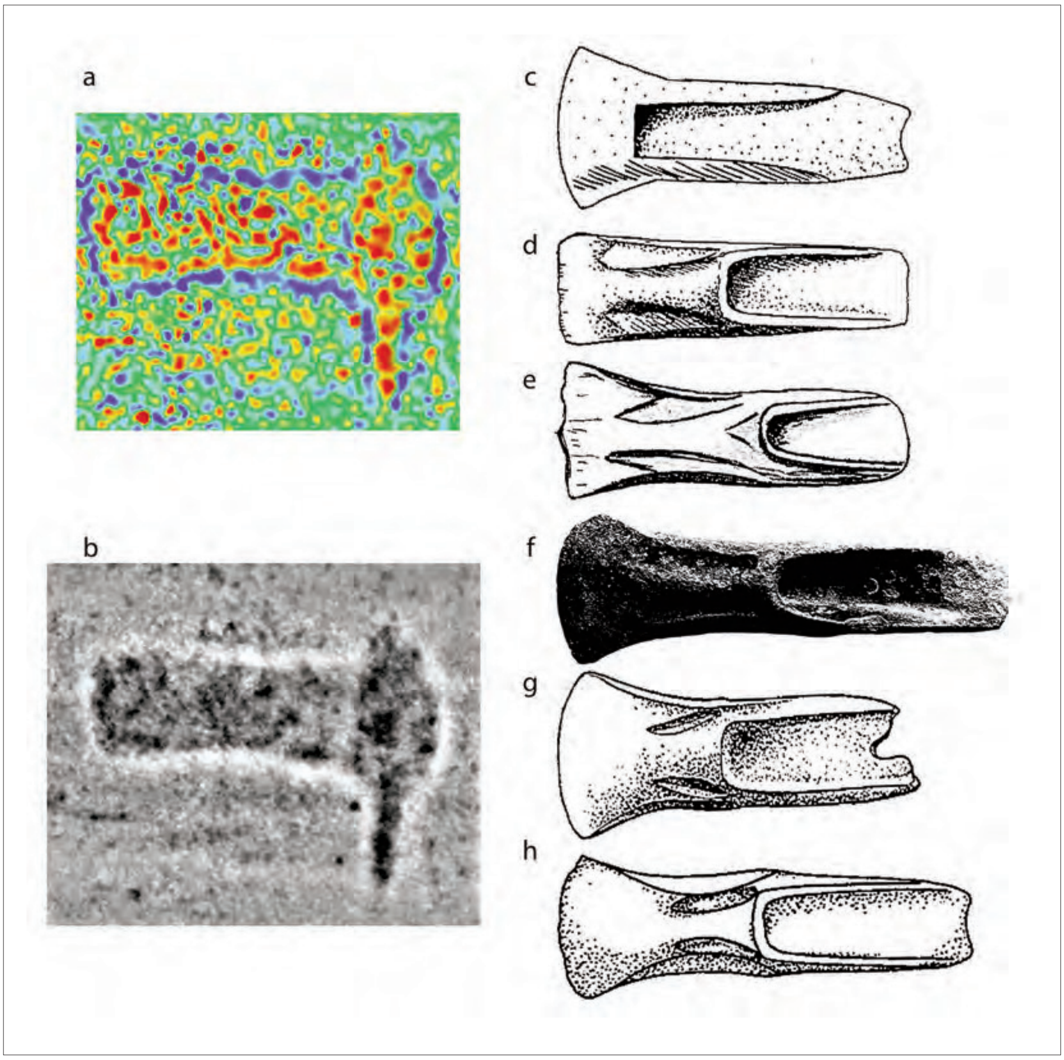

Fig. 5. 3D model of the axe from the Gerum panel: a) with colorized curvature, b) digital frottage. Comparison to a flanged axe and palstaves: c) Fjälkestad, Scania (no. 143); d) Bjännesby, Småland (no. 1829); e) Harplinge (single deposition), Halland (no. 1577); f) Harplinge, Halland (no. 1584); g) Landskrona (surroundings), Scania (no. 445); h) Sjörup, Scania (no. 687). All numbers in Oldeberg 1974.

graved "upside-down". The term "upside-down" is for now only used in the sense that these carvings have the opposite directionality to most other carvings on the panel (see below). However, it is not intended to make any presumptions of how these images were intended to be viewed. It can be assumed that the carvings were made approaching the panel from the top since they are well made without any mistakes and have the correct proportions. This leaves the possibility that the axe discussed here may have been made looking down on the panel from a higher part. To explore this possibility, we rotated the petroglyph 180° and continue to discuss it in this orientation (fig. 5 a–b).

The 3D documentation confirms the internal structure visible in the raking light photography by Almgren and Mejer (figs. 4 c–d and 5 a). In the region with the elongated line, the motif is carved deeper in a roughly oval shape. There is a slight retraction visible below the upper point of the oval. The oval form gives the end of central part of the petroglyph a u-shape with a kind of tail on the upper and lower side. On the lower part of the oval, the elongated line seems to be engraved somewhat deeper. This difference in depth, however, disappears higher up in the oval.

Discussion

When viewed with a 180° rotation, with the elongated line facing down, the oval cutting into the remaining petroglyph, and the widening on the other side, the motif still looks like an axe. However, there are some important differences. Most recognizably, it would be an axe with a depiction of the shaft-head and the upper part of a handle. While the blade would still widen, it is also narrower than presented in the older documentation (figs. 2 and 4 a).

In the following, a range of possible comparisons will be offered, as any of them are far from being a close match. As mentioned earlier, the oval shape in combination with the elongated line may indicate the hafting of the axe. Unfortunately, if that is the case then the butt end cannot be investigated. When the shaft represents a piece of wood clamping over the butt end and body, it could resemble the hafting of flanged axes and palstaves, though their body could not have been particularly long. Excluding axes that date to before period Ib, there are some axes with high flanges and palstaves that could match the petroglyphs shape (fig. 5 c–h), for example, from Fjälkestad, the surroundings of Landskrona, Sjörup (all Scania), Harplinge (Halland), and Norra Sandsjö (Småland) (Oldeberg 1974, no. 143, 445, 687, 1577 & 1829).

While axes of these types may have been depicted, there are still problematic aspects. The blades of flanged axes are too wide and they lack the slight widening before the hafting (fig. 5 c). Many palstaves have such a widening (fig. 5 d–h) and there are some with a narrow blade (fig. 5 d; see Oldeberg 1974, no. 1829). However, the hafting section is too long and would stick out of the back of any knee shafting which was as narrow as depicted on the rock. For the same reason, winged axes can be excluded. Additionally, their wings would give a more sharply tipped hafting trace, unlike the smooth oval shape represented on the rock surface. Vandkilde (1996) dates axes with high flanges to period Ib, which is also when palstaves may have originated. However, their full development reaches its peak during the developed period II, perhaps until the very early period III (Montelius 1917, pp. 43–46; Laux 2000; Oldeberg 1976, pp. 1–9).

Another possibility is that a socketed axe was depicted in the petroglyph. Since socketed axes receive the shaft in their socket, there is no need for an extended body. That would keep the knee shaft flat like in the depiction. A socketed axe discovered with a similar preserved wooden shaft has been discovered in Lögdö Bruk in Medelpad (Montelius 1917, no. 1053). The widening before the haft could represent a ridge, which many possess, on the socket opening that gives them a waisted appearance (fig. 6). A problematic aspect is that many socketed axes have a loop with which they were additionally secured on the shaft. Such a loop is missing on the petroglyph in Gerum. However, there are a few socketed axes from Scandinavia and elsewhere without such a loop (fig. 6). Some may have a hole instead. Intriguingly, one example without context has been discovered in Västergötland which could fit (Oldeberg 1974, no. 2561), but seems to be somewhat too slender (fig. 6 c). Better fitting parallels have been discovered in Norrvidinge (Scania) and Dingtuna (Västmanland) (fig. 6 d–e; Oldeberg 1974, no. 550 & 2640). Both are only weakly waisted with moderately wide blades and a ridge at the socket. These parallels are single finds. However, they can be identified with the types A and D respectively according to Oldeberg (Oldeberg 1976, pp. 8–9). These socketed axes are traditionally dated to period III of the Nordic Bronze Age (Montelius 1917, pp. 43–46), but were perhaps still in use during period IV (Badou 1953; 1960, pp. 18–19). Period V–VI simple socketed axes without a loop of the west-Nordic type seem to be more waisted and or shorter so that the overall proportions fit the axe petroglyph from Gerum less well (fig. 6 f–g; Badou 1960, p. 24). But, of course, if

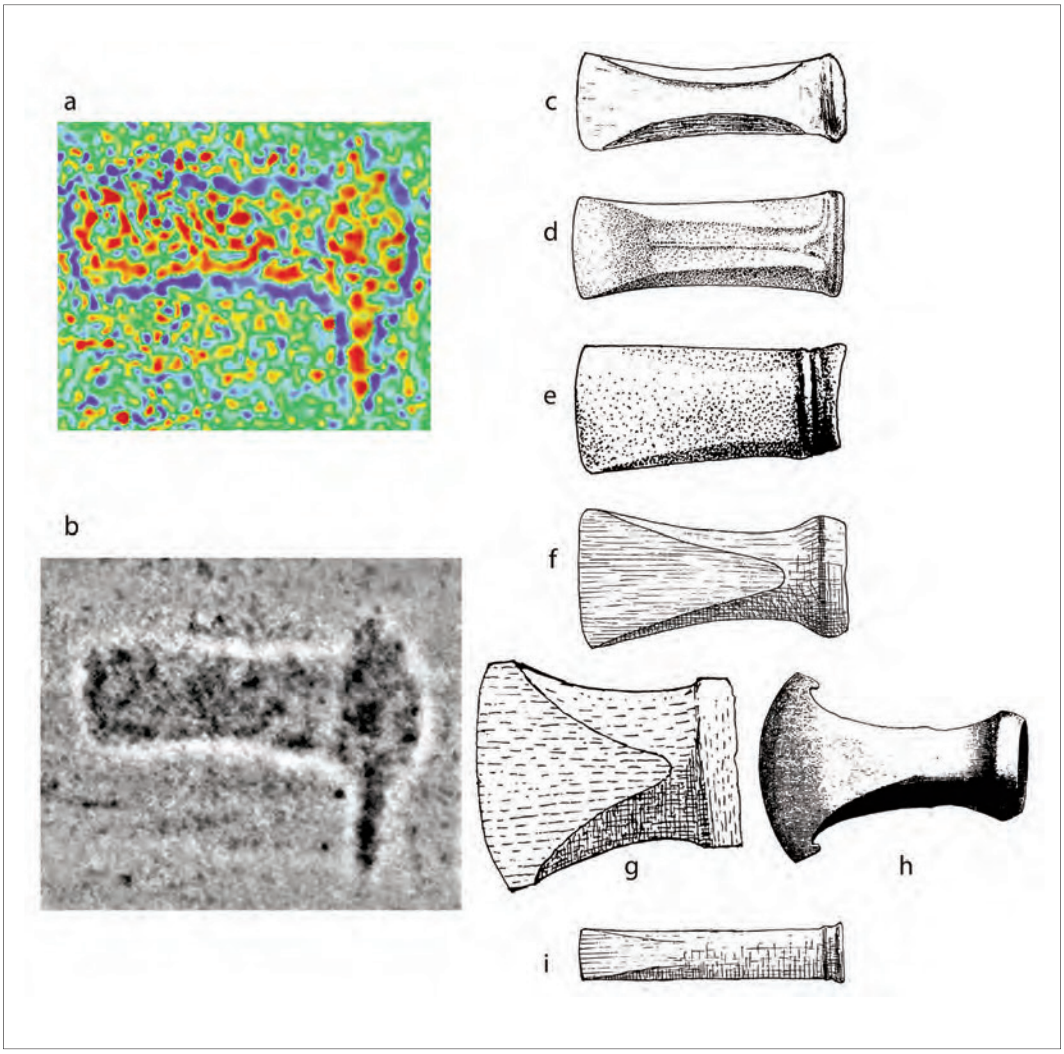

Fig. 6. 3D model of the axe from the Gerum panel: a) with colorized curvature, b) digital frottage. Comparison to socketed axes and a socketed chisel: c) no context, Västergötland (Oldeberg 1974, no. 2561), d) Norrvidinge, Scania (Oldeberg 1974, no. 550), e) Dingtuna, Västmanland (Oldeberg 1974, no. 2640), f) Alfshög, Halland (Badou, Pl. VI, VII C 2b: 4), g) surroundings of Gundestrup, Denmark (Badou 1960, Pl. VI, VII C 2b: 1), h) Reflinge, Scania (Minnen 1917, no. 1190), i) Søby, Denmark (Badou 1960, Pl.VII, IX: 12).

the original engraver was not overly concerned with proportions, one of these examples may well have been depicted. Socketed chisels were compared as well, but can most likely be discarded as a parallel (fig. 6 h).

Interpretation

Given that most rock art is the outcome of a planned and conscious process, it is likely that the elongated line on the petroglyph next to the mast-like figure in Gerum is not the outcome of an accident, but was meaningful to the engraver. The line and the oval deepening could be the outcome of a later transformation of the depiction of an

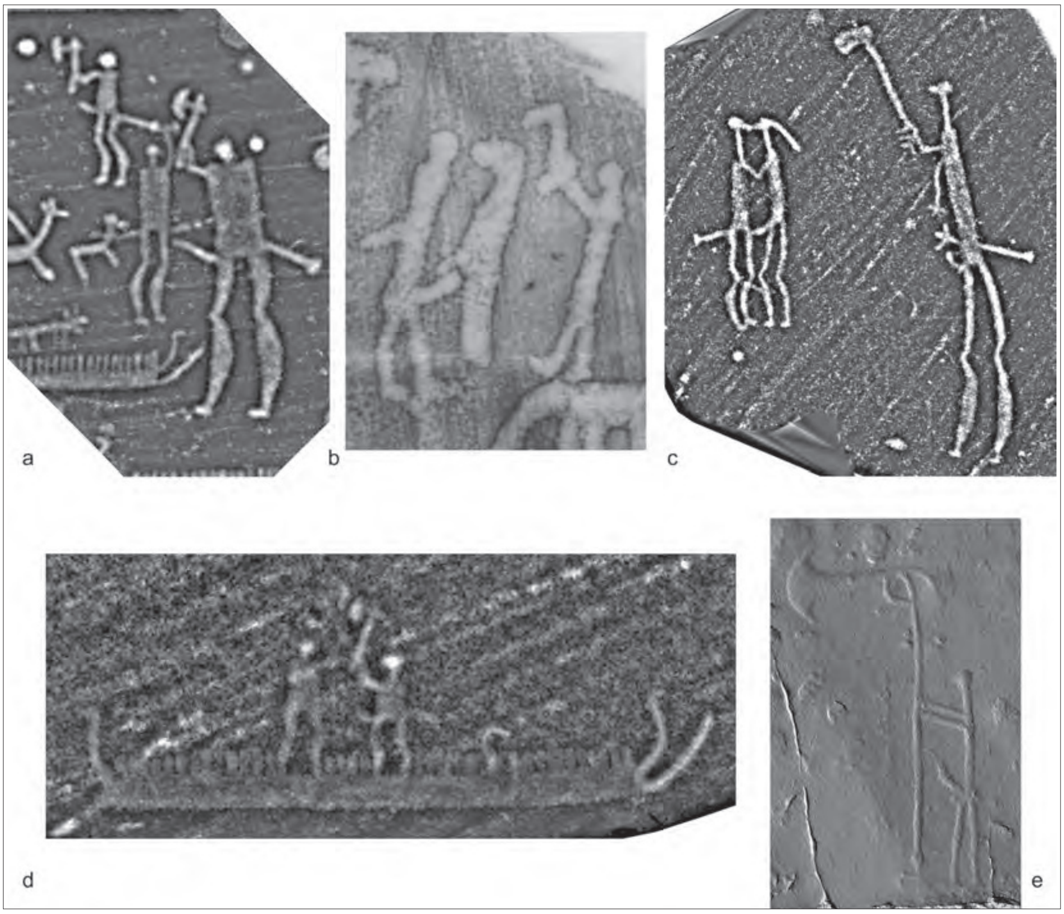

Fig. 7. Rock art representations of axes: a) fight scene between a sword and axe fighter (RAÄ Tanum 255:1), b–c) intercourse scenes with axe wielding figure (b. RAÄ Tanum 160:1, c. RAÄ Tanum 1:1), d) fight scene on a boat (RAÄ Tanum 255:1), oversized axe (RAÄ Simrishamn 23:1).

earlier axe-head. However, since the best-fitting axes date to a time when the panel was still largely submerged, this seems unlikely. At best, it is currently unverifiable in either case.

The presence of "upside-down" figures in Scandinavian rock art in general, and Gerum in particular, provides a strong possibility that the axe petroglyph is another such case. Judging by the best-fitting shape, a socketed axe including its shaft-head and upper handle were engraved on the rocky surface in Gerum sometime during period III–IV (1300–950/920 BC). At present, it is not possible to narrow this time-span any further.

Axes including socketed axes were shown by experimental studies to be multi-functional tools during the Bronze Age, usable for wood-working and other tasks (Kienlin & Ottaway 1998; Roberts & Ottaway 2003). There are many possible reasons why it was engraved on the Gerum panel. If the "may-pole" is in fact related to the storage of leaf fodder as Skoglund has argued, then the axe could have been a tool related to the production of the "may-pole" or the gathering of the leaf fodder. The close relationship between the two features may be of significance. It might be problematic that the two features are greatly out of proportion and that their position to one another seems odd. Furthermore, while there are many objects in rock art that require wood-working such as boats, spears, aards, etc., direct depictions of wood-working as an activity itself is virtually absent, or at least exceedingly rare, in the scenes and images.

Depictions of axes in warfare-related imagery, however, are frequent and may point to an important role of axes in warfare during the Nordic Bronze Age. Axe-wielding warriors can be observed in combat with sword-wielders or other axe-fighters even aboard boats, for example, on the Fossum panel (fig. 7 a–b; RAÄ Tanum 255:1). Some graphic intercourse scenes have an additional warrior behind the depicted couple wielding an axe, for example, on the famous Vitlycke panel (fig. 7 c; RAÄ Tanum 1:1) and on a panel in Hoghem (fig. 7 d; RAÄ Tanum 160:1). These scenes have traditionally been interpreted as related to fertility rituals (Almgren, O. 1927; Fari 2003; Mandt 1987) but they may have a darker dimension such as the portrayal of revenge (Horn 2018). In any case, what we see on the Vitlycke panel, as well as on the axes carried by humanoid figures in Simrislund (fig. 7 e; RAÄ Simrishamn 23:1), is that axes are enlarged in the depictions in relation to the associated human figures and the surrounding petroglyphs, emphasizing their role and importance. This is also the case in Gerum. Evidence for a combat role of axes during the Nordic Bronze Age is also beginning to emerge from the study of the use wear on bronze and copper axes (Högberg et al. 2016). Unfortunately, a systematic, quantitative study of use wear on such axes is still missing in Scandinavia.

The "upside-down" depiction of boats has been interpreted as an inversion of meaning, i.e. "upside-down" boats represent the boats of the dead (Fuglestvedt 1999). However, it has been argued that rock art such as on the panel in Gerum can be approached from different viewing angles, such as in the case of a panel in New Zalavruga (Russia) which may have had many "station points" (Janik 2014). This makes it difficult to determine which aspects were thought of or intentionally depicted as being "upside-down". Janik defines the station point by looking at the images and determining how they would stand in reality, for example she presupposes that animals would have been viewed standing on their feet. A similar argument has been made for another panel in Tanum, i.e. Finntorp (RAÄ Tanum 184:1) (Horn & Wollentz 2019). Directly comparing the panels in New Zalavruga and Gerum shows that the directionality in Gerum is much more uniform. In addition, the direction of the large majority of motifs makes them "stand" when the panel is –like today– approached from below coming from the stream that flows next to the panel. Only few depictions deviate, which makes it more likely that this way of applying the motifs in contradiction to the other images was purposeful.

Thus, in the case of the Gerum panel something similar to Fuglestvedt's interpretation may have been depicted, and perhaps the closeness to the mast-like petroglyph may have played a role in that regard. Maybe the mast represented a ritual that was supplanted by new beliefs, and the axe represents the cutting down of the old. Should the axe petroglyph date to period III–IV, then it was engraved during a time of upheaval in Europe during the transition from the Early to the Late Bronze Age and the introduction of the urnfield belief system into the north (Vandkilde 2011; Kristiansen & Larsson 2005). The discovery of the Tollense battlefield in northern Germany with perhaps hundreds of victims and potentially thousands of battle participants provides graphic evidence of that (Brinker et al. 2014; Jantzen et al. 2011; Lidke et al. 2018). Perhaps the warrior depictions on the Gerum panel, some with raised spears, point in a similar direction. This interpretation, however, depends on the dating of the mast-like figure and it being older than the axe. The verification or disproval of this future research using the best documentation methods available to investigate rock art, especially anthropomorphic figures, depictions of metalwork, and boats, is necessary.

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Article seven: "Set in Stone? Transformation and Memory in Scandinavian Rock Art

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My contribution to this article was predominantly methodological, through the creation of Reflectance Transformance Imaging (RTI) datasets, Structure from Motion (SfM) datasets and joint analysis of the results. I also wrote sections of the article. **(overall contribution 50%)**

This paper reassessed how permanent the meanings and traditions of carving rock art in Southern Scandinavia was, using examples of Bronze Age rock art panels from Finntorp, Bohuslän. It discusses how rock art was updated, offers some potential reasons for why this might have happened, and offers some theories about how the rock art was viewed by those who made it. It also describes how rock art was used as a memory device to remind about the past, and was updated to fit current traditions and ideals.

The paper concludes that the nature of Bronze Age rock art was rather more fluid than has been previously suggested. Its open nature meant that it could be frequently re-carved, though the intention was clearly not to remove the old rock art, but instead to add to it. Superimpositions are here described as potentially being metaphorical in nature. The fact that the carvings were amended suggests that they were not taboo, and therefore likely represented mortals rather than deities.

Set in Stone?
Transformation and Memory in Scandinavian Rock Art

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Introduction

The Nordic Bronze Age dating from 1700 to 550 BC has, among others, two important features;[1] rock art and metalwork. Both inform us about Bronze Age life, ritual, economy, social structures, and activities (Figure 1). More detailed approaches to rock art are hoped to improve our ability to study these aspects in ever-closer detail asking and answering new questions.[2] One such aspect of rock art will be described in this paper.

As part of the fieldwork to study rock art, different panels were documented using new 2.5 and 3D imaging techniques. Some of the discoveries will be described in this paper and the transformations that were observed will be discussed. Various authors have recognized transformations in rock art before. Joakim Goldhahn argued that the slabs of the Bredarör tomb in Kivik have been re-engraved multiple times.[3] In another study, Katty Hauptmann-Wahlgren observed that lines on images were re-engraved. When rock art is cut freshly, it appears lighter against the normal color of the rock. After some years, the color darkens and fades back to the normal color. By re-engraving lines, they show up lighter again. Hauptmann-Wahlgren argued that by doing so these parts of a carving are in a sense switched on again.[4] Others have demonstrated that panels were built-up by repeated carving acts spread out in time.[5] Per Nilsson demonstrated that even people in the Late Iron Age engaged with the Bronze Age images by adding their own engravings.[6] Most recently Ingrid Fuglestvedt has studied the imagery of the Mesolithic in Northern Europe seeing it as the visual products of the existing 'concrete logic' of the time that has been repeated and transformed.[7]

In our own work, we discovered additional ways rock art was transformed, not only on the level of the panel as prior authors have argued, but also on individual motifs. In previous research, the accumulation has been accepted as a phenomenon, but the social base has rarely been specified beyond general remarks.[8] The observations presented in this paper gives the whole phenomenon an entirely new scale. In the following, the potential connection between rock art and ancestral memory will be discussed and specified. Conversely, the results suggest that the rock art images are not linked to a godly sphere. However, it is not the aim to swing the interpretative pendulum back from religious to secular interpretations.[9] Instead, a middle ground may be presented incorporating both.

New methods

The methods will only be discussed in passing to conserve space and because a longer discussion of them has already been published elsewhere.[10] The methods used to record the panels and individual figures are all image based: Reflectance Transformation Imaging (RTI), Structure from Motion (SfM) and Optical Laser Scanning (OLS).

RTI uses a series of photographs from a static camera with repositioned lighting for each photo. The open source software RTIBuilder[11] computes surface normals based on these photos and the differing directions of the light reflection to create an artificial representation of the shape of the rock's surface.[12] The result is a 2.5D representation that can be viewed in the open source software RTIViewer. In this program lighting is infinitely adjustable and visuals can be improved using filters such as specular enhancement and diffuse gain.[13]

SfM software such as Agisoft Photoscan© identifies points in a series of photographs and calculates their position in three-dimensional space. Based on this, further points can be identified and a mesh is created. This procedure provides a full 3D model of the rocks surface.[14] For OLS a cheap Sense 3D scanner was employed previewing panel sections to identify interesting spots and locate particular images.

[1] Kneisel *et al.* 2014; Olsen *et al.* 2011.
[2] Bertilsson *et al.* 2017; Horn and Potter 2017; Nordbladh 1981.
[3] Goldhahn 2013.
[4] Hauptman Wahlgren 2004.
[5] Bengtsson 2004, Fredell n.d. 2010, Ling 2014.
[6] Nilsson 2012.
[7] Fuglestvedt 2018.
[8] Bengtsson 2004; Ling 2014.
[9] Kristiansen 2012; cf. Kaul 2004.
[10] Bertilsson *et al.* 2017; Horn and Potter 2017.
[11] Cultural Heritage Imaging 2013.
[12] Horn and Potter 2017; Jones *et al.* 2015; Malzbender *et al.* 2000; Malzbender *et al.* 2004; Mudge *et al.* 2005.
[13] Cultural Heritage Imaging 2013.
[14] Meijer 2016.

Figure 1. Map of southern Scandinavia indicating panels with anthropomorphic rock art (white dots) and the working area (star).

There are many advantages of using these new methods over older techniques.[15] Most important for the presented work is that it visualizes depth differences. This makes it easier to identify superimpositions and intersections, which are used to create a relative sequence of engraving actions on the scene or image. Differences in width, depth, and technique indicate different carvers. If archaeologically known objects were identified some of these carving actions could be brought into a chronological order indicating later additions and transformations.[16] It should be mentioned that all methods have their advantages and that old and new methods work best in conjunction with one another.

The fieldwork focused on Finntorp, a gently sloping valley in Tanum, Bohuslän (Sweden). It is located within the UNESCO world heritage area by the name Rock Carvings in Tanum. Exposed rock faces frequently bear rock art. The stone is Bohus granite with quartzite veins. The veins are usually not engraved. Lichen growth is moderate and can mostly be ignored. However, before recording rock art the panel needs to be cleared of moss, leaves and other plant material. In the following discussion, sites will be referenced by

[15] Bertilsson *et al.* 2017.
[16] Horn and Potter 2017.

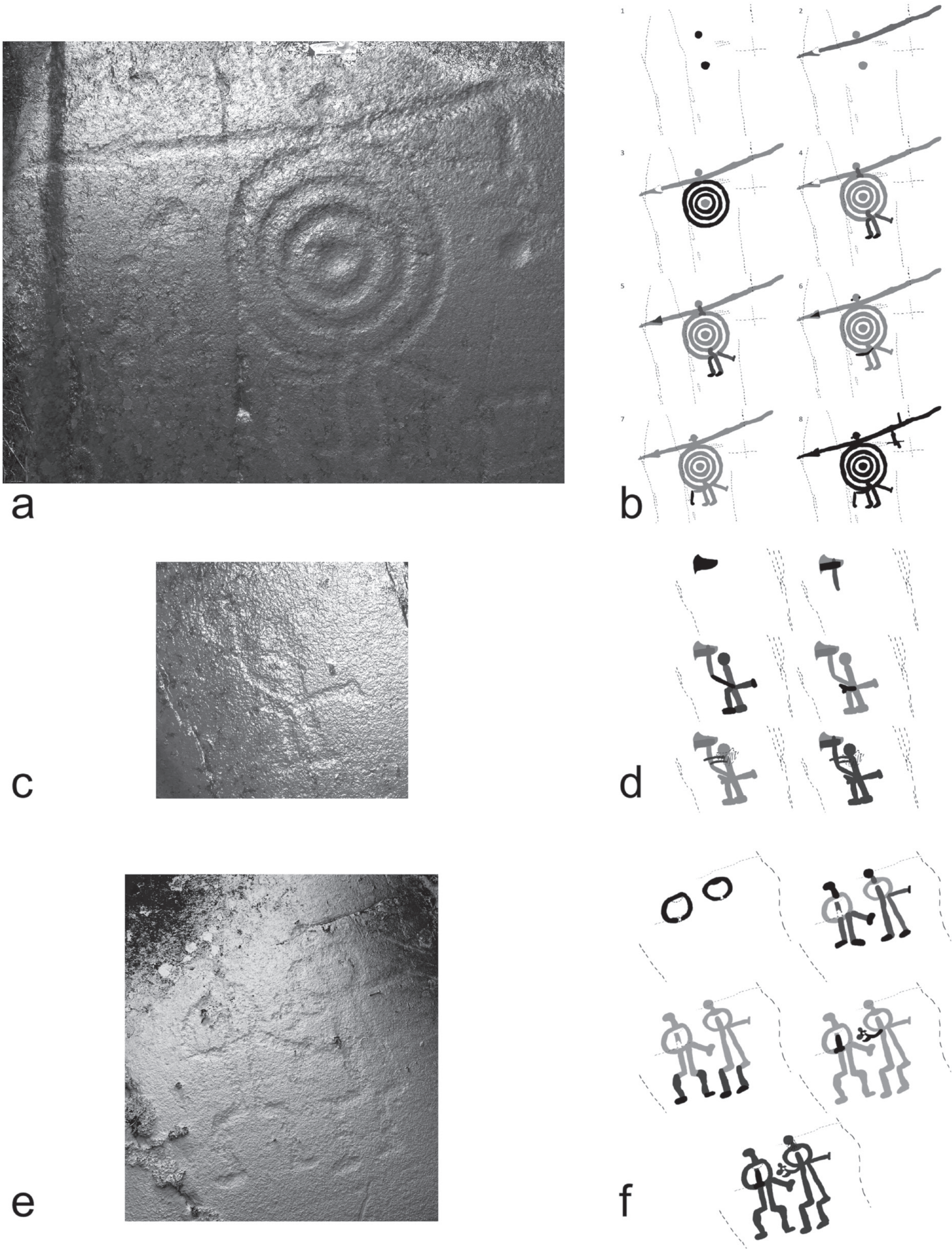

Figure 2. Case studies from Finntorp (Tanum 89:1): (a) RTI snapshot and (b) engraving sequence of the large spear warrior; (c) RTI snapshot and (d) engraving sequence of the axe warrior; (e) RTI snapshot and (f) engraving sequence of the two warriors with the pronounced knees (all images and graphics Christian Horn and Rich Potter).

the numbers provided by the Swedish Heritage Board (Riksantikvarieämbetet). These numbers and further information concerning the sites can be found in the Heritage Boards database Fornsök (http://www.fmis.raa.se) and the website of the Swedish Rock Art Research Archive (http://shfa.se).

Case Studies

Finntorp Tanum 89:1

The panel in Finntorp designated Tanum 89:1 contains fourteen canoes, seventeen human figures and at least seventeen individual cupmarks (Figure 2a). In addition, a few lines without coherent composition can be observed. RTI was conducted on four human figures. Four times on a large spearman, two times on two warriors with protruding knees, and one time on an axeman close to the two warriors.[17]

The head of the big spearman was applied in a different technique than the rest of the lines. It seems to have been ground into the rock as opposed to the lines that seem to have been pecked. The centre of the concentric circles may also have been ground. Both are bowl-shaped and deeper than any of the lines and may have been cupmarks that have been reused.[18] A neck superimposes the handle of the spear and the head. The shaft of the spear was possibly re-engraved 2-3 times so that there are 3-4 different spearheads visible. The concentric circles are around the other cupmark can possibly be interpreted as a shield. Furthermore, the sheath of a sword including a chape superimpose the outer ring of the shield. These objects provide the opportunity to compare them to bronze finds from the archaeological record.

There are considerable insecurities in comparing physical objects to depictions in rock art because of the medium, the generally downscaled proportions and the abstract nature of the images. Furthermore, objects that are not known from the archaeological record could be depicted. However, the method has been used with some success in the rock art areas of the Alps.[19] In fact, Bror Emil Hildebrand, who settled the early discussion about the general dating of Scandinavian rock art by comparing depictions with Bronze Age swords,[20] used the method. This demonstrates the merits of comparing depictions to known objects while being aware of its problems.

The results of the typological analysis have been published and will not be discussed at length here.[21] The largest spearhead possibly represents a type that may date to period Ib (1600-1500 BC). The other spearheads depicted are strongly disturbed and very abstract. They could be Late Bronze Age spearheads or spearheads made from flint.[22] The latter has recently been proposed by Ulf Bertilsson for all depicted spears in Finntorp dating them to the preceding Late Neolithic Bell Beaker phase.[23] This, however, is problematic, because neither the chronology nor the functionality for most of the flint blades he depicts as comparisons are settled or even properly investigated. This is illustrated by the one comparison that belongs to a form that has been analyzed. The flint blade in question is possibly a thick flint point. These blades are commonly associated with the earlier Funnelbeaker Culture (4300-2800 BC) dating at least 1000 years before the earliest figurative rock art in Scandinavia[24] and they were hafted perpendicular to the handle like halberds and not like spears.[25]

In any case, there is a chronological depth in the (re-) engravings of the spearheads. The same is true for the other depicted objects. The shield consists of three concentric circles and the cupmark forms a shield boss. The cup mark could like the head of the figure pre-date the concentric circles. Shields of the depicted type date to the transition from period II to III (1400-1200 BC) by Uckelmann.[26] Lastly, the chape on the sword sheath points to parallels dating to period III (1300-1100 BC).[27]

If the identification of the spear, the shield and the chape are correct, it suggests that there may be a considerable time-depth between the individual objects. This is of course highly tentative given the insecurities introduced by the typological dating and the abstract style of rock art. Thus, we will suggest a maximum and minimum time span that seem plausible if the objects were identified correctly. The shield and the first spear are separated by between 100 and 300 years. The shield and the sword sheath could have been carved almost contemporaneously to one another. However, the differences in width and depth could suggest two different carvers. A new 3D model created in 2018 supports the chronological sequence that the shield is older than the sword because it indicates that the sword cuts into the shield's outer ring (Figure 3). At the maximum, they may also be separated by 300 years. The different techniques and different styles of the cupmarks indicates that they were applied by yet another individual before the shaft of the spear was pecked. It is impossible to date when that happened. The deeply and narrowly pecked line that is the phallus may indicate yet another engraver. Summarizing all these

17 Horn and Potter 2017.
18 Horn 2016.
19 Anati 2008; Casini 1994; Lumley and Bégin-Ducornet 1995.
20 Hildebrand 1869.
21 Cf. Horn and Potter 2017.
22 Cf. Horn and Potter 2017.
23 Bertilsson 2018.
24 Müller *et al.* 2010; Persson and Sjögren 1995; Schulz Paulsson 2010.
25 Ebbessen 1992; Horn and Schenck 2016; Lübke 1997/98.
26 Uckelmann 2012.
27 Laux 2009: 137–138.

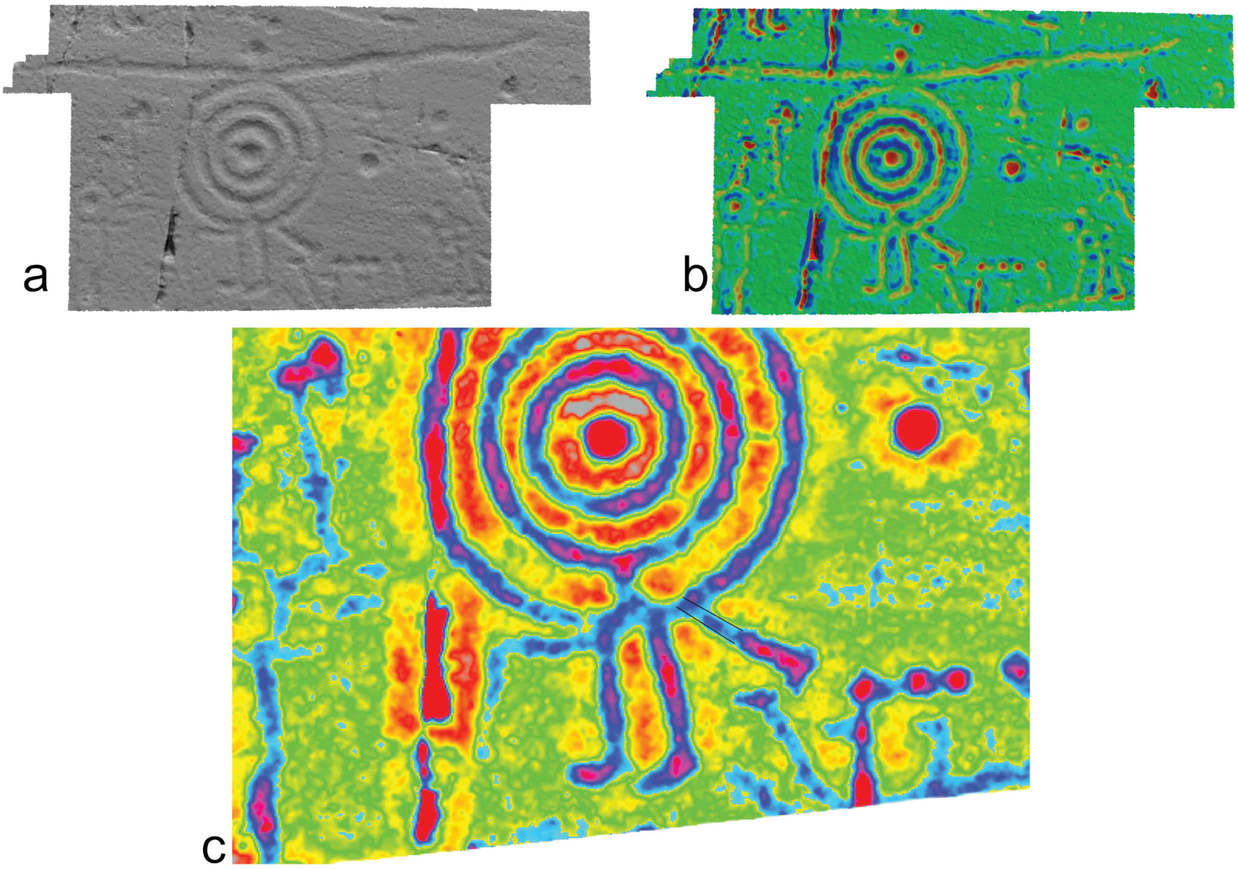

Figure 3. 3D model (photogrammetry) of the large spear warrior from Finntorp (Tanum 89:1): (a) snapshot, (b) colorized curvature, (c) local relief modelling visualized using a multi-color ramp with indication of the area in which the sword potentially cuts into the outer ring of the shield.

alterations suggests that the image was potentially transformed six to eight times (Figure 2b).

The axeman and the two warriors with pronounced knees also show indicators of repeated transformations (Figure 2c-d). The axe of the axeman was reengraved once. The arms are applied in another technique to the rest of the lines. They seem almost to be scratched into the surface. The phallus is cut deeper and somewhat narrower than the leg and the sheath and cuts across the latter. The sheath has a similar chape to that of the spearman. That potentially indicates a period III date. Since the phallus superimposes the legs and the sheath it could mean that the phallus is the latest Bronze Age addition. Potentially, four separate transformations of the figure took place.

One of the warriors with pronounced knees has also a chape like the one of the spearman, suggesting a period III date (Figure 2e-f). The pronounced knees came into being by attaching another pair of legs to the front of a pair of feet. This addition cannot be dated but given that the figures were complete with legs without the transformation, we may assume that some time past until the next engraving. The phalli on both figures superimpose all other parts and based on their style they were also later additions and could represent the latest phase. The warriors were each possibly transformed two to three times.

The chronology of the canoes on the panel shows that engraving actions took place on the panel in the proposed periods. Four canoes date to the Late Bronze Age, three between periods II to III and the one closest to the spear dates to late period I or early period II.[28] The transformations could have been applied when the canoes were added. All transformations represent additions or enhancements. Destruction or eradication cannot be observed and were presumably not intended.

Finntorp Tanum 184:1

The panel designated Finntorp Tanum 184:1 contains 11-12 anthropomorphic figures, 13-14 canoes, six animals, two wheels, one cross, over 450 cupmarks and many individual lines. The panel was recorded using SfM (Figure 4a). An older frottage of the lower part of the panel shows a setup of two ships that seem to mirror

[28] Cf. Horn and Potter 2017.

each other. Similar situations have been interpreted by Fuglestvedt as a ship of the living and a ship of the dead.[29] An argument could be made that the one vessel that has humans on board could indicate 'life' while the supposed upside-down canoe seems to be empty and represents a mirror image. Therefore, the latter could represent the canoe of the dead.

However, using the advantage of a freely rotatable 3D model, a depression between the two canoes become visible by rotating the scene to an isometric view. In fact, the canoes are not mirrored but are located on opposite sides of the depression (Figure 4b). After this discovery, we went back to the photo material for the SfM and discovered that the depression has a blackish-brown discoloration indicating that water runs frequently through it, which is confirmed by a photo taken after rain (Figure 4c). Cupmarks on the bottom of the depression may have disturbed water flows adding to the impression of a stream or water waves. Throughout the Bronze Age fjords were running through the landscape less than 100m away from the scene.[30] Previous research has of course already stressed the relation of water and rock art.[31] However, here we find that a natural configuration of the rock was transformed into a miniature landscape that could represent a fjord or perhaps a river. The canoes are floating right on top of the water's edge (Figure 4c).

Interestingly, the two canoes represent different chronological phases. The vessel without a crew has a straight keel line and upturned prows without any attachments. These features may suggest a period II date. The other canoe was perhaps applied during period V as indicated by its asymmetry, the upturned keel line and the armed warriors on board.[32] This transformed the motif into an antagonistic scene, but by adding on to it, not by destroying or erasing anything.

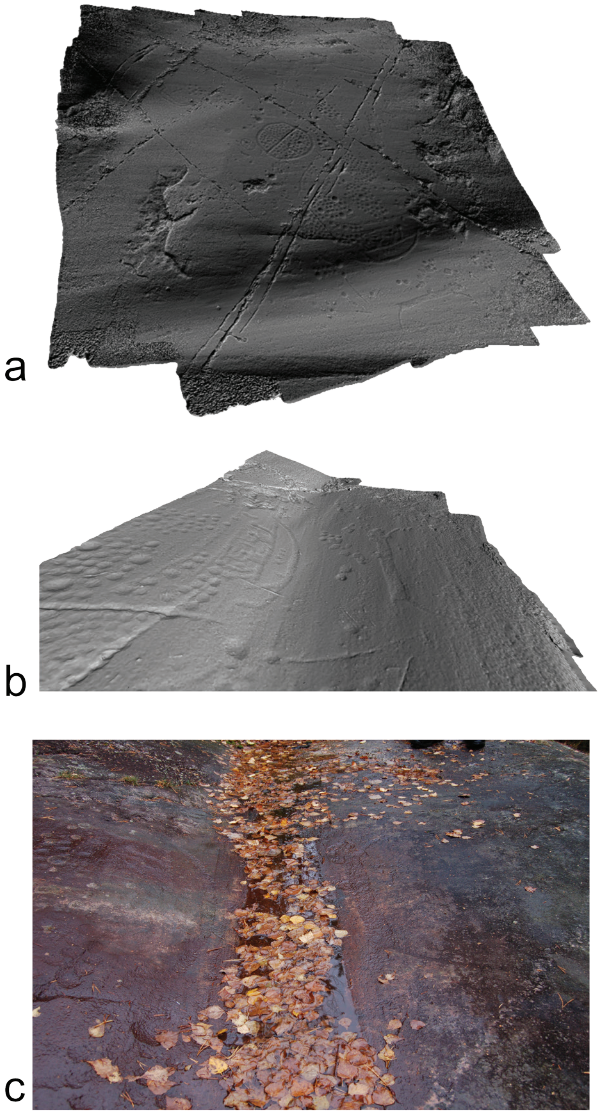

Figure 4. Rock art panel in Finntorp (Tanum 184:1): (a) snapshot of the 3D model (photogrammetry) of the entire panel, (b) 3D model rotated and zoomed to visualize the channel between the two boats, (c) photo of running water in the channel, the two boats can be seen just above the water's edge.

Anthropomorphic figures and objects

This section will briefly discuss another form of transformation that in its final form shows body parts merging into objects. Frequently, the sword sheath is extended at crotch level. This could be argued to be the sword's hilt. However, this part frequently has other features like glans, testicles, an upward curve, and is the part penetrating in intercourse scenes.[33] Considering these features, it is perhaps better to see this particular depiction as a phallus or a phallus-hilt hybrid. In many cases the human, phallus and weapon could be contemporary. However, recent 3D documentation of a panel in Fossum (Tanum 255:1) has shown that a period II sword wielded by one human figure was transformed into the hilt-phallus setup described above (Figure 5a-b). The possible dating of the axe which the second figure is wielding, suggests that this could have happened already in period II as well.[34]

Sometimes canoes are in position of the sheath-hilt-phallus setup in a process during which a human figure is superimposed on an older canoe or vice versa.[35] However, this is a much wider phenomenon. In 157 cases canoes replace body parts like arms, legs, or whole human figures are built up from canoes etc. The

[29] Fuglestvedt 1999.
[30] Ling 2014.
[31] Bengtsson 2004; Ling 2014; Melheim and Horn 2014.
[32] Cf. Ling 2014: 103–104.
[33] Fari 2003; Horn 2018.
[34] Ling and Bertilsson 2016.
[35] Ling and Bertilsson 2016: Fig. 12.

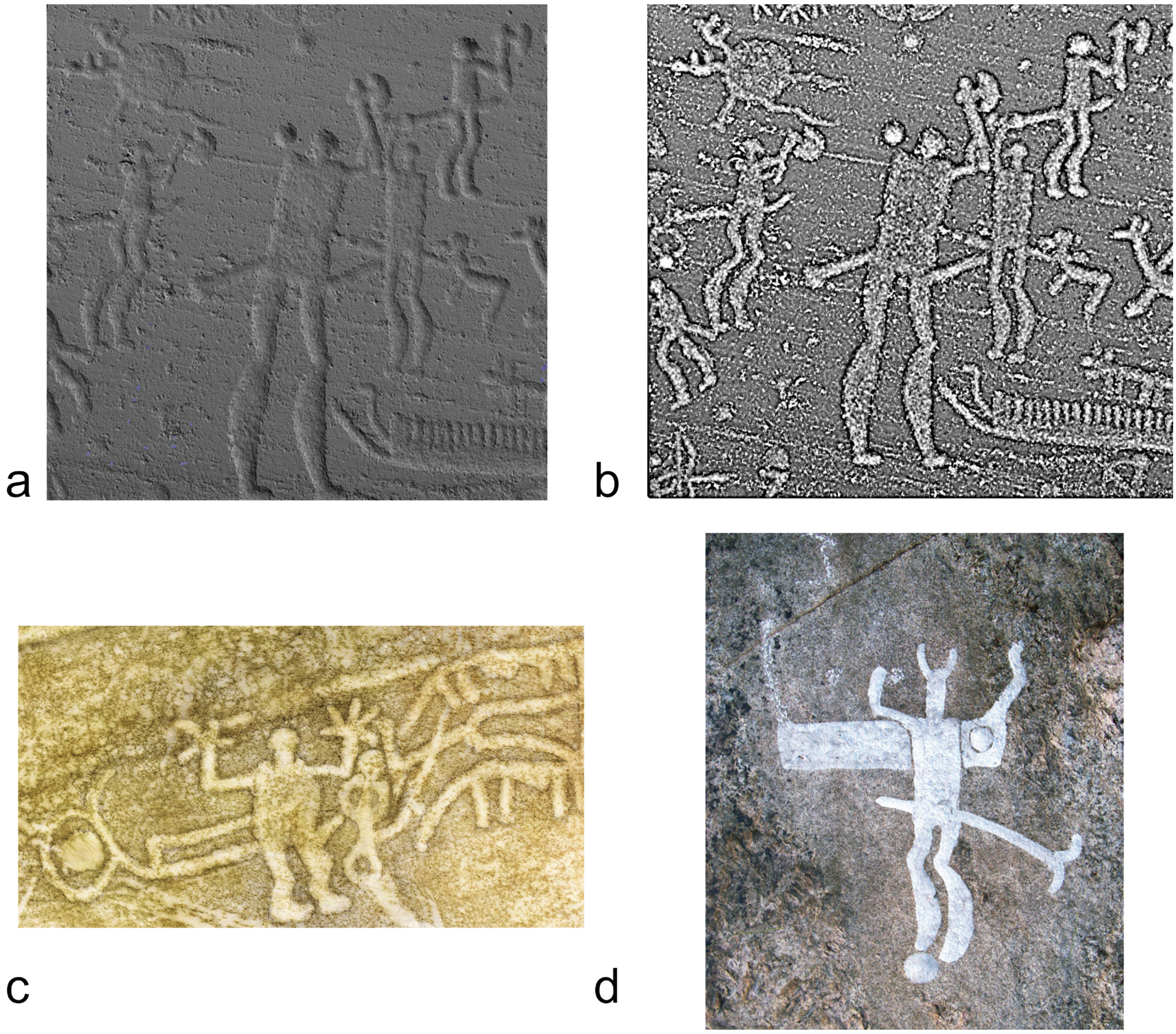

Figure 5. Detail focusing on the combat scene in Fossum (Tanum 255:1): (a) 3D model snapshot, (b) local relief modelling of the scene visualized using a black-white-color ramp. Detail of the rock art panels in Gisslegärde (Bottna 74:1) and Farläv (Bro 607:3) showing a canoe replacing the phallus and the sword (c) and the arm (d) of warrior figures.

placement is so precise that an accidental placement seems unlikely[36].

Dating these superimpositions and determining their chronology is difficult because as opposed to canoes, human figures are not well dated, and extensive research is missing. However, existing differences in engraving style indicate a time differential between the application of the images. For example, in Gisslegärde (Bottna 74:1) a very chunky figure was applied to a rather delicately engraved canoe (Figure 5c). Another example from Färlev (Bro 607:3), is a warrior with a Hallstatt-style sword sheath possibly dating to period V[37] who superimposes an Early Bronze Age canoe (Figure 5d). The straight keel line and missing crew of the canoe indicates that there is a time differential.[38]

As with the case studies before, destruction and eradication cannot be observed in any of the examples. Rather new images were applied in a manner to use the old images to enhance their own meaning or vice versa.

Discussion

The described transformations are all different in character and scale. In Finntorp 89, direct additions were used on the microscale sequentially creating a human out of something, i.e. the cupmarks, that might not have been intended to be a human and updating objects, i.e. the spear and the axe (Figure 2). In Finntorp

[36] Cf. Horn 2018.
[37] Roymans 1991.
[38] Ling 2014: 103.

184, first a natural feature was transformed into a miniature landscape, and then the configuration was transformed into an antagonistic scene by adding features to the context (Figure 4). Lastly, we saw the wider phenomenon to add humans to things and using features of prior motifs to replace body-parts by superimposing the two motifs (Figure 5).

In Finntorp 89 it is interesting to observe that it seems like some aspects were repeatedly felt missing or not matching current imagination. This does not seem to have been the case in Finntorp 184. By period II and the application of the first canoe the water in the neighboring valley was still very close, possibly close enough for water travel. That memory may have still been alive by period V when the water had further retracted. After all, the area was still a maritime region important for waterborne mobility.[39] In the process of replacing body parts with canoes the examples from Gisslegärde and Färlev but also Tuvene (Tanum 302:1) indicate that in several cases the human figure was added last. More research is necessary to find out whether this is the case in a majority of the examples. However, perhaps it can be suggested following Fuglestvedt's recent elaboration that the origin of these motifs and their transformation lies in the concrete logic of their contemporary people. In southern Scandinavia during the Bronze Age the visual output of this logic seems mostly to be concerned with activities that are socially important, i.e. warfare and seafaring, which were frequent occurrences judging from the archaeological data for combat and maritime mobility.[40]

The equation of body parts and objects has been described as pragmamorphism. The term is borrowed from physicist and economist Emanuel Derman and means infusing a human body part with the 'inner essential substance' of a material object. An example can illustrate the meaning of this term. The modern saying 'her brain works like a computer' does not literally mean that her brain works in binary code. Instead we mean an attributed inner essence of computer, i.e. that they are fast. Therefore, equating a human brain with a computer means that that the individual is thought of as a fast thinker. Thus, these superimpositions could aim to infuse warriors or a body part of them with object powers for example, canoe-like momentum.[41]

The feature that unifies all the described cases, is the use of past images. In neither case is an outright destruction visible. The images new and old enhance each other. There seems to be a sense of respectfulness, but also an inherent transformability, and always a concern for human activity. The specific purposes of these additions and superimpositions may have been very varied, for example initiation rites, pre-war rituals or even fertility rituals. The questions remain, why these transformations happened and how it relates to memory.

Interpretation

The additions made were respectful towards the older carvings. Destruction or eradication does not seem to have been the motive. The open context of rock art made it a medium hard to control. Most of the images are not connected to palisades like the panel at Madsebakke on Bornholm.[42] The manifold additions and transformations described in this paper, but also indicated by the research of others[43] demonstrate that the carvings were not sacrosanct and indeed were engaged very frequently. That means they were not untouchable or 'holy'.

All these features indicate that they were more approachable than images of gods. Based on this, it may be more likely that the rock bear images of daily activities of mortals.[44] This is not intended to swing the pendulum of interpretations of rock art back away from ritualistic interpretations,[45] but rather to find a middle ground. Those who transformed images and panels were potentially aware that other humans carved those rocks engaging in similar practices. Since the initial engravings were present before the transformation people were perhaps even aware of a rudimentary timeline. This may go along with a reverence for humans that visited these rocks before. In discussing the Sarsen stones, Gillings and Pollard point out that the permanence of stone compared to the fleeting nature of human lives may facilitate knowledge about ancestral presence.[46] In the Scandinavian case, the occurrence of older images on the rocks may amplify such beliefs and link them to stories people remembered through oral traditions. Indeed, southern Scandinavian rock art seems to fit the particular temporality which Mark Freeman called 'mythic time'. Mythic time is something that happened in the past and is anticipated to repeat in the more recent past, the present, and so on.[47] This cyclical reoccurrence fits very well with the repetition of motifs and their emergence through transformation out of pre-existing images. The latter seems to synchronize the imagined mythic time with current practices.

39 See Nimura 2015.
40 See for example Horn 2013; Ling 2014.
41 Cf. Horn 2018.
42 Sørensen 2006.
43 Hauptman Wahlgren 2004; Ling 2014; Ling and Bertilsson 2016; Milstreu 2017.
44 Ling and Cornell 2010.
45 Kristiansen 2012.
46 Gillings and Pollard 1999.
47 Freeman 1998.

Consequently, rock art may have served as a form of *lieux de memoire* as deliberately as Pierre Nora suggested they should be used in modern times.[48] In that sense, the images reminded visitors of humans who were by the rocks before them perhaps in a mythic time. However, as Jan Assmann has pointed out, memory is not stored in lieux de memoire whether they are monuments or images. Whoever visits these places cannot readily read the memories of those who made the images. However, the images have a content because they are figurative. They may have conveyed the gist of stories potentially also transmitted by oral traditions linked to important activities that made the rock art gathering places.[49] Paul Connerton[50] stresses the bodily dimension of memories. In his sense, daily activities, and routine action shape memory. In Finntorp 89, the spear may have conveyed the gist of a story of action in warfare and the memories of past violent encounters, which later observers were familiar with through personal experience. Similarly, the presence of a canoe along flowing water on the rock in Finntorp 184 was perhaps relatable because past individuals recognized the kind of depicted landscape and activity. Possibly, these activities consisted mainly of seafaring, warfare, or raiding, i.e. establishing warrior identities.[51]

By updating, transforming, and enhancing the images, memories can be maintained, shaped, and controlled. Past individuals may have tried to make the images more readable and more relatable for their own times accommodating current beliefs, social institutions, and the lived environment. Meanwhile, they were engaging with ancestors or even named individuals like heroes to 'tap into' their powers and their repeated engagement constitutes a ritual practice. Superimposing a canoe image with a warrior may, therefore, be a ritual action in order to infuse an individual or individuals with the powers attributed to canoes, for example speed, powerfulness or momentum.[52] The procedural transformation of two cupmarks into a human figure in Finntorp 89 could also reflect an emerging myth that was not previously present in the region or at least not expressed in rock art,[53] but was believed to be present at the point of transforming the rock art. Similarly, the addition of the period V canoe with armed warriors on board may have transformed the scene to accommodate an emerging myth or a recently experienced violent encounter. It is the active creation and procedural transformation of a mythic time that then preempts the ideals, identities, and ideologies present in each generation.[54]

Conclusion

Based on the described and discussed transformations, it is possible to provide an answer to the question in the title whether rock art was 'set in stone'. The answer is no. On the contrary, rock art and memories were not set in stone, both were not stable throughout time and the images we see today were not pre-conceived. This also means that wholesale interpretations of rock art remain even more problematic. However, it would also be problematic to claim that the images and their meaning were free floating. Each image, each transformation, each story, and myth streamline the next transformation of an image. The myths and past activities kept cultural memories in a general line anchored in the landscape. By so doing, the rock art was potentially reinforcing social values.

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[48] Nora 1996.
[49] Bradley 2009, Ling 2014; 2013.
[50] Connerton 2010.
[51] Ling and Cornell 2017.
[52] Horn 2018; Ling and Cornell 2010.
[53] For other narratological approaches see Fredell 2003; Kaul 2004; Rédei *et al*. 2018.
[54] Nelson 2003.

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4.4. Post processing and rock carvings

Post processing here refers to the actions taken after the creation of 3D models either by laser scanning or SfM to make the carvings and surface variations more visible. Since there is such a variety in the methods available, in the following chapter a brief description of each type of method will be given based on the output from the previously mentioned documentation methods. For a more in-depth discussion and comparison of visualisation methods see Potter et al. (2023b).

The two main exported elements used as the starting points here are the 3D mesh either from laser scanning or SFM, and Digital Elevation Maps from SfM (DEMs – described below), or alternatively point clouds converted to TIN files from laser scanned surfaces (Jaillet et al. 2017, pp. 11–12). The majority of visualisation methods which, although interesting, require coding to reproduce, will not be elaborated upon here (Hedman 2016; Sapirstein 2019). Although vRTI is technically just a variation on the RTI method, it will still be covered here.

Visualisation techniques are necessary, in part due to the difficulty of presenting 3D surfaces in 2D formats, i.e. images in a journal (Nobles and Roosevelt 2021, p. 591; Valdez-Tullett and Figueiredo Persson 2023, pp. 15–16), and also because they help to enhance carved detail which is not necessarily visible to the naked eye. Additionally, these visualisation steps help move towards a more automated system of rock art identification and classification (Horn et al. 2022b; Jalandoni and Shuker 2021; Melnik et al. 2022). As has been demonstrated, and as will be presented below, visualising rock art also helps to reveal undiscovered details about the rock art, as well as completely new motifs (Horn and Potter 2019; Potter et al. 2022).

4.4.1. Work with Digital Elevation Maps

Digital Elevation Maps are 2D representations of a 3D surface (Nobles and Roosevelt 2021, p. 591), though they still technically retain their third dimension by means of the black and white value that each cell holds, some information is inevitably lost (Rolland et al. 2021, p. 36). As such, DEMs can be used to perform landscape style analyses on the surface of rock art, and can enable high-resolution outputs across large surfaces. The 2D DEM and the processed results are significantly smaller files than the 3D surfaces and are much easier to disseminate and view by those without high-specification computers. The results are also much easier to publish and can be easier for others to understand (Pires et al. 2015, p. 420).

One of the major breakthroughs that the SHFA had documenting rock art panels was using DEMs in ArcGIS to create a Local Relief Map (LRM, Horn et al. 2019), using a technique initially developed for LiDAR landscape surveys (Hesse 2010). While not the first to use this method on rock art (Monna et al. 2018; Trinks et al. 2005), the SHFA were the first to obtain and publish good results using the methodology in an accessible and reproducible way (Horn and Potter 2019). The method essentially creates a highly detailed and scalable digital frottage of the surface, which can be used to obtain information about new carvings on rock panels (Horn et al. 2019; Horn and Potter 2019).

Since then, the SHFA have had great success in finding new carvings, supported by using traditional methods. The output created can instantly be recognised as being similar to the results of traditional frottage by those not familiar with digital methods (Horn and Potter 2019; Horn et al. 2019; Potter et al. 2022). This method also benefits from the fact that it is produced in ArcGIS, a software which is commonly used and understood by many archaeologists. Similarly, it can be used in open-source software (QGIS,[23] LiVT,[24] or TVT[25]) to the same effect.

23. QGIS - https://qgis.org/en/site/ (accessed 20/07/23)
24. LiVT (Lidar Visualisation Toolbox) - http://www.arcland.eu/outreach/software-tools/1806-lidar-visualisation-toolbox-livt (accessed 20/07/23)
25. TVT (Topographic Visualisation Toolbox) - https://tvt.dh.gu.se/ (accessed 20/07/23)

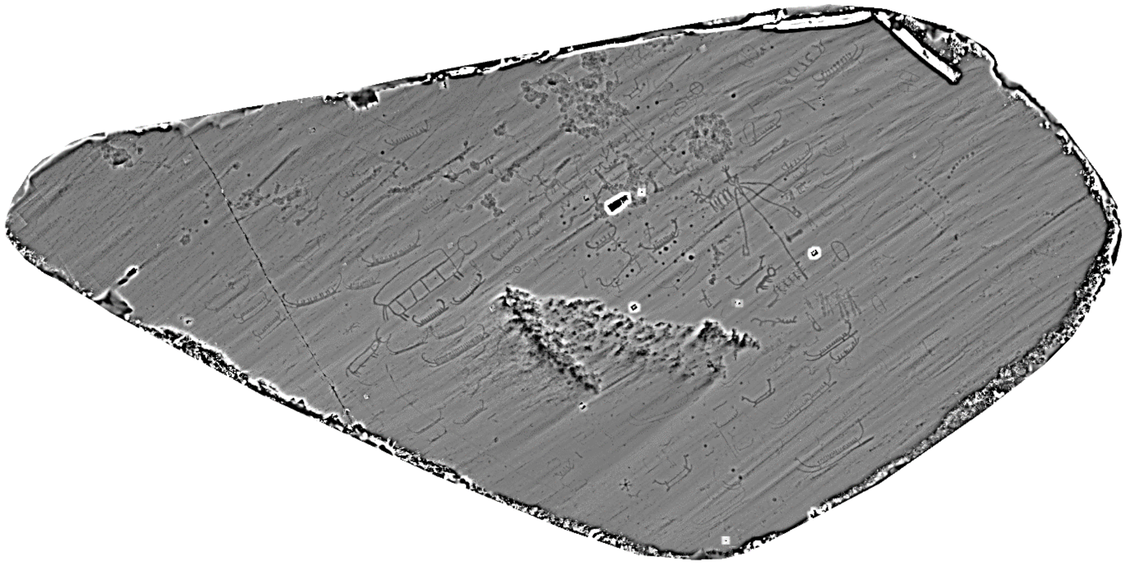

Figure 31: *Results of LRM processing from panel Tanum 311:1.*

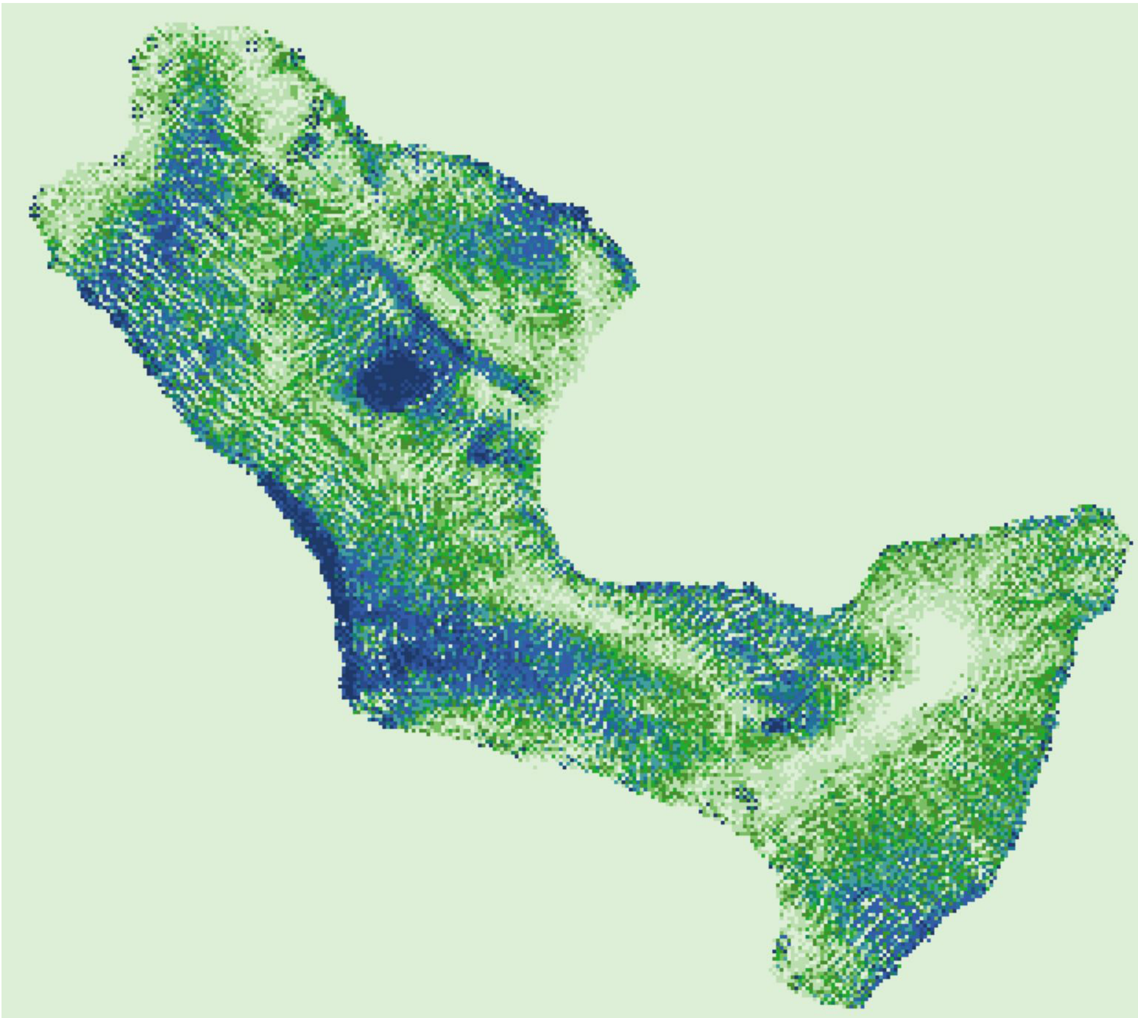

Figure 32: *Water-flows calculated by Netlogo with blue showing more water accumulation (Horn et al. 2022d).*

DEMs have additionally been used for the analysis of waterflow over the panels. It is clear that water had a direct importance to the position of rock art in the landscape (Ling 2014), and although it was assumed that rock art was placed on the rock surfaces in an organised fashion related to water flowing over it (Coles 2008; Hauptman Wahlgren 1998), it had not been quantifiably demonstrated that this was the case. Using a combination of the DEM from SfM modelling, and agent based modelling (ABM) in NetLogo,[26] a series of simulations were programmed to attempt to determine where water flowed and collected on the panels (Horn et al. 2022d).

The results, which were confirmed by comparing them to existing water staining on the rocks and photographs taken during rain, showed that there was indeed a correlation between the types of motifs and where they were carved into the surface in relation to the water-flow. The project was created in an open-source software, and the code for the NetLogo project was released with the article. As of yet, no instructions have been created other than the notes in the code, but there are plans for video instructions in the coming year.

4.4.2. Work with 3D meshes

This second form of analysis methods make use of the 3D mesh, and largely fall into two distinct groups. One uses the shape of the mesh itself to distinguish where carvings are, and the other compares the mesh against a lower resolution and smoothed version of itself. While there is a detailed discussion and comparison of these methods in Potter et al. (2023b), they are outlined below.

4.4.3. Using mesh characteristics

The following methods make use of the actual shape of the mesh to calculate certain characteristics. Although it is not within the scope of this thesis to go into an in depth

26. NetLogo - https://ccl.northwestern.edu/netlogo/ (accessed 20/07/23)

discussion of each of these methods, the general types of each will be discussed. Methods that were presented in the papers submitted within this thesis will be described in greater detail.

One of the most frequently used tools for examining meshes is a software called MeshLab (Cignoni et al. 2008).[27] MeshLab is open-source, but many of its features lack instructions, and as such it can be difficult to understand for those who are not accustomed to it. The majority of the instructions are links to scientific papers which present the maths, but little of the functionality since the publications focus on the algorithms. Instructions are instead presented via a series of by now very old YouTube tutorials.[28] One of the basic features that makes MeshLab so useful for rock carvings is the possibility to interactively move a light across the surface of a mesh simulating a raking light, as well as being able to turn textures off and on. In addition, MeshLab offers a variety of more advanced algorithms making it possible to measure

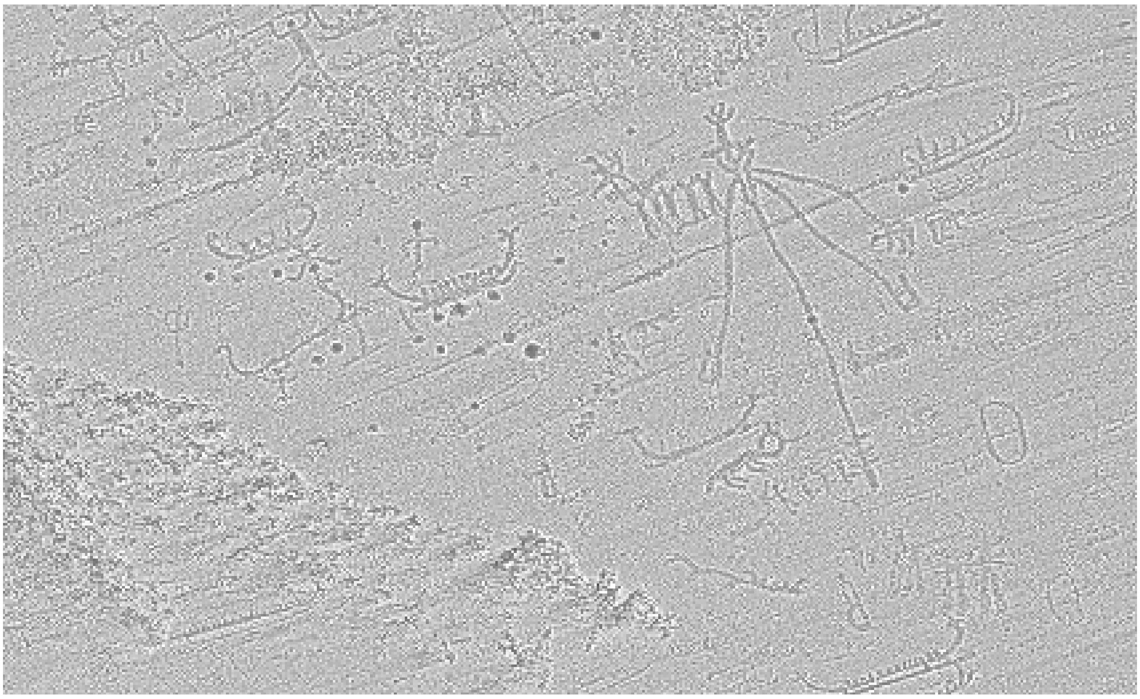

Figure 33: *Tanum 311:1 using Lambertian Radiance Scaling with enhancement set to 1.*

27. MeshLab - https://www.MeshLab.net/ (accessed 20/07/23)
28. MeshLab tutorials - https://www.youtube.com/@MrPMeshLabTutorials/videos (accessed 20/07/23)

variations on the surface of a mesh. The most commonly used is radiance scaling which enhances the object shape based on the curvature of a surface (Vergne et al. 2010). The implementation in MeshLab is simple to use, and has several modes which can enhance the carvings in different ways (Mark and Billo 2021).

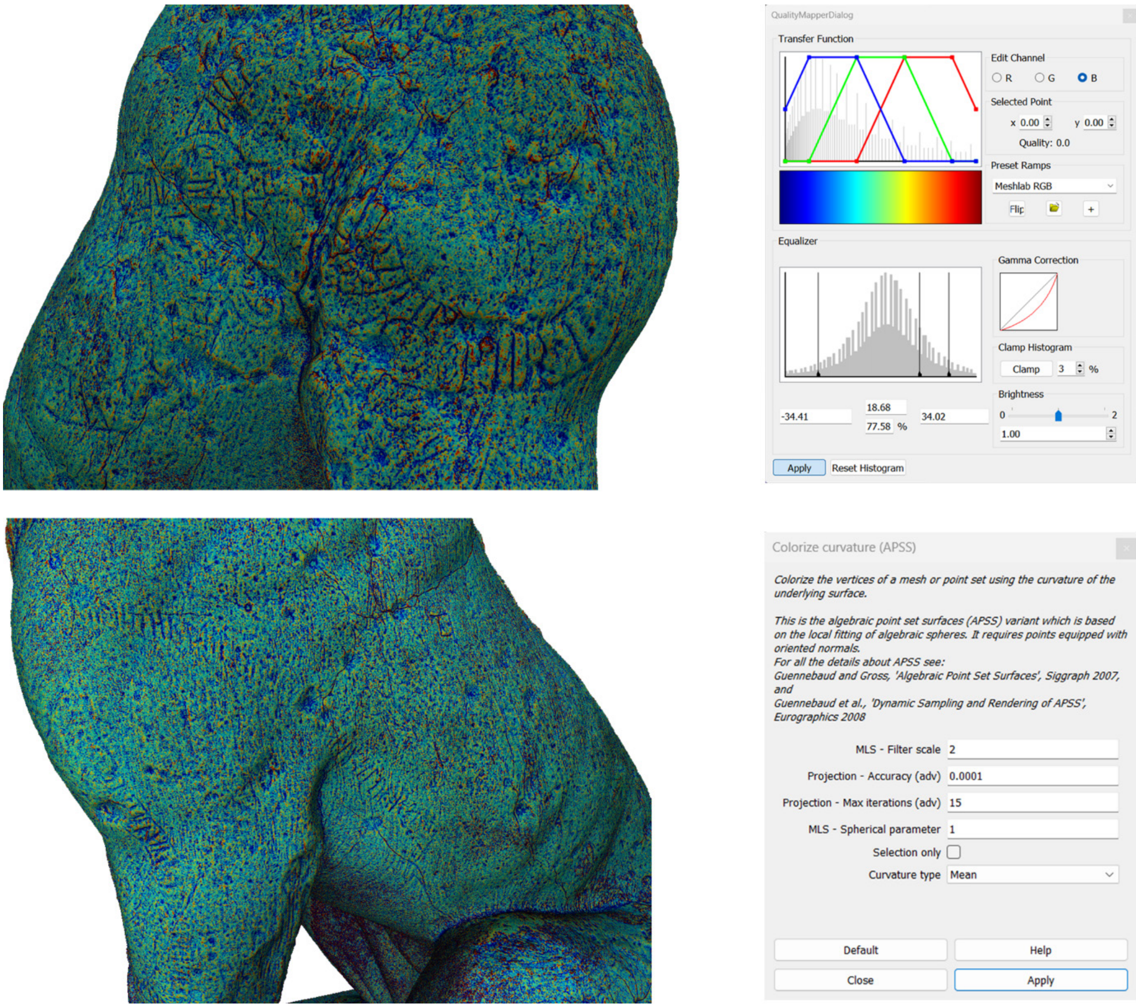

Figure 34: *APSS of the Pireaus lion statue in Venice (Potter et al. 2023b).*

Algebraic Point Set Surfaces (APSS) is a another frequently mentioned method which essentially calculates the average position of a vertex in relation to its neighbours (based on a sphere of influence moving across the surface) and assigns a value which can then be represented on a colour scale (Carrero-Pazos et al. 2016; Espinosa et al. 2021). While the method itself works rather well, the only help on offer is two very technical papers which give little instruction about which parameters might be best for a specific model (Guennebaud and Gross 2007; Guennebaud et al. 2008), they also do not mention how it should be accomplished in MeshLab.

Ambient Occlusion is a tool which adds extra contrast to the surface of a model based on where light can reach (i.e. light occlusion from nearby geometry). This is useful for carvings as the depth of the carvings add occluded areas, which are therefore highlighted by the application of an Ambient Occlusion filter. This filter can be added in MeshLab, but recently a more advanced bespoke method was published by Rolland et al. (2021). This paper makes use of the programming language R to add Ambient Occlusion to the surface of models in an effective way. While parts of the code were released with the project, it is unfortunately missing one of the files that the main code section calls, meaning that it does not work (as of 23/06/23).[29] Additionally, two of the packages that are called by R are no longer available, meaning that this code is no longer useable.[30] [31] Unfortunately, this means that the results have not been reproduceable, and it has not been possible to test the method independently.

The Topographic Visualisation Toolbox (TVT), was created by the SHFA and Centre for Digital Humanities (CDH) in collaboration with Chalmers Technical University in Gothenburg, and is another method which directly uses the mesh to calculate a result. TVT converts the mesh to a point cloud, cleans it up by removing outliers, and then performs an incremental principal component analysis. The cloud is then converted into a number of 2D images including depth maps, topographic maps, and texture maps, which are then blended to make enhanced variants of the maps (Horn et al. 2022b).

29. An attempt was made to contact the corresponding author, but without reply.
30. Cran page for HI package https://CRAN.R-project.org/package=HI (accessed 20/07/23)
31. Cran page for cwhmisc package https://CRAN.R-project.org/package=cwhmisc (accessed 20/07/23)

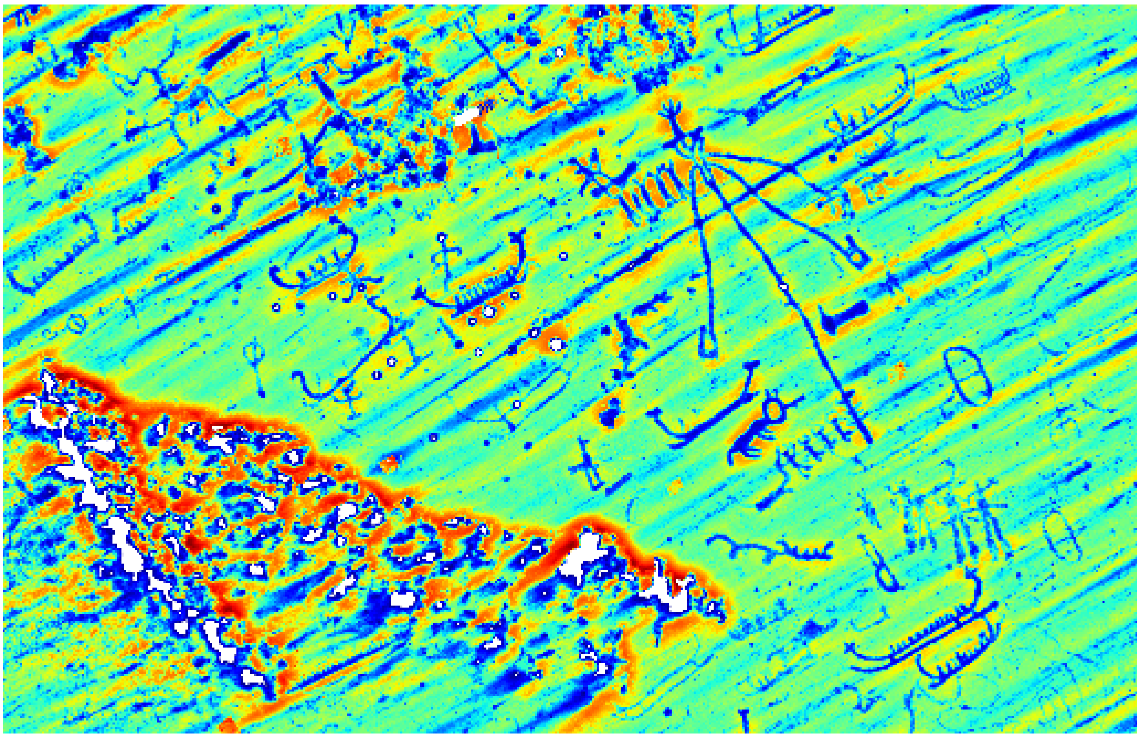

Figure 35: *Output of Tanum 311:1 from TVT.*

This array of 2D images is the output of the software. TVT is open-source and freely available from the University of Gothenburg and Centre for Digital Humanities website.[32] There are also instructional videos available for its use.

As with radiance scaling, the surface's curvature can be isolated from the mesh and used to determine the position of rock art motifs. Substance Painter, which is a 3D object painting software more commonly used for texture painting 3D models created for film and games, is a software that has the possibility to generate curvature maps. The method was initially tested on a 3D model of the Pireaus lion, a fourth century BCE marble statue currently located in Venice, as a way of visualising carvings on a non-planar 3D model (Potter et al. 2023b). This method proved beneficial since, as well as working on both full 3D objects and 3D planar objects (like rock art panels), it also creates texture maps that can easily be disseminated alongside the model. It also allows the user to paint directly on to the model's surface in a non-destructive

32. TVT (Topographic Visualisation Toolbox) - https://tvt.dh.gu.se/ (accessed 20/07/23)

Figure 36: *Substance Painter output of Tanum 311:1*

way, directly marking in carvings onto the surface, which can be used both for research purposes and demonstration/discussion. This method can either make use of a high-resolution model, or for especially large models, it can bake maps from a high-resolution model to a low-resolution model. This allows for lower-resolution models to be disseminated to those who do not have powerful hardware, or for sharing publicly. Unfortunately, Substance Painter is not open-source, and comes with a subscription to Adobe.

Blender is an open-source 3D software which has the possibility to create similar visualisations to Substance Painter. There are two methods presented in Potter et al. (2023b) which offer similar outputs, one of which allows for texture maps to be made. However, the process of creating the curvature map is somewhat more challenging than in Substance Painter. While this does not mean that it is less suitable, it does require more effort to understand its set up.

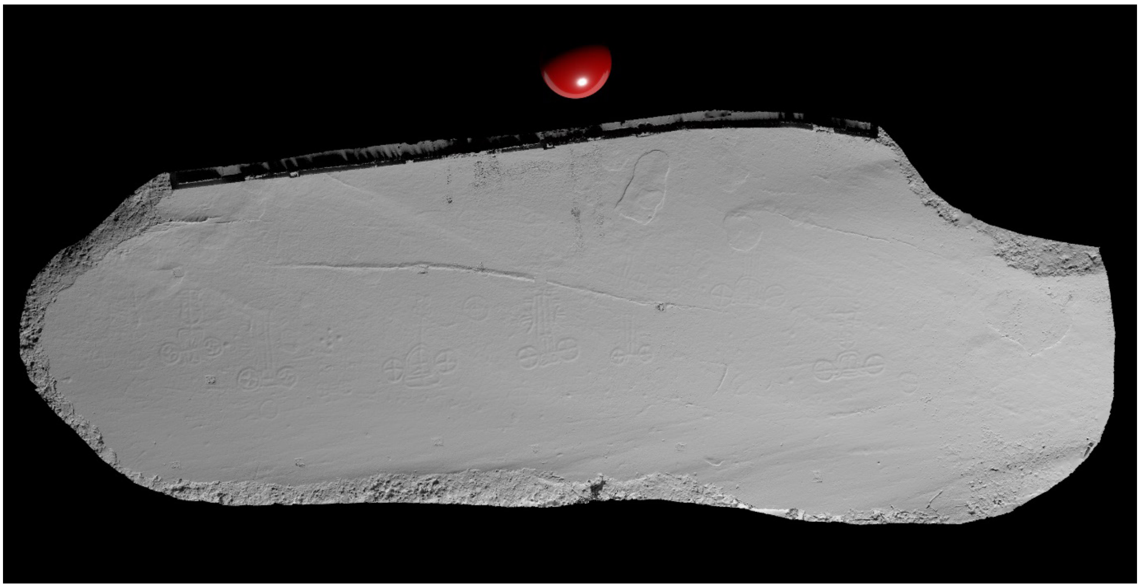

Figure 37: *vRTI image ready to be processed in RTI Builder.*

It is also possible to use the 3D mesh to create a vRTI documentation using a simple set up in Blender (Green 2018, p. 3; Mudge et al. 2010, p. 118; Pires et al. 2015, p. 418). An example set up would be a light placed facing the mesh, which is keyframed to rotate 45 degrees for eight frames. On the ninth frame, the light moves 45 degrees round and 15 degrees up and continues round and up every ninth frame to create the umbrella of lights that is needed for RTI processing. The sphere is handled by adding a shiny spherical red or black mesh into the frame. Each frame is then rendered out at the desired size, and then processed as it would be for a normal RTI documentation. This does, of course, rely upon the original SfM data being high quality.

This method has several benefits over regular RTI, in particular because there are no issues with shadows, and because the light coverage will be perfect every time, with lights at exactly equal spaces from the centre point. This also negates the issues created by poor outdoor conditions and means less equipment is required to be carried into the field.

Another recent method, ArchCut-3D, allows a more in-depth evaluation of micromorphological features of rock art, allowing researchers to examine how carvings were produced (Dubinsky et al. 2023). In tandem with macro photography and SfM, this promises to provide exciting results.

4.4.4. Smoothing

The second type of mesh-based calculation relies on comparisons between a high-resolution mesh and a smoothed low-resolution version of the same mesh. There are a number of different names for this method, including MRM (Edmondson 2021; Fabián et al. 2021; Pires et al. 2014; 2015), AsTrend (Carrero-Pazos et al. 2016), and Xshade (Carrero-Pazos et al. 2018; Espinosa et al. 2021). The basic principle of this methodology is largely the same as that of the LRM method described above in that it too works by subtracting a defocused version of the mesh from the high-resolution version.

This smoothing method is possible to carry out in MeshLab using built-in tools to decimate and smooth and can then be completed using the Hausdorff Distance or Distance From Reference Mesh filter. The results are colour coded and adjusted/visualised through the Quality Mapper in MeshLab. Again, though these methods rely on free software, the instructions in both the articles and the software are lacking, so experimentation is required to obtain a result (Edmondson 2021; Fabián et al. 2021; Pires et al. 2014; 2015).

Xshade uses the same principle, but is a standalone software (Carrero-Pazos et al. 2018; Espinosa et al. 2021).[33] The software, while being open-source is sadly outdated, and can only handle lower-resolution models (Potter et al. 2023b). As such the results are of low quality compared to those already mentioned.

Similar to a DEM, Agisoft Metashape has recently offered the possibility to create displacement maps. A displacement map is again a black and white image that

33. Xshade - https://gfx.cs.princeton.edu/proj/xshade/ (accessed 20/07/23)

Figure 38: *An example of a smoothing method output from Tanum 311:1 using Hausdorff Distance.*

demonstrates how far in or out something is from an averaged version of a model. The process requires that a smoothed and decimated model is created in Agisoft Metashape, and then it is compared to the original model, creating a displacement map. In theory, the displacement map should be similar to a DEM of the surface, and should therefore allow for the aforementioned LRM method to be calculated on non-planar surfaces. However, in testing this has not yet proven to work as well as expected (Potter et al. 2023b).

4.4.5. Related articles

The following presents three articles that are related to my work with visualisation methods. The first covers the development of an agent-based modelling solution that helped quantitively determine that water-flow over rock art panels was seemingly a factor in the placement of the motifs. The second article introduces using Substance Painter as a tool to highlight carvings on rock art, and evaluates it against existing visualisation methods using the Pireaus lion as a case study. The third article brings together a collection of visualisation techniques, including traditional methods and argues that the best form of evaluation makes use of multiple visualisation techniques. Each article is introduced in further detail, along with a description of how I contributed to them. For a more detailed breakdown of my contribution, see figure 1.

Article eight: Water flows and water accumulations on bedrock as a structuring element of rock art

Horn, Christian; **Potter, Rich**; Peternell, Mark (2022c): Water Flows and Water Accumulations on Bedrock as a Structuring Element of Rock Art. In *Journal of Archaeological Method and Theory*. DOI: 10.1007/s10816-022-09578-2.

I contributed to this article by developing the direction of the project, programming the NetLogo[38] simulation, processing the outputs, and capturing and creating the SfM models that were used for the analysis. Additionally, I was also involved in the analysis of the results, and wrote sections of the article. **(overall contribution 45%)**

This important article sought to quantifiably investigate whether there was a causal link between rock art placement in panels and the way that water runs down and collects on the surface. This was achieved by creating an agent-based simulation in NetLogo that calculated waterflow based on several different parameters including rain density, and then output a heat-map of where water ran and collected. Five rock art panels in the Bohuslän area were analysed, and it was determined that water did appear to have an influence on the placement of motifs, specifically that boats tended to be placed within or next to water-flow, and human and animal motifs tended to avoid it.

The software used for this project was open-source, and the source code for the project was made available alongside the article. While no instructional videos were released, this is planned for the near future.

38. Netlogo Homepage: https://ccl.northwestern.edu/netlogo/ Accessed 09/08/2022.

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Water Flows and Water Accumulations on Bedrock as a Structuring Element of Rock Art

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Abstract
The paper proposes a new method to quantify the flow of water and water accumulation zones on bedrock panels. This can be used to investigate how water influences the placement of rock art. The analysis is based on photogrammetric models on which water flows and accumulations were modelled using a NetLogo simulation and the SAGA hydrology package. To test the hypothesis that water was a structuring element in the creation of rock art, case studies of Bohus-granite panels from south-western Sweden were used. The described approach should be possible to use on most rock art placed on bedrock panels regardless of rock type, its state of cleaning, or present microfauna. The modelling of water flows and accumulations is a powerful tool to compare the image placement and image density in relation to water even on widely separated panels on which such observations cannot be made directly.

Keywords Rock Art · Waterflow · Agent-Based Modelling · Topography · Hydrology · Scandinavia

Introduction

Rock art in southern Scandinavia is mostly applied by engravings which form a negative relief on the bedrock panels. This rock art is typically dated to the Nordic Bronze Age (ca. 1700–500 BC) and its figurative images mostly depict boats and warriors. It has been shown that this rock art was often closely associated to the ancient coastline and was often carved next to the water in bays and fjords.

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Numerous authors have commented on the close relationship between Nordic Bronze Age rock art and a maritime setting in which the depicted warriors were characterised as maritime warriors (Coles, 2008; Goldhahn, 2002; Ling, 2014; Nimura, 2015; Wrigglesworth, 2011). To modern visitors, this maritime character of the rock art may be lost, as after the ice masses melted at the end of the last Ice Age, the Scandinavian landmass rebounded and lifted upwards. This caused the coastline to recede further, and the former coastline—including the rock art, to be located further inland today. Recent work has highlighted that rock art also follows other water bodies such as rivers and lakes (Nimura et al. 2020).

It has variously been commented how water on the panels themselves may have been a structuring element for the placement of images. However, such work has been hampered by field observations dependent on certain events, like rainfall, the disparate placement of the carved surfaces in the landscape, their immovable nature, and other factors. This paper suggests a new methodology which introduces an accurate way of analysing the flow of water across the rock art panels in a systematic way. The approach opens for a comparative perspective on how rock art was positioned in relation to water, and it enables this comparison to be made. It is hoped that this will eventually lead to a better understanding of Scandinavian rock art and the influence of various waterbodies and maritime practices of Nordic Bronze Age societies. The proposed method is based on surface topography and gravitational forces. Therefore, it can also benefit the study of other rock art located on bedrock panels.

Previous Research

Early on, Carl Georg Brunius noticed that rock art was often found on panels which had water running down causing a black discoloration (Brunius, 1868; see also Malmer, 1989). Since then, several authors have commented on waterflows across rock art panels (Coles, 2008; Fredell, 2004; Hauptman Wahlgren, 1998). Tilley (2016) theorized that the rock carvings at Nämforsen could have been periodically submerged during flooding in the past. On the example of carvings in Vingen, Tilley showed how rock art panels were demarcated by flowing water, observing that the largest water puddle coincided with the largest concentration of rock art on the panel in Brattebakken (Tilley & Bennett, 2008). Lise Nordenborg Myhre (2004) provided the most in-depth analysis of the phenomenon observing water "overrun[ing] the images from springs above or sources from the interior of the rock" on several examples from Norway. She mostly analysed the relationship between such waters and images of boats, footprints, and abstract motifs, arguing that the water increased the dynamism of the scenes and hinted at (mystical) boat journeys (Bradley et al., 2002; Nordenborg Myhre, 2004). Earlier, Knut Helskog observed that melting snow, rain, and other water would enliven rock art, with bears being a central figure of a journey to the underworld where water collected on the panel (Helskog, 1999). Magnus Tangen (2018) observed natural features and the microtopography influencing rock art panels' placement. Similar discussions have also begun in other rock art regions, for example, in the context of alpine rock art (Fossati, 2015).

The aforementioned work mostly rests on qualitative observations based on photos or field observations of discolorations through microfauna or actual flowing water. The lack of a quantitative approach has variously been remarked upon (Goldhahn, 2008; Tangen, 2018). To accommodate such a study a new way of displaying rock art documentation has been suggested to show topography. The work conducted so far has often relied on impressive cases like Revheim (Bradley et al., 2002; Nordenborg Myhre, 2004), Bergbukten (Helskog, 1999), on relatively constant water flow through springs, or by splashing water on the panels (Goldhahn, 2002; Tilley, 2016; Tilley & Bennett, 2008). Although many panels indicate flowing water through discoloration, this cannot be taken for granted since while many panels, especially in tourist regions, are cleaned (Bottna 88:1), others are completely or mostly black from microfauna (Bottna 1:1) making it impossible to distinguish water accumulations. Lastly, the waterflow on panels in disparate locations cannot be compared directly, and researchers have had to rely on static notes and photographs. These issues impeded comparative and quantitative research on the relationship of rock art and water on the panels themselves.

The approach put forward in this paper is based on new 3D documentation, creative use of GIS, and Agent-Based Modelling seeking to investigate the flow and accumulation of water on rock art panels, independent of surface colour and current location. It takes the subtle topography of the panels into account which may not be immediately obvious to modern observers. The case studies used herein are all within the Bottna and Tanum communities, southwestern Sweden, and from rock panels of a homogenous monzogranite called Bohus granite (Fig. 1). The panels discussed below are identified by the number designated to them by the Swedish National Heritage board.

Material and Method

Bohus Granite

The majority of the carvings in the investigated area are engraved on relatively flat rock panels of Bohus granite (Fig. 1). The late Sveconorwegian (Grenvillian) granite intruded ~ 920–890 Ma in an extensional stress regime, and along a gently easterly dipping fault zone (Bingen et al., 2021; Eliasson et al., 2003). The intrusive body mainly consists of granitic and fewer intermediate to mafic rocks (Fig. 1). Most of the rock art can be found on the homogenous, medium grained phase of the monzogranitic granite, with quartz, k-feldspar, plagioclase, and biotite being the main mineral phases. The dominant granitic landscape in the investigated area represents a Sub-Mesozoic etchsurface with a pronounced structural control (Johansson et al., 2001). Ice movement overprint during the last glacial maximum (~ 22 ka; Kleman et al., 1997) led to glacial forms such as roches moutonnées, p-forms, crescentic gouges, crescentic fractures, and striae (Johansson et al., 2001; Ljungner, 1930). All the investigated sites are post glacial, flat, and mainly polished granitic surfaces, which were often used by the Bronze Age carvers for their artwork.

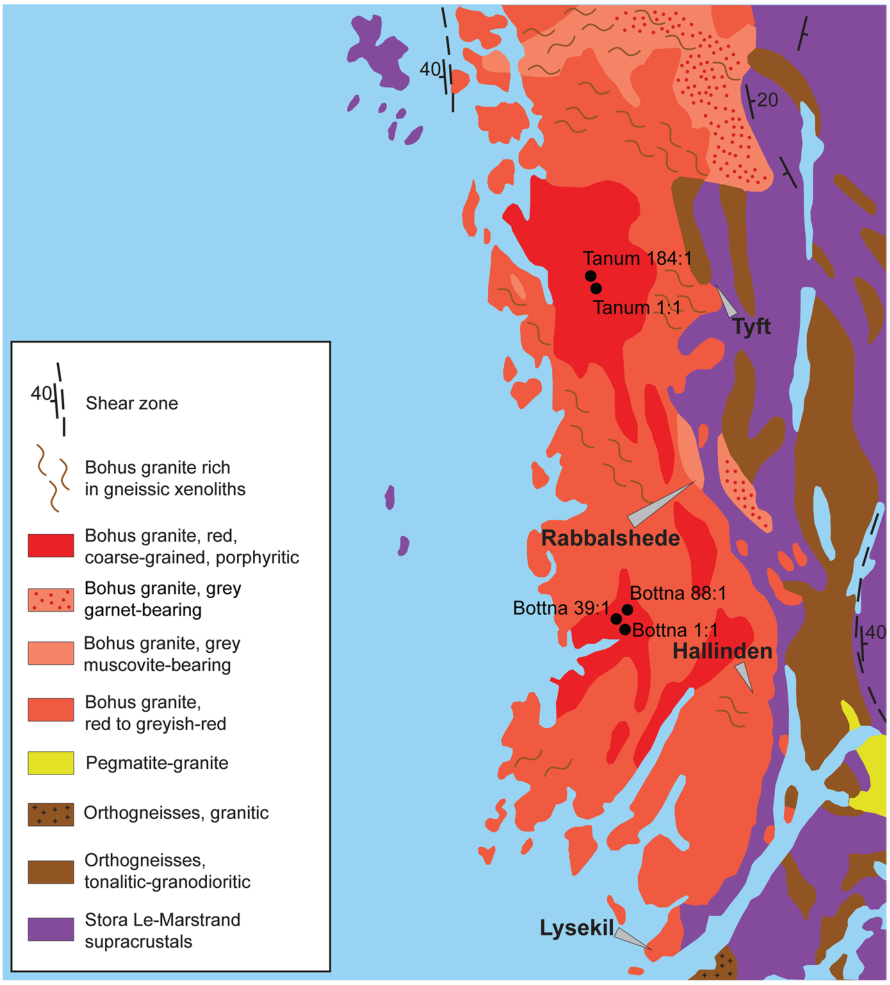

Fig. 1 Geological map of main rock types in Bohuslän with case study sites indicated

The Bohus granite is a mechanically strong rock (Åkesson et al., 2004), and the majority of near-surface weathering of the granite was removed during this last glacial overprint meaning that the recent surface topography has mainly been affected by Holocene weathering after the Late Weichselian deglaciation (c. 12 ka; Swantesson, 1992). However, Swantesson (1985; 1992) has shown that microweathering phenomena in southern and central Sweden during the Holocene have only changed the surface topography by a few centimetres and involves a complex interaction of several processes. He relates larger breakdown of the granitic structures to the geological history of the rocks. The surface topography of the rock panels in the Bohus granite, which were used by the Bronze Age carvers, has only changed by up to a centimetre, and even less where the polished, glacially derived surface is still preserved. Pre-glacial, tectonic fractures, and joints may have been widened and deepened since the carvers were active on the panels, but this mostly leads to a pronouncement of the overall segmentation of the panels and not to a general change in its topography.

Photogrammetry

For this research, three-dimensional models of rock art were produced using photogrammetry involving Structure from Motion with Agisoft Metashape©, which is capable of reconstructing highly precise 3D surface models (Micheletti et al., 2015). Before taking the photos, the surfaces were cleaned using a broom and moss patches were removed manually. Low growing lichens were left in place since they do not impede the flow of water and to reduce the risk of accidentally damaging the surface. The models were georeferenced by measuring coordinates in situ using a Leica Viva© GS15 GPS system to guarantee that the models had the correct orientation, and each point had the correct height relative to every other point, which was a requirement to model the actual water flow across the surface. From the 3D model, we calculated digital elevation models (DEM) that were used to create visualizations (see Horn et al., 2019) and to model the waterflow. Two of the case studies are panels from the Tanum world heritage area (1, 184) and the other three panels are located further to the South outside the protected area in Bottna parish (1, 39, 88; Fig. 1). All panels, except for Bottna 39, can be considered as large panels with over 50 figurative motifs each. The sample includes panels with dramatic (Tanum 184, Bottna 88; Sects. 3.3, 3.5) and more subtle topographies (Tanum 1:1, Bottna 39; Sect. 3.2). These panels were selected because they had a varied topography, differing numbers and types of motifs, and because they were representative of other panels. While it would have been ideal to be able to have collected areas of bare rock connected to panels to observe how water flowed onto them, this was unfortunately not possible as only the areas with visible rock art are uncovered; the areas outside of the panels are covered in vegetation, trees, and grass which we could not remove. As such this study relies on looking at the panels which all included some areas of uncarved rock surface across which water moved on to the engraved surfaces.

Agent-Based Modelling (ABM), SAGA Hydrology, and the Location of Rock Art

To calculate water flows and accumulations, NetLogo, the SAGA hydrology package, and ArcGIS were used. These packages also allowed us to compare the waterflow relationship to the motif distribution. The agent-based modelling (ABM) approach used herein complies with the theoretical-methodological framework for ABM (Wurzer et al., 2015), but it must be stressed that in this case it is not the actions of conscious actors (Banitz et al., 2015; Cortier et al., 2019; Jaxa-Rozen et al., 2019), but of a physical process.

After several iterations fine-tuning the ABM model, the DEMs were used in NetLogo to program actors (turtles) to react to parameters stored in patches, *i.e.* segments of the DEM below them (Fig. 2). For the following, it is important to

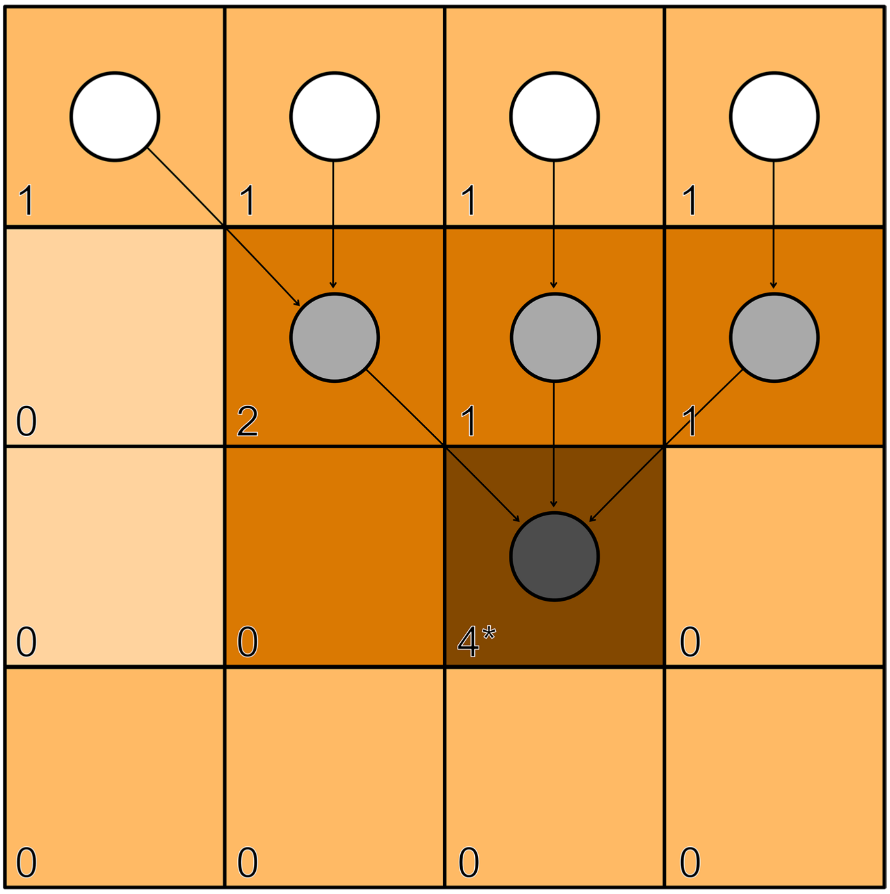

Fig. 2 Schematic representation of the ABM to visualize water flow and accumulations. Circle: turtle, darker colors subsequent step. Square: patch, darker colors lower down. Number: accumulated turtles in this patch. Star: lowest laying patch from which the turtles cannot escape any more, and thus, will be eliminated

note that while we speak of rainfall, this is a theoretical assumption that water could be deposited on the panel through rainfall. Another potential water source could be snowmelt. Furthermore, the turtles do not represent a single rain drop, rather they could be conceptualized as an amount of water sufficient to overcome the "light rain, micro topography" limitation, and to run from where it first touches the panel to where it will come to rest and eventually evaporate. There are few detailed regional studies on prehistoric precipitation in the Nordic sphere, but the data seems to indicate a fluctuating climate with long periods of increased rainfall with extreme rain events during the earliest part of the Bronze Age (Scholz, 2012). The time between the wetter climatic phases was not rain-free, and we can, therefore, assume that there was regularly enough water on the panels for it to run down and accumulate.

Turtles were placed on each patch that had a value, *i.e.* had a grayscale value that was neither black nor white (null values) simulating rainfall that would affect the entire panel. The turtles were instructed to move downhill one patch at the time based on the grayscale value in the same direction in order to limit the amount of turtles that became stuck in small chips or bumps on the surface. Once turtles had stopped moving or were massing in one area, the simulation was stopped. Every time a turtle moved across a patch, a variable called "value" was increased by one showing how often this patch was crossed at the end of the simulation. This was then visualized with a heatmap dividing the value by two to create a good colour spread. After cross-checking with photos of the panels taken following rainfall, we verified that the results indicated water accumulation zones very well.

The turtles were also instructed to draw multicolored lines indicating the direction of each step. Their accumulation shows in which direction water flows down the surface, highlighting channels. Eight colours were used, each representing a direction within a range of 45°. The ability to place turtles on the highest points of the panel (top 30% grayscale value), to spawn them along the outermost edges, and to draw them interactively on patches were added. With this, it was possible to investigate water flows seeping on the panel from the surrounding soil cover, during various precipitation events (with the possibility to increase and decrease the amount of rain that was calculated on the panel), and from specific points of interest.

To increase the resolution and as a control, we used the topographical wetness index in SAGA which visualises water flow and collection based on surface characteristics including slope and relative position. The output confirmed the results of the NetLogo model. While the SAGA outputs do not visualize flow directions or accumulations, they are a quantitative representation of the water flows across the panels. Saga also outputs an aspect visualization which indicates the compass direction the topography is facing with radiance further highlighting slope effects. This offers a better understanding of the topographic structure of the panels as it emphasises three-dimensional topographic features in a 2D visualization. Therefore, these images were included for all panels.

To complement the analysis of the relationship of rock art motifs and water, the most prevalent motifs were marked on the outputs and a kernel density estimate was calculated, discarding the lowest two values to show location of the highest concentrations on the panels. The outputs were then compared to investigate how water flow and accumulation matched up with the overall distribution of motifs.

Applicability to Other Rock Art Regions

Although the case studies focus on Scandinavian panels, this approach can be used on most rock art panels regardless of location or geology, since it models gravitational forces on surface topography, such as shape, gradients, and orientation. However, one exception is the combination of light rain and a high rock-surface roughness (highly irregular micro-topography), which impede weaker waterflows. The surfaces should not be entirely vertical or horizontal, because water would either fall straight down or would not flow. Although in the latter case, water accumulation, for example in puddles, may still be of interest. Thus, few regions and some materials may be excluded, like the painted vertical rock faces in Finland or the stelae in Iberia. From this discussion, we expect that the proposed method works best on bedrock outcrops with a gradient in regions at least with occasional rainfall or other sources of water running across the surface. Examples of this could be the bedrock panels in northwest Iberia, the Alps, or the Lake Onega seashores. The input data should be the same as for the Scandinavian examples which means a DEM derived from a georeferenced 3D model should be created for NetLogo and SAGA.

Surface Topography, Water, and Images—Case Studies

Bottna 1:1

The rock art panel Bottna 1 is relatively flat and extends at least 10 × 11 m. In the NW, it falls sharply towards a shallow valley which was filled with water during the Early Bronze Age. In the SE, a higher part of the panel is separated by a ridge running for ca. 9 m SW–NE and flattening out towards the NE (Fig. 3a). Some of the rock art in the northern part is partially covered by a large block of earth and vegetation which had to remain in place. The motifs surrounding this area were visible. Water accumulates around the area which probably forms a deeper puddle (Fig. 4a).

Water flows from the elevated part of the panel above the ridge, and curves down at its NE ending into a wide channel that crosses the entire panel along a SW-NE axis, roughly splitting the panel in half (Fig. 4a-c). This flow is the strongest into the channel (Fig. 4a, c) with the highest water accumulation (Fig. 4b). The channel runs from one edge of the bedrock panel to the other and through the vegetation spot that was not removed, emptying into the valley in the N. (Fig. 4a-b).

The panel contains 114 cupmarks, 69 boats, 21 humans, and 7 foot-soles (Fig. 3). Only one motif could tentatively be an animal, for that reason it was left out of the analysis. Generally, rock art accumulates in the waterflow areas in the large channel, especially at the confluence with the NE ending of the ridge and in the SE of the channel (Figs. 3a-b, 4–5). Another carved area lies between the puddle and the edge of the panel (Figs. 3a-b, 4–5). The only exception is a cluster of cupmarks at the western edge of the panel (Fig. 5b). The kernel density estimates for boats and cupmarks closely follows the curved flow at the confluence at the NE ending of the ridge (Fig. 5a). Boats are less densely distributed in the area at the northern edge of the puddle, while cupmarks and humans are stronger. Conversely to boats and cupmarks, humans are more densely distributed in the higher part above the ridge (Fig. 5c).

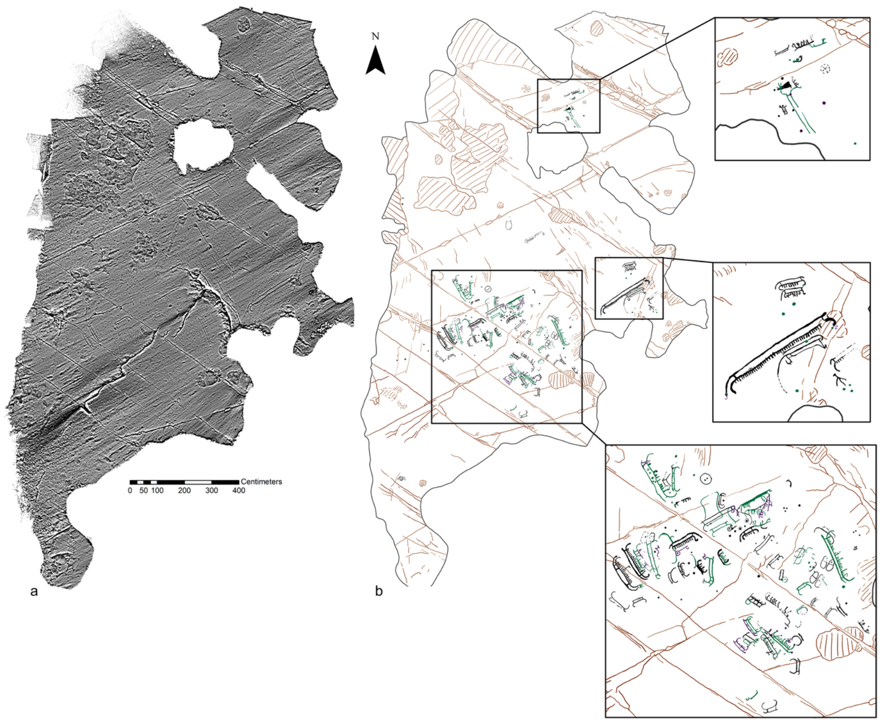

Fig. 3 Bottna 1: **a** DEM visualisation, **b** interpretation squares with enlarged sections of the panel

Bottna 39:1

Bottna 39 is a relatively small rock art panel at 8.5×3 m (Fig. 6a). Apart from cupmarks, there are very few motifs on this panel; as such, it was analysed without kernel density estimates. Overall, the panel slopes weakly with a noticeable downward incline at the western edge of the panel facing NW (Fig. 6a-b). Here water does not accumulate and runs off quickly (Fig. 7). A channel runs E-W in which water accumulates and clearly flows in a W direction widening slightly to the NW (Fig. 7a-c). This channel also widens at the centre of the panel and flows a short distance south (Fig. 7c-d). Rather than an extension, this could also be a second channel. In the NW, there are two weaker water accumulation channels (Fig. 7a, c).

There are 134 cupmarks on the panel, but only 4 footsoles, 2 or 3 boats, and 1 wagon (Fig. 6). Cupmarks seem to accumulate along the smaller channel in the eastern end of the panel. The cupmark distribution follows in and next to the channel where there is a weaker water accumulation area. However, the remaining cupmarks on the panel are generally in drier areas (Fig. 7b). The smaller boat is located in an area where water accumulates and begins to flow into the smaller channel. Its long axis is oriented horizontally along the downslope of the panel (Fig. 7b).

A very large boat (2.45 m long) is located right on the border where the panel falls towards the NW (Fig. 7b-d). Water flows strongly in this direction and the boat

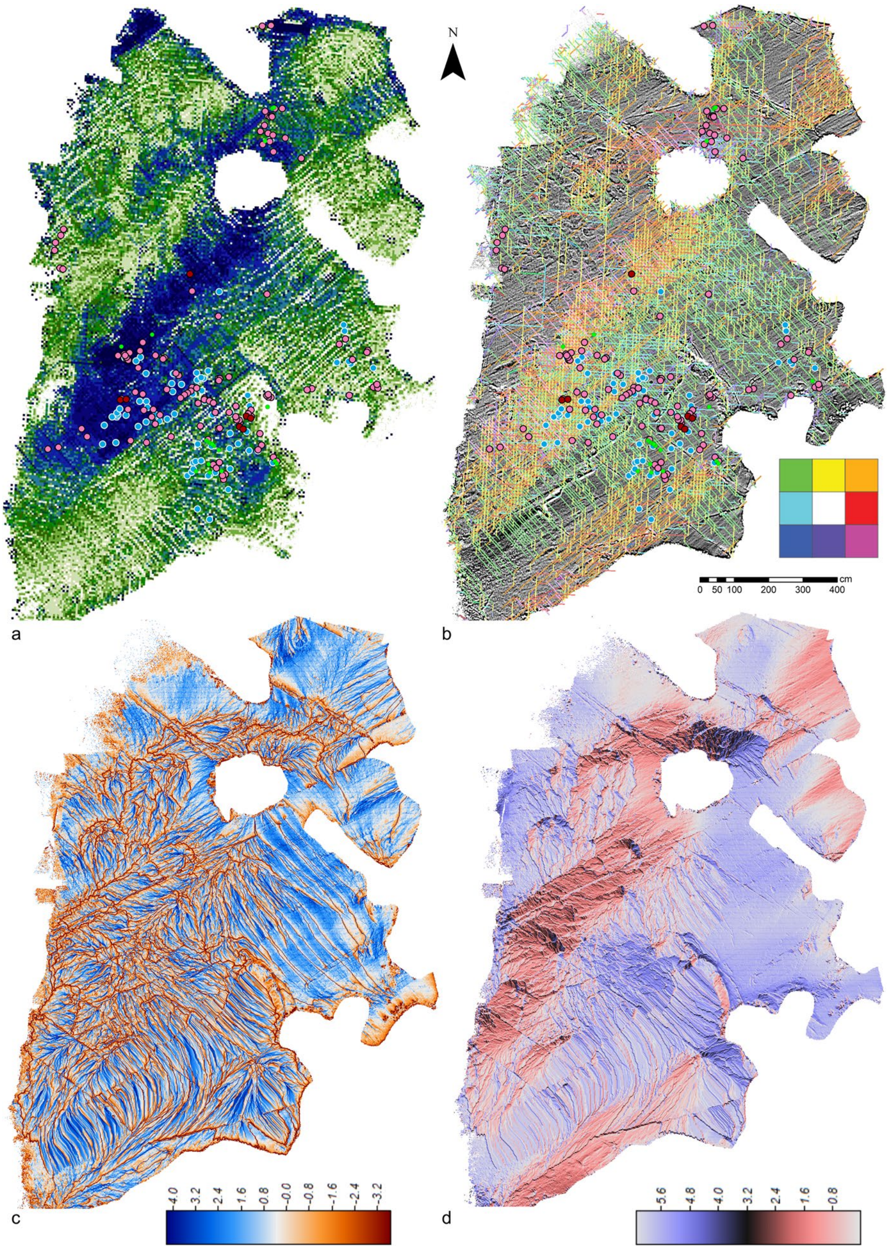

Fig. 4 Bottna 1: **a** water accumulation, **b** water flows, **c** topographical wetness index, **d** aspect

is oriented along the area where the flow originates with a NE-SW longitudinal axis (Fig. 7b). The southern prow of this boat, which was updated at least once (Milstreu, 2017), ends in the southern water accumulation channel. The prow in the N does not lie in a water accumulation, but the northern end of the boats hull is placed in the

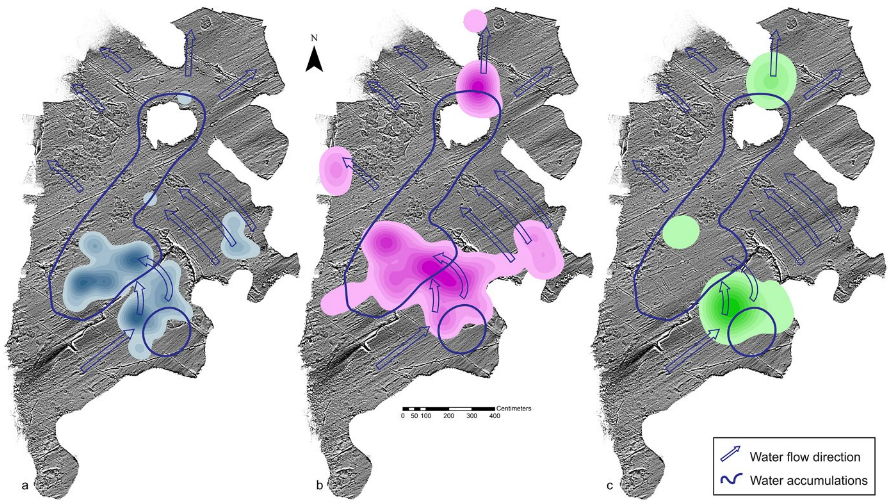

Fig. 5 Bottna 1 heatmaps: **a** boats, **b** cupmarks, and **c** humans

weaker water accumulation zone in the centre W of the panel (Fig. 7a-b). The large wagon and one footprint are carved next to the channel carrying water in a western direction. Both are aligned with the axis of this channel. The SW wheel lies within the water stream (Fig. 7b).

Bottna 88:1

The rock art on the Bottna 88 panel extends 8.4×4 m (Fig. 8). In the NW of the documented area, there is a water flow running down towards the S which is a stronger water accumulation zone (Fig. 9a-b). This stream meets roughly at the centre of the documented area with a stream flowing northwest (Fig. 9a-c). A prominent fracture runs through the panel (Figs. 8, 9d). One larger water accumulation zone is located below the fracture, a smaller one above (Fig. 9). There are further water accumulation zones below the puddle where the two flows meet. At the southern extent of the panel towards the east, there is an upwards sloping surface with a slight crest which bears no images. Water flows down across the entire surface toward N and SE depending on which side of the crest the turtles were placed.

There are 91 cupmarks, 33 boats, 18 humans, and 17 animals (Figs. 8, 10). The densest distribution of boats is within the central puddle which is the strongest water accumulation zone. Other boats are located on drier parts in the confluence zone at the centre of the rock art panel (Fig. 10a). Cupmarks accumulate south of the central puddle including the water flow. However, they seem to avoid the lowest parts of the panel where most water accumulates (Figs. 9ab, 10b). The densest distribution of human figures follows the NW flow closely in a S–SE direction (Fig. 10c). The largest and most obvious humans, which could be mythical figures with wings, are in a channel in which water

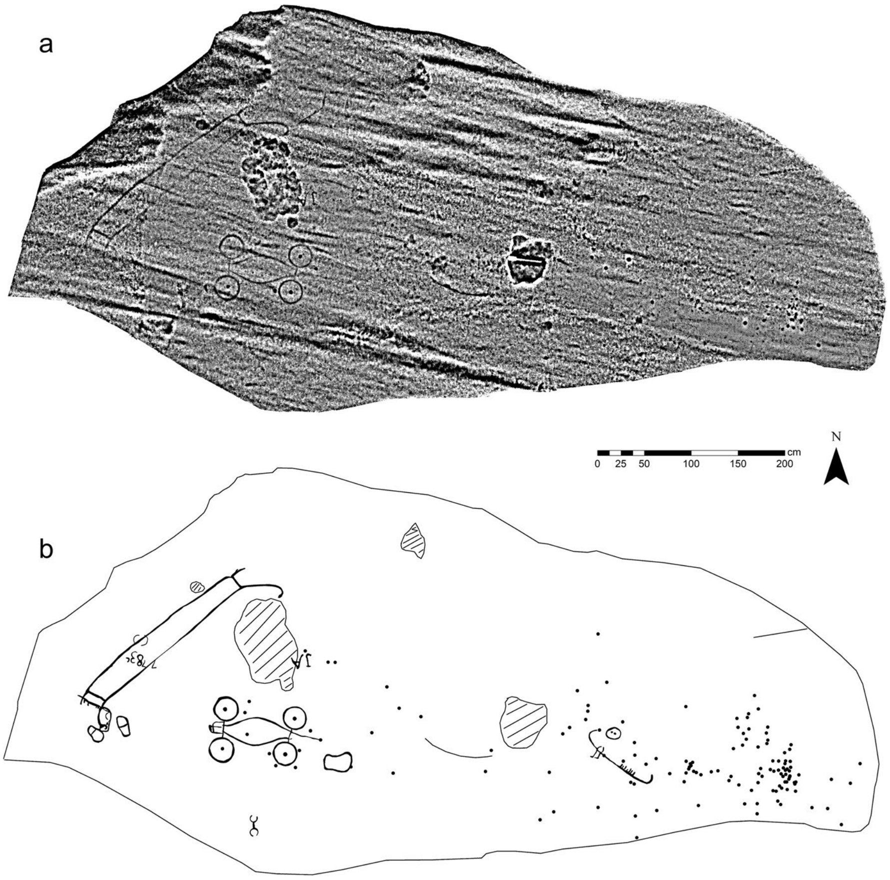

Fig. 6 Bottna 39: **a** DEM visualisation and **b** interpretation

accumulates (Figs. 8, 9a-b). However, other human figures are rather located next to the wettest part to the SE. They also reach lower into the water agglomeration zones than the cupmarks (Figs. 9a, 10c).

There is an interesting pattern for the animal figures on this panel. The densest area is in a relatively dry zone (Fig. 10d). This seems to be a herd or procession of animals that begins in the wettest area of the SE-E flow and is depicted as walking to the central puddle (Figs. 8, 9a). The front animals' heads end right in the puddle (Figs. 8, 9c-d). All animals except for a horseback rider are facing the lower puddle.

Tanum 1:1

The panel Tanum 1, also known as the Vitlycke panel, is the largest Bronze Age rock art panel currently known. It has an extent of ca. 21×6 m (Fig. 11). The panel itself is relatively steep with a shallow depression in its centre (Fig. 12d). This

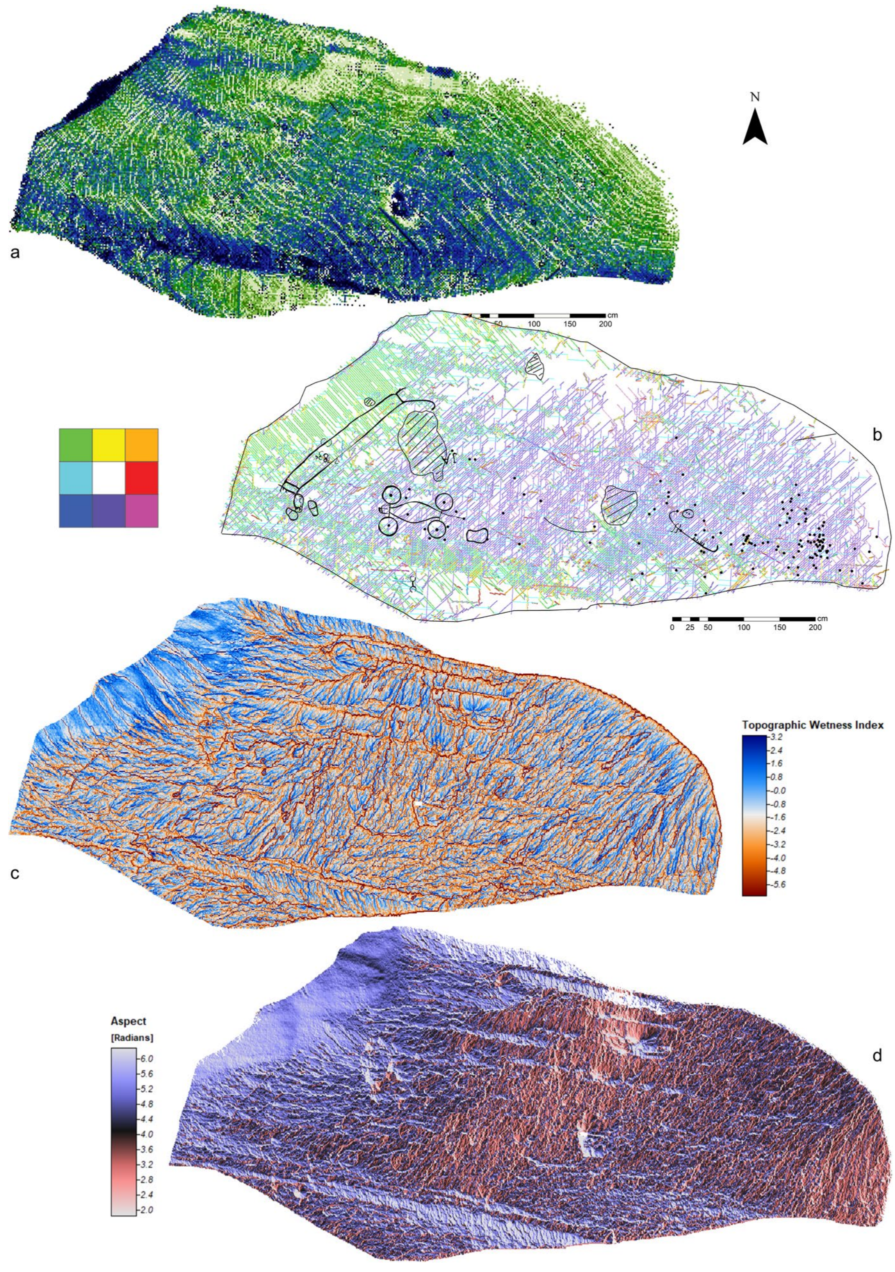

Fig. 7 Bottna 39: **a** water accumulation, **b** water flows, **c** topographical wetness index, **d** aspect

depression has two wider channels in which water accumulates (Fig. 12a). Water from the N runs in a SE direction and from the S in a NE direction into this depression (Fig. 12a-c).

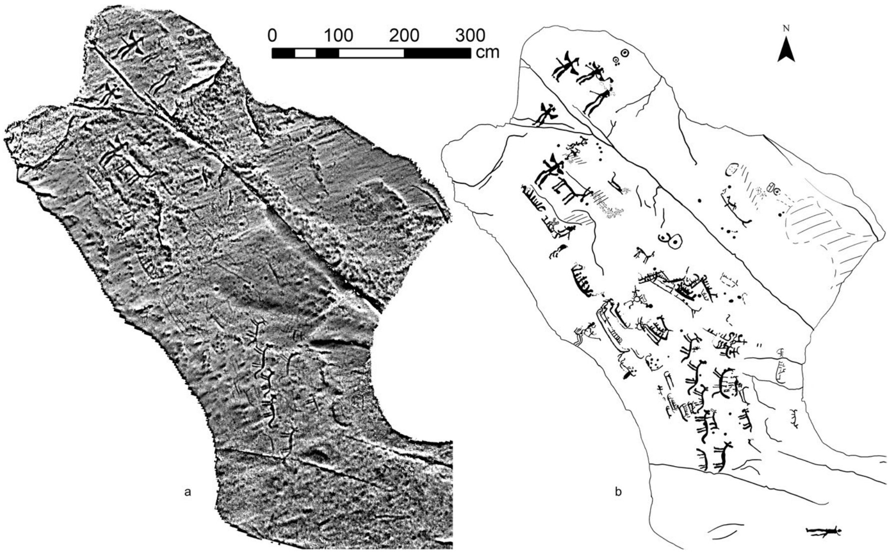

Fig. 8 Bottna 88: **a** DEM visualisation, **b** interpretation

The panel carries 281 cupmarks, 123 boats, 117 humans, and 52 animals. Overall, the highest densities of the rock art distribution on the panel correspond well with the two wide water accumulation channels (Figs. 11, 12a). Even the smaller hot-spots of all images are in zones where water streams accumulate (Figs. 12b-c, 13). The only exception is a procession of smaller human figures that seem to follow a comparatively large warrior located on a drier part of the panel (Figs. 11, 12a). The prominent vertical row of cupmarks on the panel was placed directly into the strongest water accumulation zone for the more northern of the two streams (Figs. 12a-b, 13b). There is another conspicuous row of cupmarks which is less obvious to the observer as it was reused as the heads of the crew of a very large boat (Horn, 2016). The row accurately mirrors the N-S extent of the more southern of the two water accumulation zones (Figs. 12a, 13b). The boat itself is over 3.5 m long and is oriented horizontally along the strongest water accumulation at the bottom of the wide depression. The densest distribution of boats also follows these wetter parts of the panel (Figs. 12a-b, 13a). Boats have a tendency to be lower down on the panel closer to the strongest water accumulation within the central depression, especially in the confluence of the two streams (Figs. 12a-b, 13a). Humans are on average higher up on the panel than boats, and while they are generally within water accumulation zones, they seem to avoid the wettest parts, being next to or between these (Figs. 12a-b, 13c). The densest animal distribution is linked to the more northern stream in which water accumulates. However, there is a second hotspot on a drier part higher up between the two large water accumulation zones (Figs. 12a-b, 13c).

Lastly, it should be noted that the kernel density estimates for boats, humans, and animals while being placed closely together, may occupy distinct zones (Fig. 13). Only higher up in the southern water accumulation zone, below a prominent crack

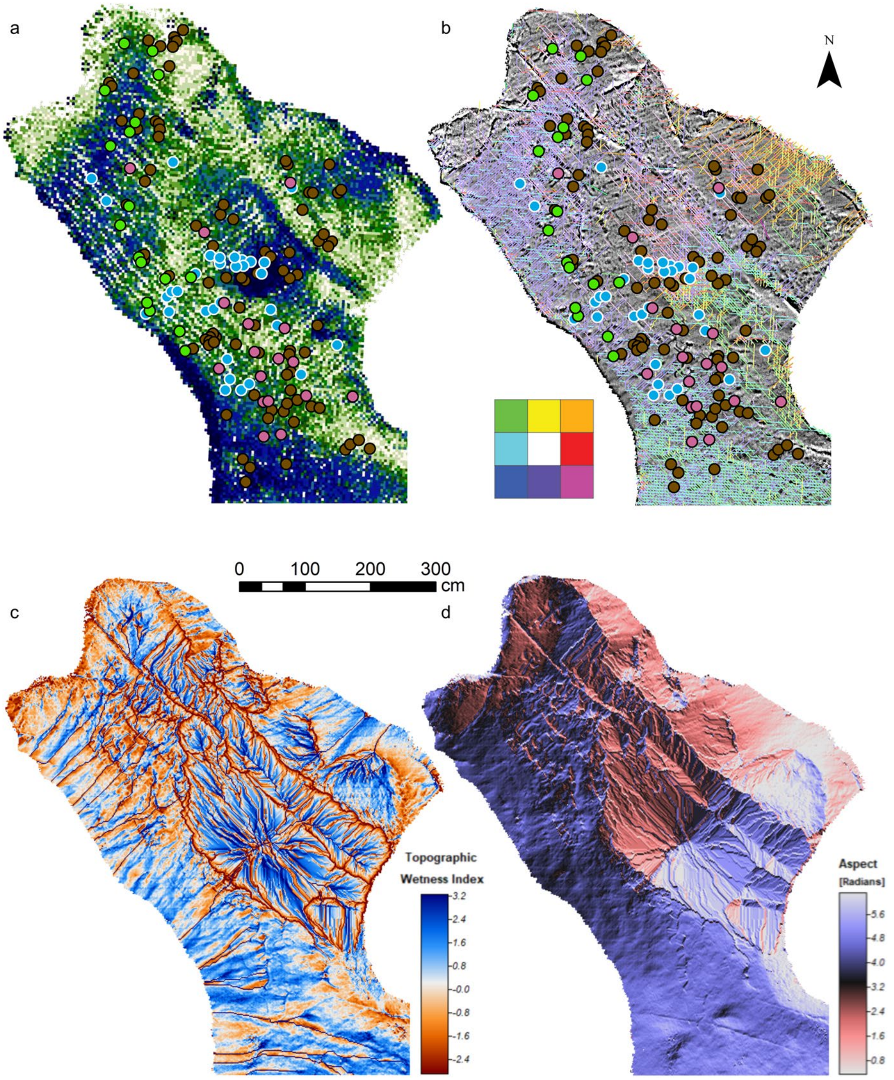

Fig. 9 Bottna 88: **a** water accumulation, **b** water flow, **c** topographical wetness index, **d** aspect

that propagates through most of the panel, do the higher densities of all three motifs overlap (Fig. 7e-f.

Tanum 184:1

At 45 m above sea level, Tanum 184 is one of the panels located higher up in the landscape. The rock art extends across a surface of roughly 4.8 × 3.9 m (Fig. 14). The bedrock has a flat part on top in which a puddle is located (Fig. 15). Below this the surface slopes down in a wide relatively steep area (Fig. 15d) where the

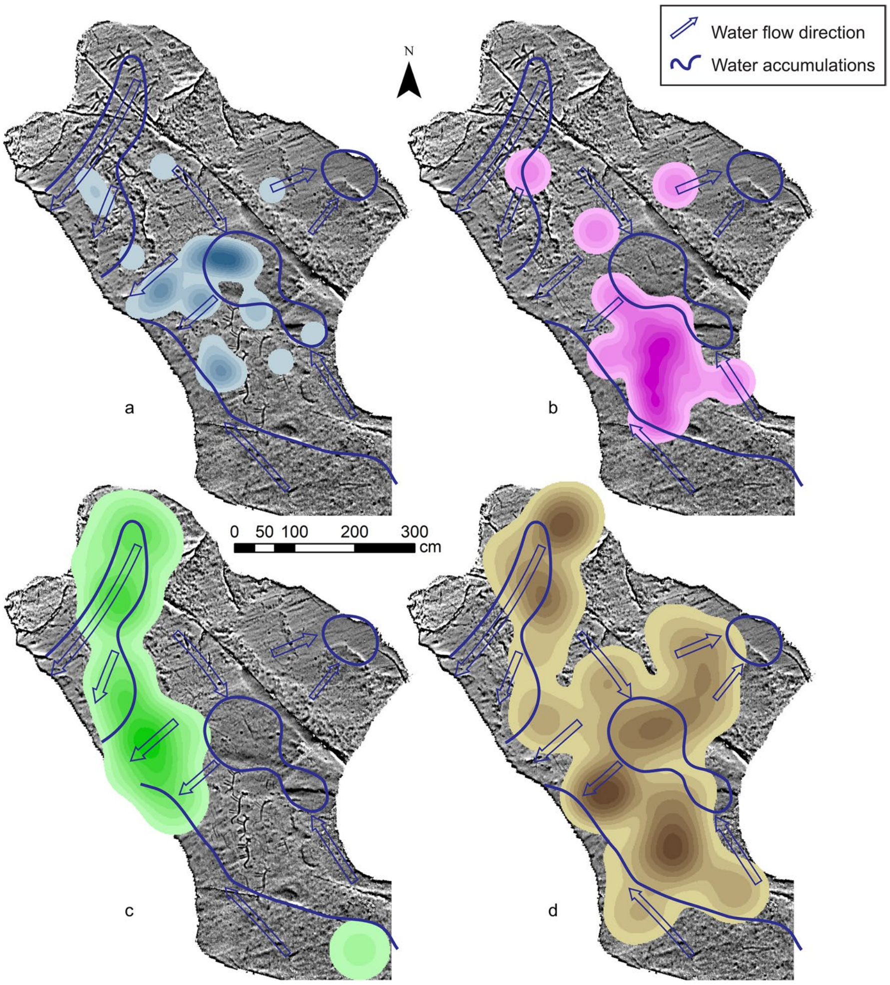

Fig. 10 Bottna 88 heatmaps: **a** boats, **b** boatscupmarks, **c** humans, and **d** animals

water flows SE in a ca. 2 m wide stretch (Fig. 15b, c). There is a gentle slope to the S and SE direction beyond which the water streams somewhat closer to a southern direction (Fig. 15b-d). The wide slope ends in a strong natural channel going from N-S. Adjacent to this in the E is a narrow flat part before the rock slopes down a small cliff (Figs. 14a, 15d). In the SE of the cliff area, there is a boat carved which has not yet been captured as the constant light moisture combined with the moss and lichen makes this part of the panel very slippery. The risk for injury was considered too high to stand and walk there to take images for photogrammetry. Instead, we compared our documentation to rubbings taken from that area and marked the boat in our model to include it in the calculation (Figs. 14, 15, 16a). Two cracks form an x shape across the entire panel

Fig. 11 Tanum 1: **a** DEM visualisation, **b** interpretation

propagating NW–SE and NE–SW respectively (Fig. 14a). How this additionally structures the rock art was discussed elsewhere (Horn & Wollentz, 2019).

On the panel there are 622 cupmarks, 16 humans, 12 boats, and seven animals (Fig. 14). Rock art is clearly most concentrated on the slope with the wide water flow (Fig. 15a, b). Boats are also densely distributed in the wide SE flow down the slope. However, their densest distribution extends across the channel at the bottom of the panel (Fig. 16a). Here two boats are located in opposition to each other on either side of the panel. They were applied to the rock in a way that they are right

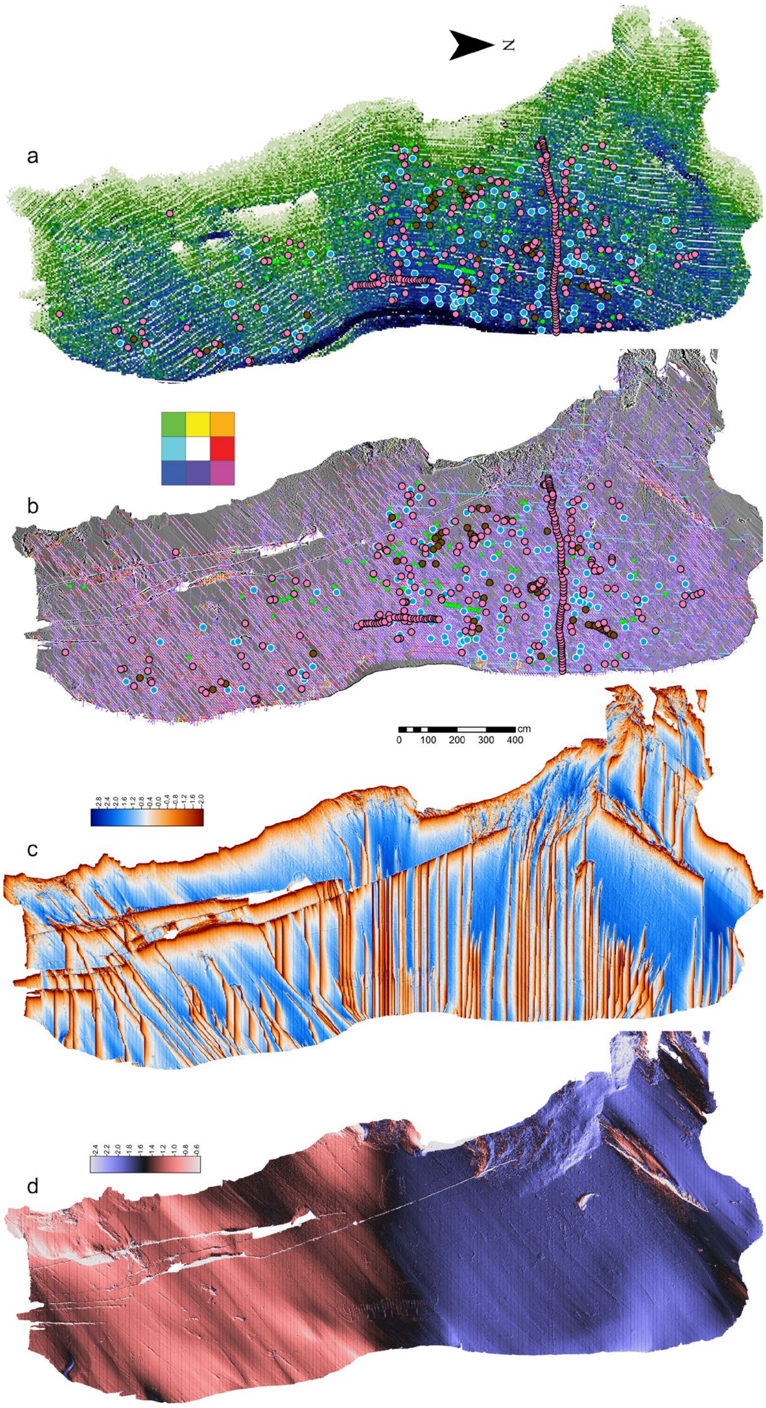

Fig. 12 Tanum 1: **a** water accumulation, **b** water flow, **c** topographical wetness index, **d** aspect

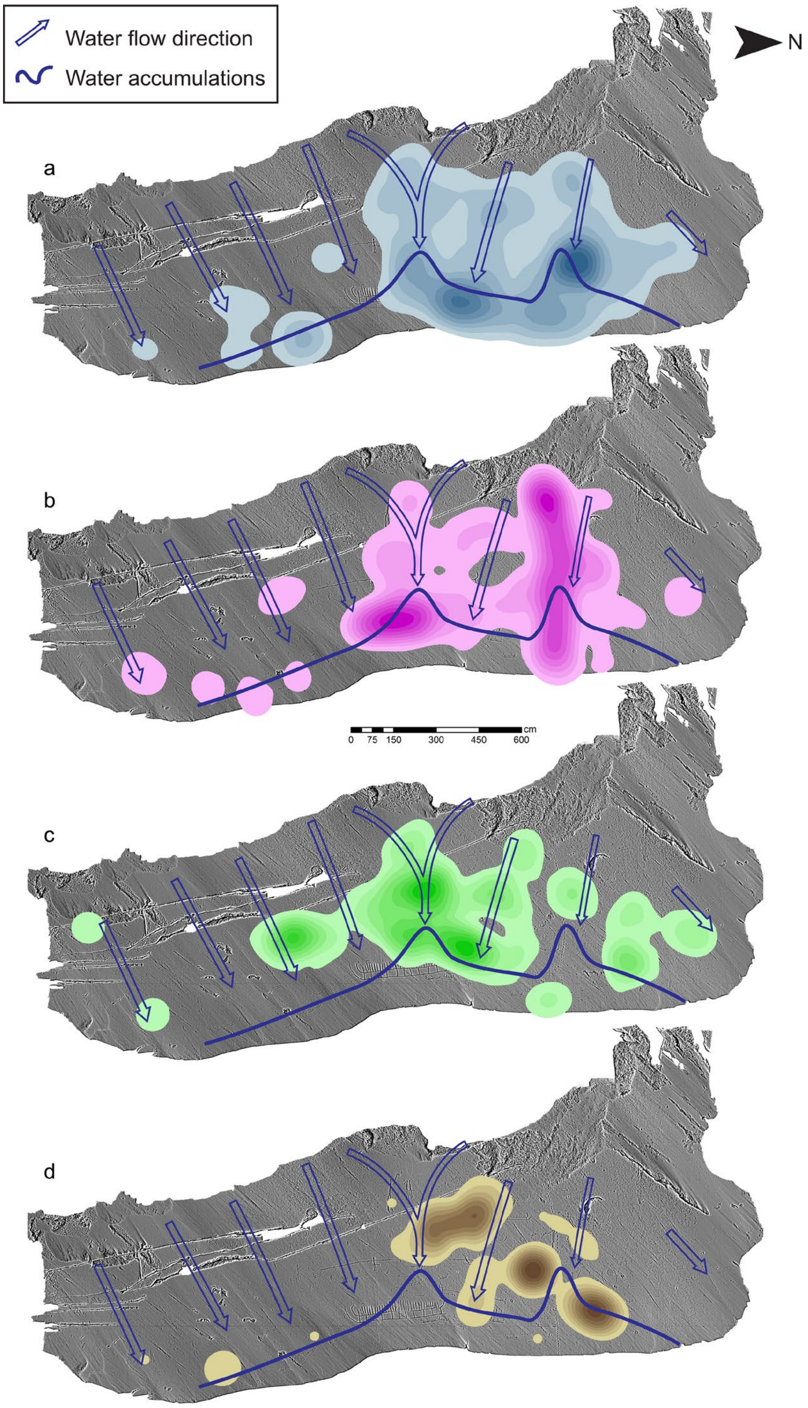

Fig. 13 Tanum 1 heatmaps: **a** boats, **b** cupmarks, **c** humans, and **d** animals

Fig. 14 Tanum 184: **a** DEM visualisation, **b** interpretation

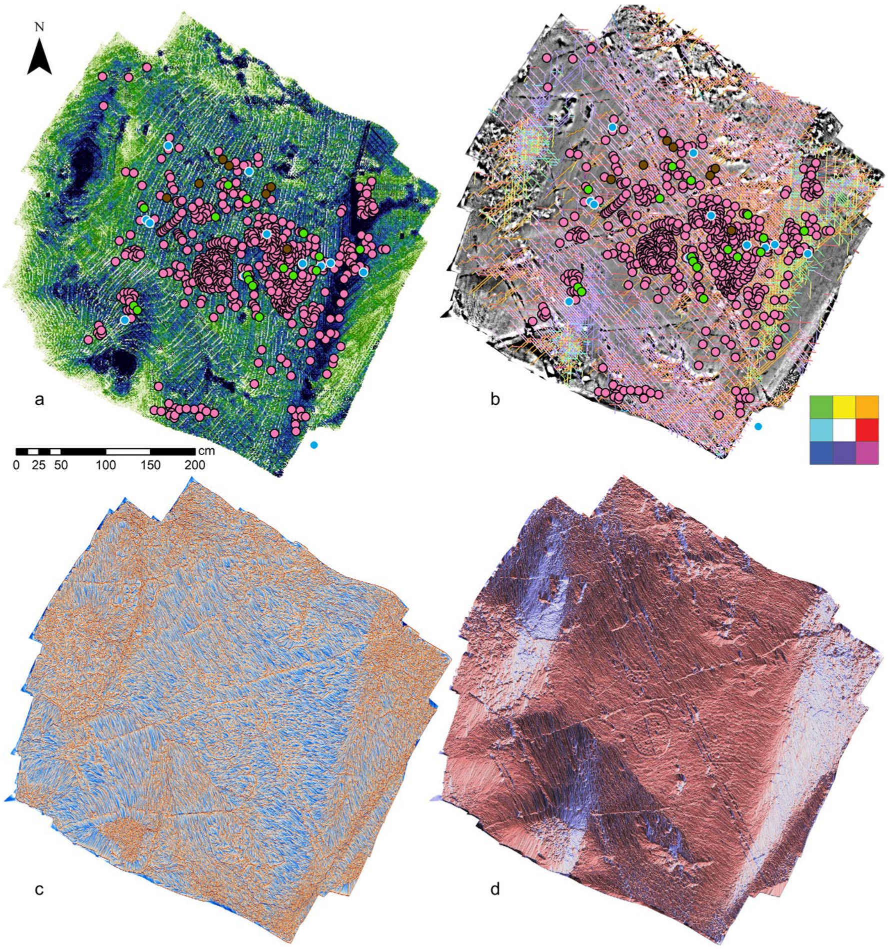

Fig. 15 Tanum 184: **a** water accumulation, **b** water flow, **c** topographical wetness index, **d** aspect

on the water's edge at different fill levels of the channel (Horn & Potter, 2020; Horn & Wollentz, 2019). The panel is dominated by the numerous cupmarks which concentrate in the wide flow down the slope and in the channel. However, cupmarks are also found on drier parts of the panel (Fig. 16b). The densest part of the kernel density estimate for humans mirrors the distribution of the boats, because they are the crews of the boats in this area (Fig. 16c). In the other areas, higher densities of humans and boats are in similar but distinct locations. Animals are not located in the channel area, but higher up on the panel in the wide water flow from the N (Fig. 16d).

On the panel, there is a large circle-cross that is filled with cupmarks in each quarter. In a sense, this resembles the overall structure of the panel with the large cross formed by the natural cracks. The circle and the deeper cupmarks seem to redirect some of the water at the edge of the central flow towards a general SE direction

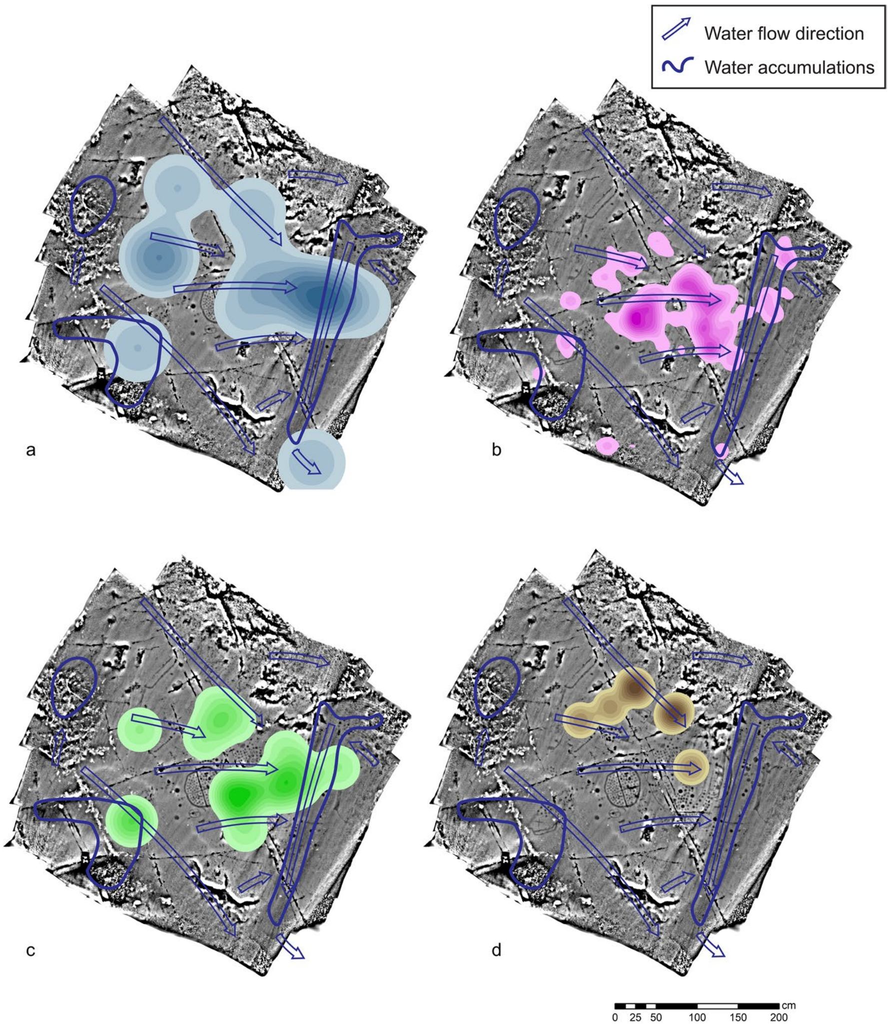

Fig. 16 Tanum 184 heatmaps: **a** boats, **b** cupmarks, **c** humans, and **d** animals

(Fig. 15b-c). Whether this is coincidence or whether rock art was perhaps deliberately placed to affect water flows across a panel is not the focus of this paper, but needs to be studied in the future.

Water as Structuring Element for Rock Art—Discussion

In all our case studies, there is a relationship between the placement of images on the rocks and water flows and accumulations on the rock art panels. This is based on quantitative and qualitative observations. Boats may be most directly associated with water as their densest distribution often follow streams directly like in Bottna 1, Tanum 1, and 184, or water accumulation zones like in Bottna 88 and Tanum 1. The longitudinal orientation of some boats either within these zones or next to them may also be determined by water flows. In Bottna 39, the axis of the large boat follows the length of the area where it drops off and causes a strong water flow. In Tanum 184, the lower two boats are clearly oriented along the channel. The largest boat in Tanum 1 rides on top of the strongest water accumulation. This association to water streams has been noted at various places in Norway, for example Revheim (Bradley et al., 2002; Nordenborg Myhre, 2004). A very specific parallel to Tanum 184 has been discovered in Valle Søndre (Norway) where at least seven boat carvings were placed either side of a natural channel through which water runs. Like in Tanum, the boats are oriented along the channel with their bottom facing the water (Tangen, 2018; other examples in Nordenborg Myhre, 2004). More qualitative observations that were made during fieldwork in Tanum can also be added.

We first noticed that the boats in Tanum 184 are placed precisely on top of the water flowing through the small channel after a period of rain (Fig. 17a). On Panels in Lövåsen (Tanum 321) and Litsleby (Tanum 75), several boats were also placed directly in the water flows (Fig. 17b-c). However, these two panels have not yet been documented in a way that quantitative analysis can be carried out.

Although humans are also often associated with water streams, for example in Tanum 1, they tend to be beside, but not in, the strongest water accumulation zones. In Bottna 1, for example, human figures were carved next to the puddle in the weaker water accumulation zone. Likewise, in Bottna 88:1, the most prominent human figures are in the northern stream flowing NE–SW. However, the densest distribution diverts SE following the waterflow and lies between the two strongest water accumulations. This could be the result of the association of human figures with boats when they have naturalistically articulated crews, because then the images are counted as humans and as boats (see Tanum 184). However, as the procession following the large warrior on Tanum 1 shows, humans also occupy areas that are dry and have no apparent position in relation to any water flow.

The interplay between animals and water on the panels is somewhat more difficult to assess. They are only present on four of the five panels, and on these, they are always the smallest class of motifs. From a qualitative viewpoint, Bottna 88 stands out since, much like in Tanum 184, the natural topography of the rock and water is used to tell a story. In this case, animals appear to walk from a stream to a pond. It is less clear on the other panels: on Tanum 1, there is a cluster of animals on a drier part, but it could be argued that they face both water streams to the left and right of them. The two other clusters on this panel are within the northern flow next to the cupmark line. Animals on Tanum 184 only have a generic relationship to the general broad central waterflow, and nothing more specific can be observed.

The wagon and foot soles on Bottna 39 are oriented along the waterflows. On Bottna 1, the situation appears to be similar, but here the densest distribution of foot soles is situated within the wide flow on the gentle downward slope. Despite their small number, this seems to suggest that placement of these motifs was also shaped by the presence of water flows and accumulations on the panels.

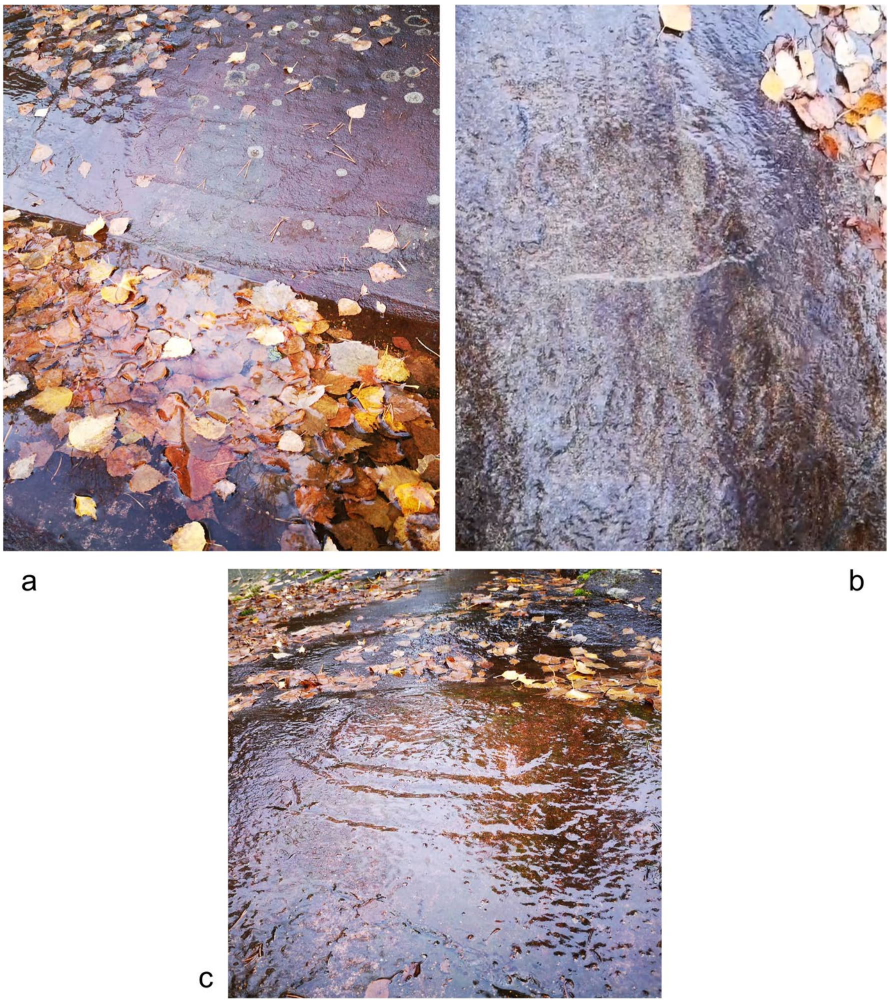

Fig. 17 Flowing water and accumulations after rainfalls in relationship to rock art boats: **a** Tanum 184, **b** Lövåsen, Tanum 321, **c** Litsleby, Tanum 75

Due to the generic nature of cupmarks, their position cannot easily be studied qualitatively in terms of orientation and directionality like for boats, animals, wagons, and foot soles. However, from the kernel density estimates, it is clear that they generally cluster in water flows and accumulation zones. Other than being merely placed in these streams, observations in Tanum 1, 184, and perhaps Bottna 39, suggest that in some instances their placement may be an attempt to actively influence the waterflow's direction or appearance. As previously mentioned, in Tanum 184, it appears that the cupmarks in and around the large circle cross may redirect some of the waterflow (see also Hauptman Wahlgren, 1998). Further down the panel, within the channel, the cupmarks may have been added to disturb the shallow waterflow.

This may have added motion and liveliness to the streams so that they appeared more life-like.

Water was, of course, not the only structuring feature on the panels—as has been noted previously. Other aspects like the physical closeness to water bodies, glacial lines, fractures, etc. also played important roles in the locations that were chosen to make rock art (see Nordenborg Myhre, 2004; Wrigglesworth, 2011).

Conclusion

In this article, we have explored the relationship between rock art, water flows and water accumulation zones in southern Scandinavia using case studies from Bohuslän, southwestern Sweden. Using agent-based modelling, we wanted to provide a quantitative means to study the flow and collection of water on bedrock panels using 3D models in order to enable a comparative investigation of panels that are cleaned, completely overgrown with microvegetation, or are in disparate locations. The case studies demonstrate this possibility.

Overall, carvers seem to have sought out waterflows and accumulations—even those which are more discrete, and thus, they appear to structure the placement of rock art. The results of the research presented in this article show that this is the case for both dramatic and more subtle sites. Furthermore, they indicate keen observational skills of the carvers, since features that mimic real-world water bodies, like puddles that could be lakes or water flows that could be rivers or fjords, where utilised to portray scenes that were probably observed in real life.

Together, the topography of the rocks, water flows, and accumulations formed a potent framework to support and empower Bronze Age narratives, rituals, and religious beliefs when carvers applied images to this canvas. Water was one of the structuring elements of rock art, it interplays with the other elements like perspective, position in the landscape, rock composition, other natural features, and the content of the linked narratives. Larger scale comparative analysis of these aspects may in the future bring us closer to an understanding of the content of Bronze Age narratives and the role carvers played in telling and shaping them. Future work should test and validate or falsify these findings for other Scandinavian and European rock art regions.

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Data Availability The models are part of the SHFA database and as such available under a creative commons license (CC BY-NC-ND 4.0). Since the models are too large to be shared online, it is necessary to request the models from the SHFA or directly from the authors.

The NetLogo code has been submitted with the supplementary material and will be made publicly available on the NetLogo website should the paper be accepted.

Declarations

Conflict of Interest The authors declare no competing interests.

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Article nine: An evaluation of Substance Painter and Mari as visualisation methods using the Piraeus Lion and its runic inscriptions as a case study

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I was the main author for this article. In addition to writing the majority of the article, I also created the SfM documentation of the Pireaus lion, and performed the analysis of the model. **(overall contribution 90%)**

This article presents Substance Painter and Mari as potential tools for bringing out carved details in full 3D surfaces using the Pireaus lion statue in Venice as a case study. In addition to introducing a novel workflow for creating curvature visualisations using Substance Painter and Mari, the results are critically evaluated alongside several other established methodologies, the processes of which are all described in a democratic and open fashion. The paper outlined detailed workflows for each method and showed that, while Mari was not ideal, Substance Painter presented a relatively easy and, although not free, cheap method of creating an interpretation. It also allows researchers to paint directly onto the model in a non-destructive fashion, which can be baked to a texture-map that can be turned off and on and easily be shared. Substance Painter makes it possible to use a lower-resolution model, with the higher-resolution data baked to the surface, meaning that lower end hardware can easily be used to analyse models.

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An evaluation of Substance Painter and Mari as visualisation methods using the Piraeus Lion and its runic inscriptions as a case study

Rich Potter[1*], Robin Rönnlund[2] and Jenny Wallensten[2]

Abstract

This paper explores the effectiveness in the use of texture painting software packages, which are more commonly used in the film and game industries, as a method for detecting and recording carvings on non-planar surfaces. This new approach is demonstrated through a case study of the Piraeus Lion, a sculpture in Venice which has documented engravings that are subtle and have proven difficult to fully recorded and interpret using traditional approaches. Through the creation of a new digital documentation of the Piraeus Lion using Structure from Motion, the model was processed using existing methods and other experimental visualisation techniques. The outputs from these were then compared to the those from two software, Substance Painter and Mari. These software packages helped to visualise the carvings and showed that the method has potential for a wide range of uses, both within epigraphy and other fields of study relating to carvings on stone including rock art and runology. The presented method is intended to be used alongside existing digital and analogue methods as a tool for annotating, evaluating, and discovering new carvings in their original context. In particular, Substance Painter offers a repeatable, easy to use, and intuitive solution to creating easily distributable visualisations and annotated models.

Keywords Carvings, Substance Painter, Rock art, Statue, 3D, SfM, Visualisation, Venice, Greece

Introduction

This paper presents the results of a new digital documentation of the Piraeus Lion, a fourth century BC marble statue presently located in Venice, Italy. The first documented location of the sculpture was in the port of Piraeus, Greece, where it formed a well-known landmark until it was taken as war booty in 1688 by the Venetian navy.[1] The sculpture, which is on display outside the entrance to the Arsenal complex, stands at around three metres tall and is sculptured in what may be Hymettian marble [1]. The sides of the statue are covered in Runic inscriptions of the eleventh century AD, probably made by Swedish mercenaries in Byzantine employ.

As well as implementing and testing two new methods of visualisation, this investigation aimed to examine and compare digital capture and imaging techniques previously utilised in rock art and epigraphy studies (introduced below) to see if they could be adapted and applied to this medium.

When assessing rock art, subjects are typically inscribed on relatively flat surfaces, which makes it possible to utilise a variety of methods to enhance the visibility of smaller details on the panels (see below). In the case of the Piraeus Lion, the sculpture has more than one side and an undulating non-planar surface, meaning that an alternative method was required to visualise the details of

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[1] The Sculpture is very likely to be a funerary monument, in which case the Piraeus location is not the original setting of the lion.

the inscriptions in their original context. This was desirable as it would not only aid the understanding of the full carvings and their placement on the statue, but also how they relate to each other. It is advantageous to be able to see the carvings as a whole prior to trimming to individual sections so that potential new carvings can be identified in areas that are not ordinarily examined. While additional delimited assessments of carved areas will also be included in the eventual interpretation of the carvings, this paper presents a method for visualising and evaluating the entire 3D surface with the carvings in their holistic context. By using the digital texture painting software *Substance Painter* and *Mari*—both of which are more commonly associated with the creation of 3D models for video games and film—we were able to make the smaller carved details on the statue visible in a more interactive[2] way than through traditional, non-digital techniques (for example, frottage or tracing). These approaches essentially allow complex, three-dimensional surfaces to be 'unwrapped' in order to extract key micro-topographical details which are then visualised using a variety of filters, and can even be non-destructively annotated. There are several existing methods for visualising fully three-dimensional models which will be introduced and compared here: they will be assessed in terms of results, ease of use, time taken to process, their potential to work with high-polygon models, practicality, and their possibility of creating lasting texture maps. Other software which can be used to enhance features, such as Adobe *Photoshop,* have limited 3D tools and will not be introduced here. In the case of *Photoshop*, the 3D elements it previously had have been superseded by those in *Substance Painter*, which is now also owned by Adobe. While other 3D software can be used to similar effect, there are often steep learning curves and prohibitive price tags that prevent their widespread use.

There are a number of methods for visualising stone carvings on 3D models, ranging from complex programmatic solutions [2–5] to simpler solutions using tools readily available to archaeologists [6–8]. However, a large portion of these methods can only be applied on essentially flat surfaces [2, 3, 9, 10], the plane of an object surface [11] or—in the case of Sapirstein [5], objects that can easily be flattened programmatically. Several methods, for example, morphological residual modelling (MRM)—a method in which a high-resolution model is compared against a smoothed low-resolution model—can be applied to 3D surfaces, but require trial and error to get a good result [12–16].

There are also other similar methods including *Xshade* [6, 17], and APSS [17, 18], as well as using simple tools like radiance scaling within *MeshLab* [6, 17, 19–22]. Another method that has recently been presented used ambient occlusion to find the areas where light would not fall from every angle [4].

Reflectance transformation imaging (RTI) could certainly be a useful tool here [23–27], particularly using vRTI from planes of the 3D mesh [28], but we were interested in finding a way to work with a visualisation of the entire mesh in 3D as we wanted to see the relative positioning of the carvings.

While complex solutions such as Sapirstein's [5] and Rolland's [4] are not undesirable, they often lack user-oriented interfaces and/or practical instructions adopted to non-programmers. The challenges addressed in this study relate to developing a workflow that suits models of non-planar surfaces on full 3D models, yet which can still be executed by non-specialists, with repeatable and shareable results.

The majority of these examples, excluding RTI and those that reduce the 3D form to 2D forms (e.g. LRM), retain the properties of the 3D model, i.e. scale, carving depth, etc. This is also true for the method presented here as it works from the original carvings. The exception to this is when it is used with a decimated low-resolution model as this relies on baked information (as will be discussed below).

It should be noted from the outset that this paper does not intend to dismiss other more traditional or existing digital methods. The strongest analysis of any surface is achieved by utilising the results of as many suitable methods as possible in tandem to create a complete assessment [29]. The aim of this paper is to add to the existing toolset by determining whether 3D asset texturing software is a viable method for highlighting carvings. The main focus of this paper is on the visualisation of carvings, with the purpose of seeing them in their original context, and in the discovery of new carvings. As this paper presents new methods, it is not advantageous to rank specific existing methods as it is impossible to be unbiased about one's own methodologies. Additionally, interpretation in these methods is highly subjective and the results can differ greatly depending on the medium it is applied to. As such, they are presented as alternative and additional methods that can also be used to help visualise carvings. This method does not represent the end point of an investigation into carvings on a surface, but more of a starting point in which carvings can be identified and annotated on the surface. While it is still

[2] Interactive in the sense that it is possible to zoom in, rotate, relight from different directions, and annotate non-destructively. This interactivity offers a greater sense of authenticity for researchers working with the model, and enables easier access, analysis, and make it easier to present ideas through annotation.

possible to measure carvings and depth on the 3D mesh, that is not the main intention of this method.

History of the sculpture and the attempts at reading its inscriptions

The history of the statue is well-documented [1] as being an ancient funerary-type monument (later reused as a fountainhead), sculptured and put up somewhere in the vicinity of the Athenian port of Piraeus, Greece, probably in the 360 s BC. At some point in the Classical period the lion was moved to central Piraeus and became such an important landmark at the harbour that Piraeus became known in the Middle Ages as *Porto Drako* ("Port Beast" in Greek) or *Porto Leone* ("Port Lion" in Italian). The statue was taken to Venice in March 1688 as a trophy after the 1687 Venetian victory over the Ottoman Turks at Piraeus and Athens, and was put up in its present location of display after some repairs in 1692. An 1890s plaster cast of the lion is exhibited in the National Museum of History in Stockholm, and a full-size marble copy was erected in the port of Piraeus in 2002.

In the final years of the eighteenth century, the Swedish diplomat and linguist Johan David Åkerblad noted that the lion was covered in three runic inscriptions, and the statue and its carvings have since been much debated by Scandinavian runologists [30–32]. The decorative nature of the carvings, including the spiral design and snakes head motif, display many similar characteristics to runestones found in the region of Uppland, Sweden. It is most probable that the inscriptions were made by Swedish mercenaries—so-called Varangians—in the employ of the Byzantine emperor in the eleventh century AD [1].

The main difficulties in interpreting the runic inscription have been the eroded state of the surfaces as well as the near-translucency of the marble. In spite of numerous reading suggestions [30, 33, 34] there is no consensus of the contents of the inscriptions. The most recent attempt by Snædal [1] combining older readings with her own substantial examinations, highlighted the damaged state of the inscriptions, with many eroded sections and musket holes from the 1687 fighting. Snædal's reconstruction of the texts show that the first and the third runic carvings were made by groups of Swedes commemorating fallen comrades, and that the smaller second carving was just a short graffito.

Recording the lion

The statue was recorded by creating a 3D model using Structure from Motion (SfM). SfM, a form of digital multi-stereo image photogrammetry, has been used extensively in archaeology and follows well established workflows [28]. The method as employed in this study used a structured set of photographs taken by the authors, extensively covering the surface of the statue. These were processed using *Agisoft Metashape*[3] to produce a 3D mesh.

In total, 1988 photographs were taken of the sculpture, collected first along vertical axes and then in concentric circles to ensure adequate coverage of all surfaces. Additional photographs of the top of the sculpture were taken on a ladder and with a monopod. The camera was a mirrorless Canon EOS R5 with a Canon RF 28–70 mm *f*/2L USM lens locked to 28 mm. This particular focal length (the shortest) was chosen to avoid accidental adjustment during recording which could impact the results.

The photographs were processed in *Agisoft Metashape*, using a standard workflow for full 3D models [6, 17, 26, 35, 36]. All backgrounds in the photographs were manually masked to achieve shorter processing times and a cleaner result. The dense point cloud confidence was calculated and all values below four (i.e. low quality points) were removed (Fig. 1).

The lion model was created in three separate iterations, a high-resolution model (88 million polygons), a medium-resolution model (22 million polygons) and a low-resolution model (200,000 polygons).[4]

Due to the difficulty of creating UV maps (2D coordinate representations of the 3D geometry which allow for textures to be applied in the correct position on a mesh) for high-resolution models, the workflow needed to allow for UV maps to be created directly within *Agisoft Metashape*. As such, textures were created within the software, automatically producing UV maps for all models. All of the meshes were then exported from *Agisoft Metashape* as.obj files.

Testing in Substance Painter and Mari

Mari and *Substance Painter* are two standalone software packages with similar functionality that allows users to create textures for 3D models. Both software utilise the geometry of input 3D meshes to determine the placement of textures that can relate to rust, dirt, grime, etc. in a realistic fashion based directly on the characteristics of the mesh. These characteristics are determined by calculating texture maps (as described below), traditionally using a higher-resolution (more detailed) mesh to "bake"

[3] https://www.agisoft.com/ (accessed 12.07.2023) While it is acknowledged that other photogrammetric solutions exist, this is the software that the authors are most experienced with.

[4] The average edge length was also calculated for each of the models where larger values indicate lower resolution. High: 0.004237, Medium: 0.007814, Low: 0.058071.

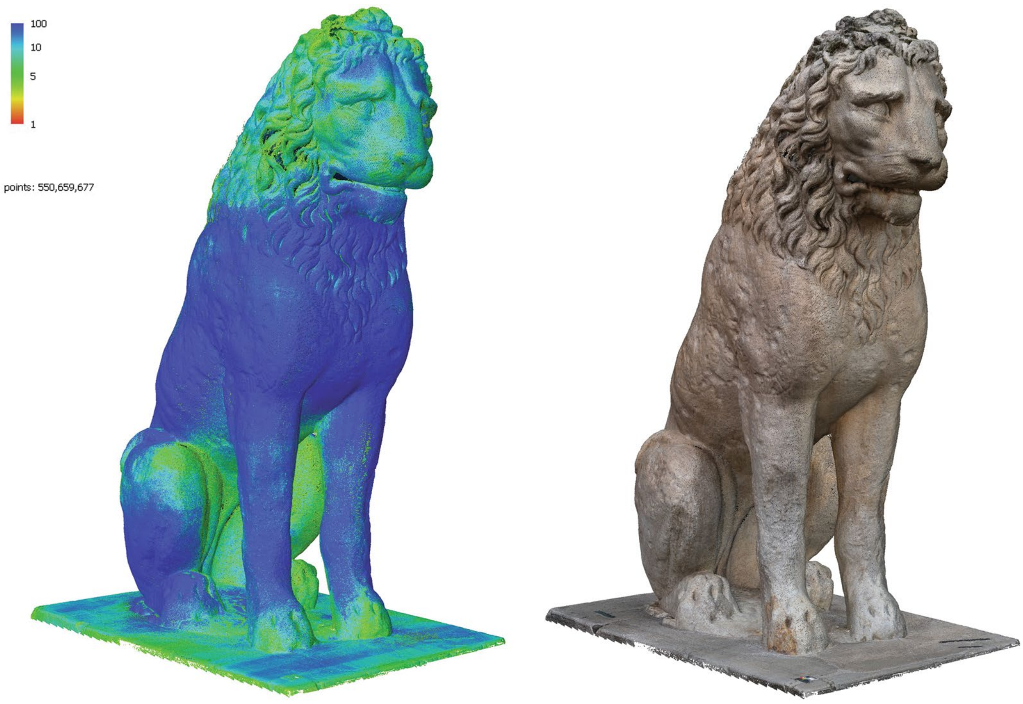

Fig. 1 The cleaned dense point cloud in Agisoft Metashape, with the scaled point cloud confidence on the left

details into the texture maps that are not present on a lower-resolution version of the same mesh. This reduces final polygon counts and makes the mesh more hardware efficient for animation and games. Both software can make use of the curvature of a mesh to dynamically place colour, i.e. where the model has either convex or concave features, which made it possible to utilise this software for visualising carvings on 3D surfaces.

The high-resolution model was tested in both *Substance Painter* and *Mari* as the base for the curvature map to observe whether there was a noticeable difference between that and the medium-resolution mesh (2 GB). However, it was determined that although possible, the size of the high-resolution mesh (5 GB) was too large to run sufficiently smoothly for any analysis to take place in *Substance Painter*, and the difference in detail level between the two resolutions was determined to be negligible. Additional tests were made in *Substance Painter* using the medium-resolution model, and the low-resolution model with the high-resolution model baked down to it.

The low-resolution workflow involved bringing the UV-mapped[5] low-resolution polygon model of the sculpture into *Substance Painter* and baking (read: rendering) the normals (Fig. 2),[6] height, curvature, and ambient occlusion from the detail of the high-resolution model down to 2D maps, which would then be projected onto the lower-resolution model. These maps were then used to drive filters within *Substance Painter* (See Fig. 2 for overview of method). While this still makes use of the high-resolution model, it is only used for a short period of time while the maps are baked. Following this, the light-weight low-resolution model is used (~ 20 MB), with the detail of the high-resolution model projected onto it, meaning that it can be used on less powerful computers. While this transition from 3 to 2D removes 3D data including depth [37], the baked maps retain enough surface detail to create an accurate visualisation of the small details, while also reducing file size and demand on hardware (Fig. 3). When only using a higher resolution mesh, the maps are baked from the mesh to itself.

[5] UV mapping, or unwrapping, is the practice of separating a 3D surface into segments which can be represented in a 2D space. The 2D space is cartesian in nature and named after its axes U and V, which replace the usual X and Y to differentiate between 2 and 3D space. When a texture map is created in Agisoft Metashape, it automatically unwraps the model creating a UV map. The texture is then placed on the 2D surface and is matched by the UV coordinates into its correct position on the 3D mesh. This means that any additional marks or annotations that are added to the 2D texture file are added to the appropriate position on the mesh.

[6] A 2D representation of the direction of each polygon which can be used to add higher perceived detail to a model without increasing the polygon count. This image, or map rather, can be used by the software to calculate where colour should be applied to surfaces based on direction, small details, convex/concave areas, etc.

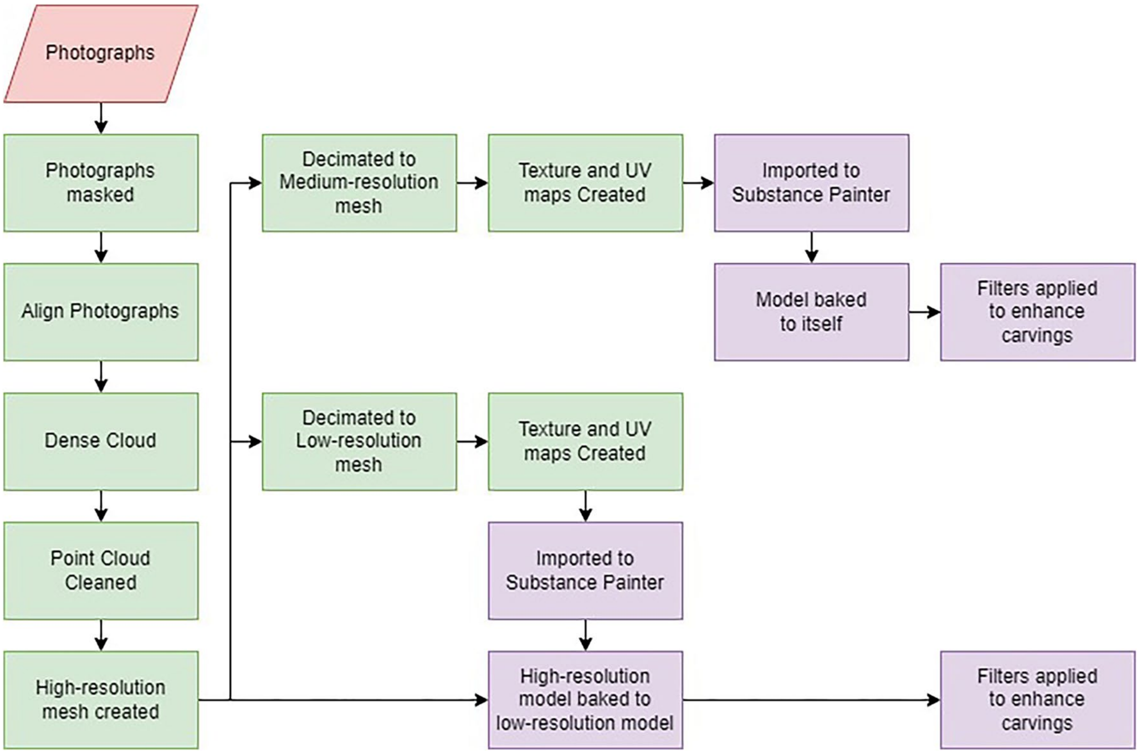

Fig. 2 Flowchart showing the process of the two baking methods in Substance Painter

The curvature map was primarily used for the methods described here. This map determines where curvature deviations, i.e. convex and concave features, are present on the model surface, based on the normal map. A detailed description of the methodology and the results are given after a comparison of methods.

Comparison of methods

In order to determine the usefulness of the proposed methods, they must be compared to other existing and known visualisation techniques. In the interest of openness and the democratization of methodologies, a brief overview of how the processes were carried out—from start to finish—will be given below. There are two areas of the lion which have been focused on by research, represented by two different sets of carvings on either side of the lion. Both of these areas will be presented below for each method.

The results of these tests are to be used as a baseline for which the viability of *Substance Painter* and *Mari* as visualisation tools can be assessed. For each method the same computer hardware was used (Intel 13900 k, Nvidia RTX 4080) to evaluate how long each method took. Where possible, the high-resolution model was used, but the medium-resolution model was chosen when it was more sensible due to lengthy processing/testing times or difficulty working with the model. Many of the methods described below are similar techniques utilized in different ways, and primarily work with a high-resolution model being compared to a smoothed and decimated version of itself.

Radiance scaling

The mesh was examined in the *MeshLab*[7] software using the common practice of relighting the model and using radiance scaling to enhance the curvature [6, 17, 19–21]. This works in a similar way to shadow and relief marks in aerial photography and raking light photography in rock art, where the low angle of the light highlights subtle features, with the added functionality of being able to interactively move the light. This workflow made use of the high-resolution model (Fig. 4).

Radiance scaling in *MeshLab* is activated under the render menu, then shaders, and radiance scaling. It is then operated using a simple slider bar to adjust the intensity of the effect. A large portion of the carvings were visible on the model, but the radiance scaling value maxes out too low, and would have produced a better result if more contrast could be added. Lambertian radiance scaling

[7] https://www.meshlab.net/ accessed 12.07.2023.

Fig. 3 Illustration of the outcomes of baking the textures

worked best here with grey descriptor a close second. To improve visibility, colour textures should be turned off [38].

Local Relief Modelling (LRM)

A segment of the model was exported from *Agisoft Metashape* as a DEM (Digital Elevation Model) and processed using the Local Relief Modelling (LRM) method [39], previously described in its application of rock art by Horn et al. [7] and similarly, though under a different name, by Trinks et al. [40]. In essence, a DEM is produced, exported to a GIS software where it is smoothed (Focal statistics in *ArcGIS*, r.neighbors in *QGIS*) and then the result is subtracted from the original DEM (Minus in *ArcGIS*, Raster Math in *QGIS*). This can also be achieved by simply using the local relief tool in the *Grass* addon in *QGIS*.[8] Although this method does not work with full 3D models, this segment was used as a base point to confirm that the results that were produced in the other methodologies presented here were comparable to other established methods (Fig. 5). This process is also possible to achieve in standalone software such as the LiDAR

[8] https://grass.osgeo.org/grass82/manuals/addons/r.local.relief.html accessed 12.07.2023.

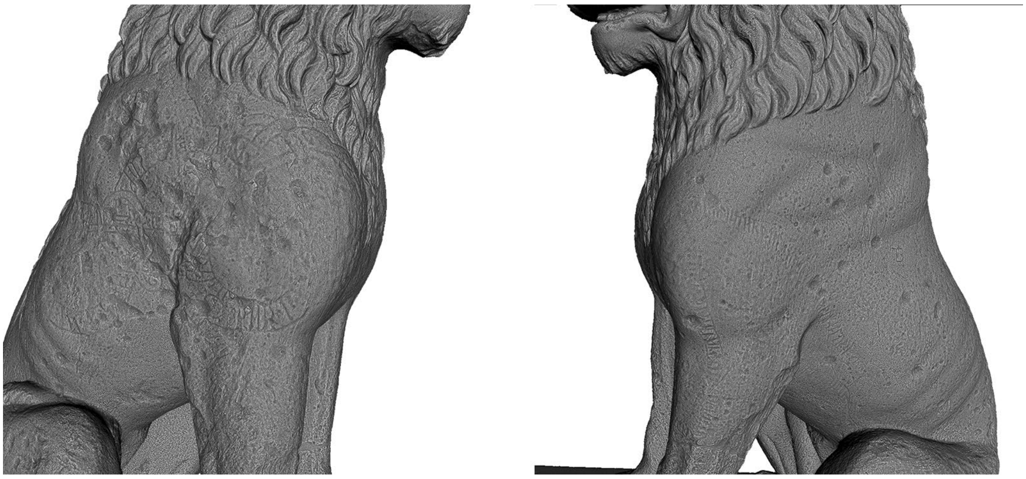

Fig. 4 Lambertian radiance scaling in MeshLab with enhancement set to 1.0 showing the two carved areas of interest on the high-resolution model

Visualization Toolbox[9] and the Topography Visualisation Toolbox.[10]

While the results are a good representation of the carvings, they suffer from the non-planar nature of the object. Since the surface features significant curves the distribution of the scale of shading in the carved areas is minimal, as the height difference between the carved and uncarved surfaces is low.

Agisoft metashape displacement mapping

Agisoft Metashape 2.0 allows for the creation of displacement maps that are UV mapped to the object. A displacement map is created by comparing a high-resolution model to a smoothed low-resolution model and determining where differences in height exist. This then creates a greyscale colour map showing height (Fig. 6).

This was tested using various resolutions, the best results coming from the medium-resolution polygon model, decimated to 50,000 polygons, smoothed three times, and then a displacement map baked to a single 16,834 by 16,834 pixel map within *Agisoft Metashape*. This was then run through the LRM process as described above. Unfortunately, while from a distance it produced good results, zoomed in the results were quite poor. It may be that there are better variables available (i.e. percentage to decimate to), but as yet the documentation gives no indication as to what they are.

Morphological Residue Modelling (MRM)

Morphological Residue Modelling (MRM) is a method in which the model is decimated, smoothed,[11] and then compared using the distance from reference mesh filter in *MeshLab* [13–16]. The smoothed and decimated model removes the smaller carvings creating something akin to an averaged mesh. When this is compared to the original mesh the areas that are carved are now in a different position and are thereby highlighted by the filter.

In this test the high-resolution mesh was decimated (simplification: quadric edge collapse decimation) to around 10% of the original polygon count (nine million polygons), then smoothed using Laplacian smooth with 30 steps. The models were then passed through the distance from reference mesh filter with the default distance value (Hausdorff distance can also be used with similar results [17]. The low-resolution model was used as the measured mesh, with the high-resolution mesh as the reference mesh. Once the process had completed the quality mapper was opened and the histogram altered as required (Fig. 7).

The carvings were highlighted quite strongly, but the shallower carvings suffered somewhat. It was also possible to present the results in a variety of colour schemes, should accessibility issues arise.

Algebraic Point Set Surfaces (APSS)

Algebraic Point Set Surfaces (APSS) rely on smoothing a copy of the mesh, and then mathematically comparing

9 LiVT website: http://www.arcland.eu/outreach/software-tools/1806-lidar-visualisation-toolbox-livt accessed 12.07.2023.

10 Topography Visualisation Toolbox website: https://tvt.dh.gu.se/ accessed 12.07.2023.

11 Smoothing refers to the removal of sharper edges by a variety of techniques including the averaging of normals. This often reduces the size of the dimensions of the model slightly, which allows differences to be highlighted between smoothed and unsmoothed models.

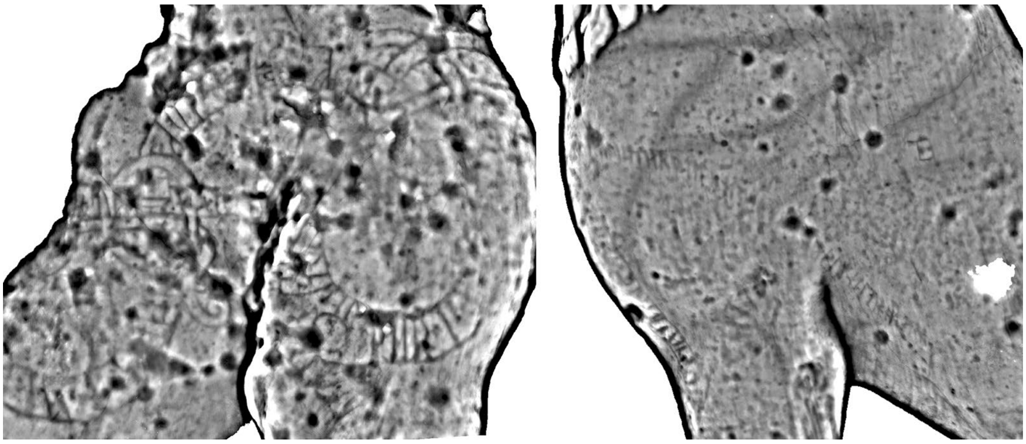

Fig. 5 Example of the carved areas demonstrated by using LRM

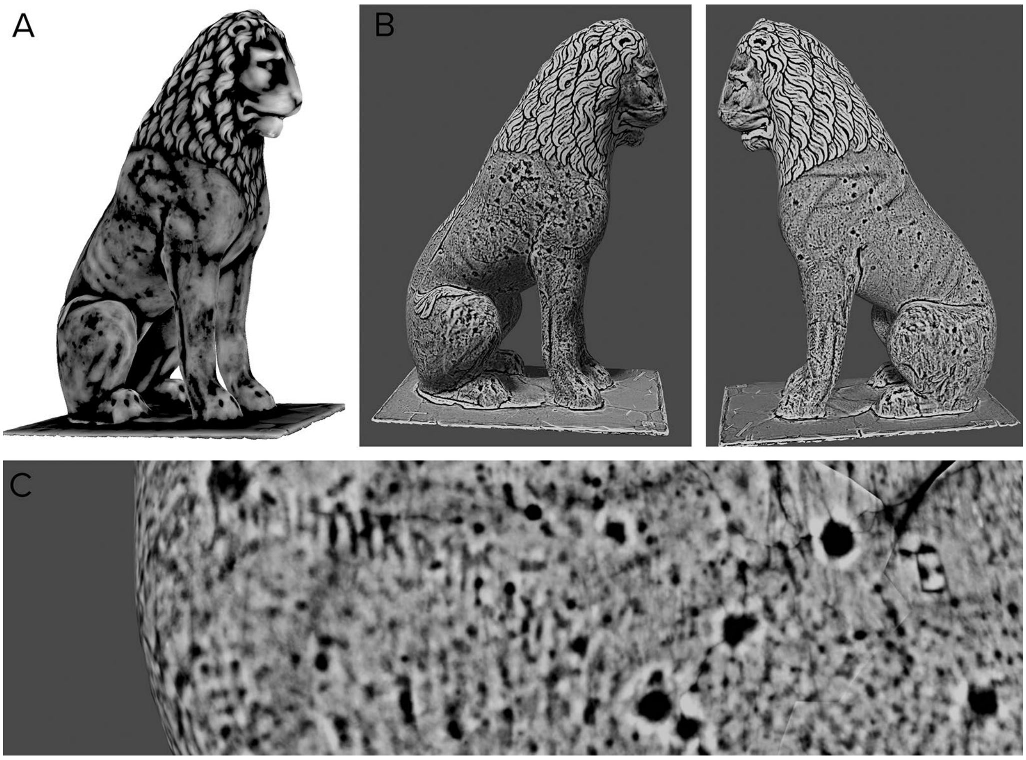

Fig. 6 **A** The raw displacement map shown on the model in Agisoft. **B** The LRM processed displacement map presented in Blender. **C** A close up of the carving showing that, while still largely readable, detail is lacking

the original model versus the smoothed model using a "floating sphere" [41, 42]. The size and accuracy of the sphere can be modified to vary the result. APSS visualisations are created in *MeshLab* using filters, colour creation and processing, and then colourize curvature (APSS). The colour histogram is then amended in the quality mapper until the carved areas are highlighted appropriately [17].

For this test, the medium-resolution model was used, as the processing of the high-resolution model took over 24 h to process, and the histogram became unresponsive due to the file-size. Using the default settings (although a number of other less successful tests were also undertaken) the carvings became fairly visible, with the advantage that it was possible, as with MRM, to adjust the

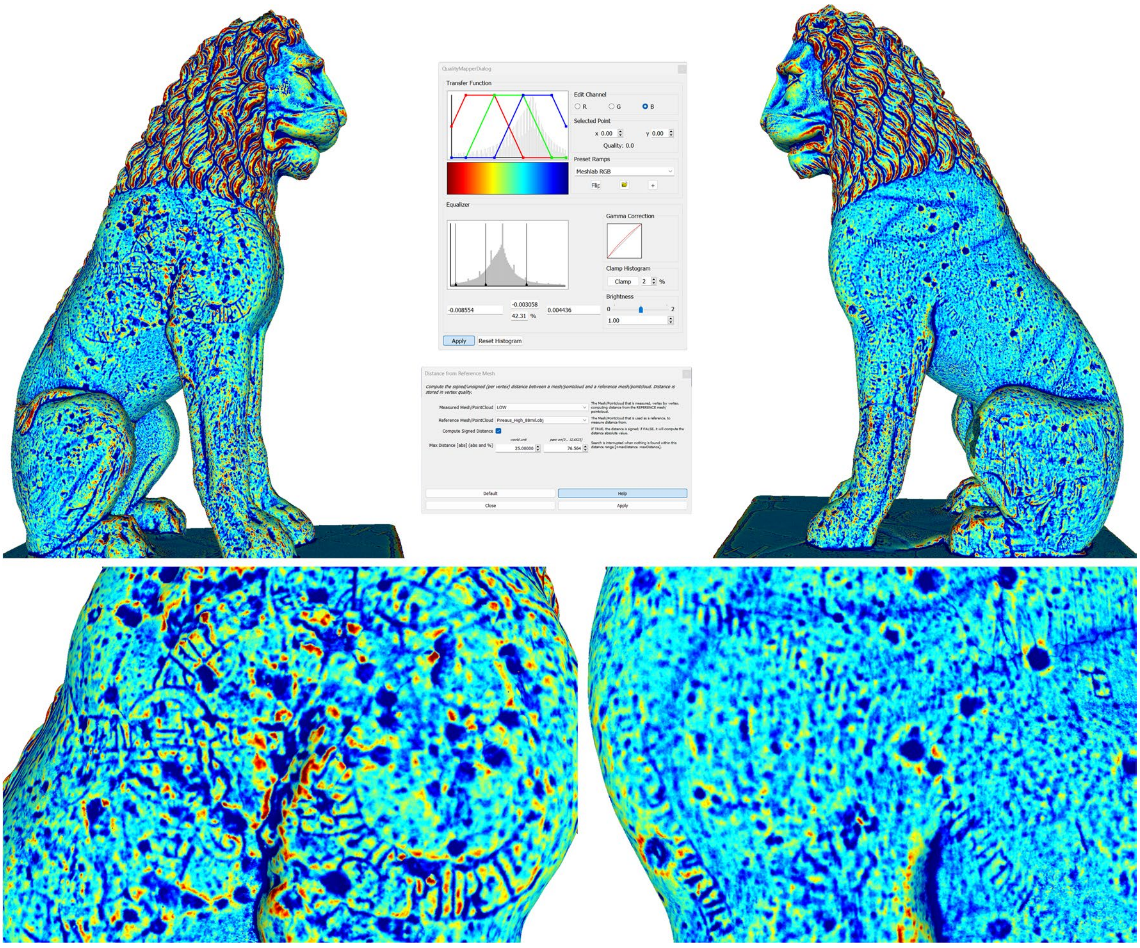

Fig. 7 The result from the MRM with closeups of the carvings at the bottom. The settings used for filter are in the middle

histogram interactively depending on the carving depth (Fig. 8).

It was slightly problematic that the areas with greater curvature, i.e. the mane, gained stronger highlights than the lesser curved areas, which, as shown above, seems to be an intrinsic issue with several of the methods. The carvings were highlighted quite strongly, but the shallower carvings suffered somewhat. Again, the results can be shifted into a variety of colour schemes, for accessibility or preferential reasons.

The APSS processing was rather slow -with some iterations taking several hours to run, and often produced results that were unusable due to the histogram being too spread out to get a good colour separation.

Xshade

Xshade[12] is a free open-source software which has successfully been used in the past to highlight details on models of carved objects [6, 17]. However, it is now showing its age, with its last update in 2011.[13] As such, it is 32-bit architecture only and unable to load larger models. At the time of writing, the latest version of the software did not work, but the older 1.0 version did. The software is run by dragging an.obj file onto the *xshade-make.exe* file to produce an.xsh file, which is then opened by being dragged onto the *xshade.exe* file. Both processes can alternatively be operated using command prompt and opening the.exe file and amending the file name (i.e. xshade-make.exe model.obj). This makes it possible to record the time it takes for each smoothing step and find the limits of the process.

[12] https://gfx.cs.princeton.edu/proj/xshade/ accessed 12.07.2023.

[13] https://gfx.cs.princeton.edu/proj/xshade/src/ As of 12.07.2023.

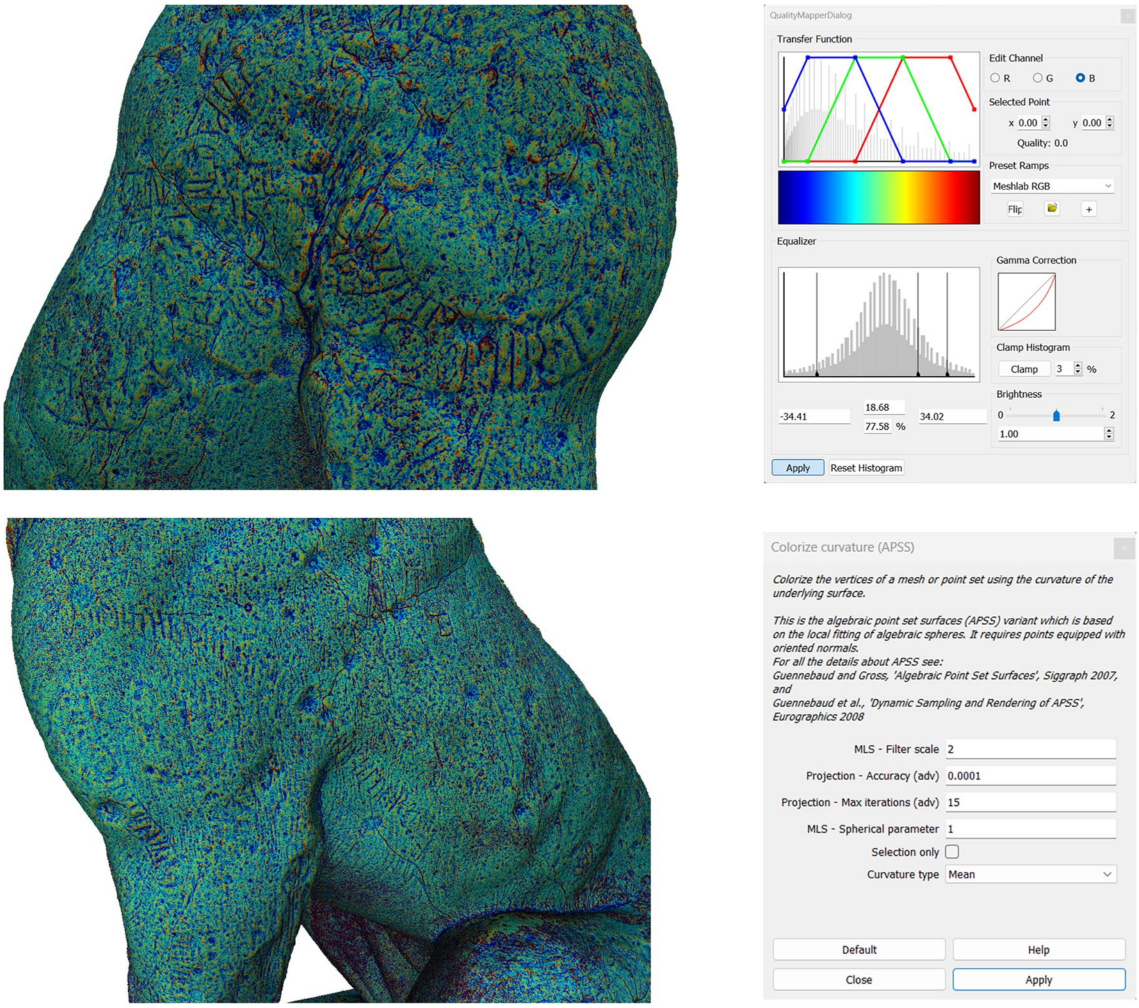

Fig. 8 The results and the settings of the APSS tests

A series of tests seemed to place the limit of polygons at about six million polygons, far below both the medium- and high-resolution polygons in the lion models. This meant that only sections of the lion were able to be analysed at any given time at a high-resolution. Processing the.obj files into.xsh files took approximately two hours, but were quick to open in *Xshade*, and smooth to operate, though higher polygon models exhibited some movement lag.

While *Xshade* produced quite readable results, portions were not particularly clear, especially on areas that had shallow details (Fig. 9). For further testing, a scaled down six million polygon model of the full statue was tested, with the results presented below (Fig. 10).

Although the inscription is rather easy to see when zoomed out, closer inspection shows that details are lacking due to the low-polygon nature of the model.

Blender

Blender[14] is a free, open-source 3D modelling software package which has a raft of extra functionality. In the first instance, the visualisation technique was kept as simple as possible. The model was loaded, and then the viewport method was set to solid shaded. Within the viewport settings, the cavity option was enabled with the cavity type set to both world and screen space. The values were then adjusted upwards until the carvings became quite visible (Fig. 11).

Additionally, a second test took place, in which the model was given an empty texture, then nodes were added to the shading graph. In this case a geometry node with the pointiness output connected to a colour ramp node. The colour ramp, which was connected to the base

[14] https://www.blender.org/ accessed 12.07.2023.

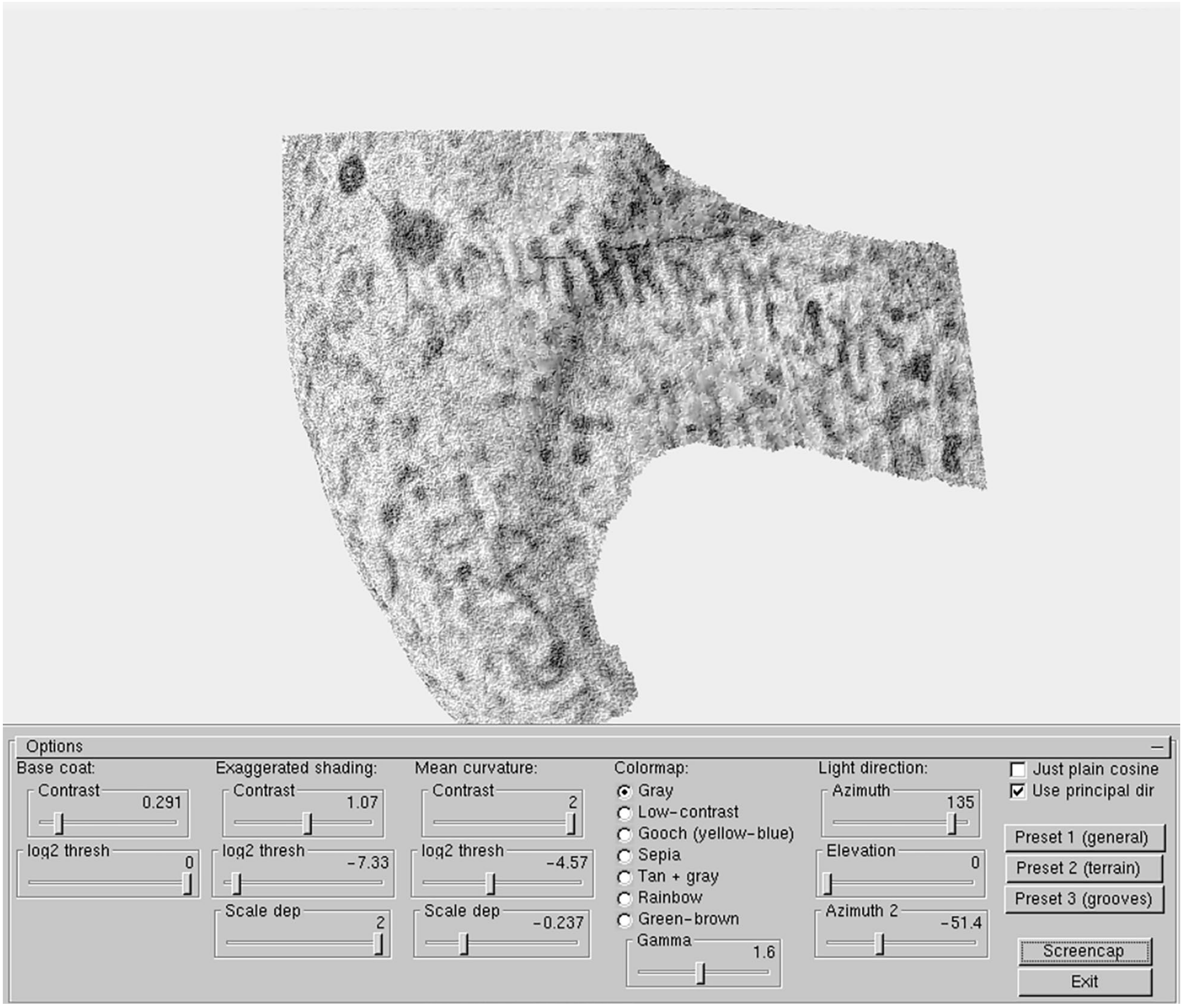

Fig. 9 The results form Xshade on a segment of the lion

colour output of the main shader was then adjusted until the carvings and lower details became visible (Fig. 12).

The process was very quick, with the majority of the time spent loading the model. While it worked with the high-resolution model, it was much easier to work with the medium-resolution model in this instance.

Substance Painter

There are two possible methods using *Substance Painter*. The first method used the high-resolution mesh baked down to the low-resolution model. Within *Substance Painter*,[15] the low-resolution mesh which, as described above, had already been UV-mapped in *Agisoft Metashape*, was imported, and then texture maps (i.e. normal maps, curvature maps, thickness maps, etc.) were baked to the mesh from the high-resolution model (Fig. 12). Once the maps were baked (at 8192 by 8192 pixels), a fill layer was added, and then the curvature map was used as the albedo (colour) for this layer. This was then enhanced via a levels histogram editor (Fig. 13).

Within *Substance Painter*, details were highly discernible relatively consistently across the model (Fig. 14). While there is a lot of 'noise' (non-inscription details, such as scratches and dents), it was still quite possible to discern individual runes in the model.

The second method only used the medium-resolution model. This method is largely the same, with the model first being imported, and then textures being baked to the mesh at 8,192 by 8,192 pixels, but this time without adding a higher-resolution model: the mesh is instead baked

[15] https://www.adobe.com/products/substance3d-painter.html Accessed 15.08.23.

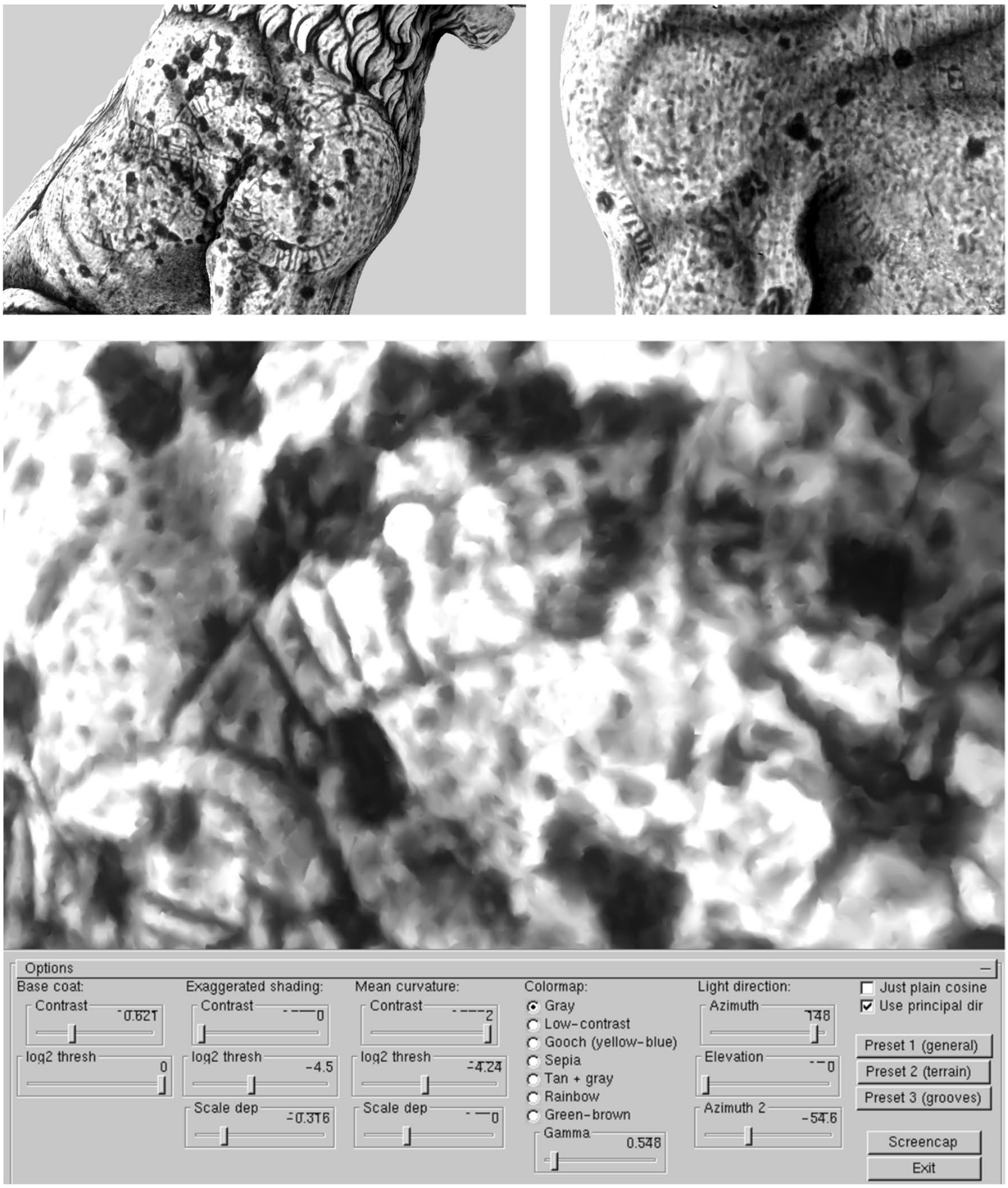

Fig. 10 The results from Xshade on the complete six million polygon model. The close up of the carving shows the lack of detail. The settings used for all visualisations here is shown at the bottom

to itself. The same fill layer populated by the curvature map was used and again enhanced by the levels histogram editor. The results were highly comparable to the baked low-resolution model, but seemed to have more peak areas than the low-polygon model (represented by the white areas on the model, Fig. 15).

Since one of the main functions of *Substance Painter* is for 3D artists to paint on models, it is also possible to annotate and apply interpretations directly to the model non-destructively (i.e. they are saved on layers that allow you to turn them off when required, Fig. 16). This can then be baked out as a high-resolution map (8,192 by

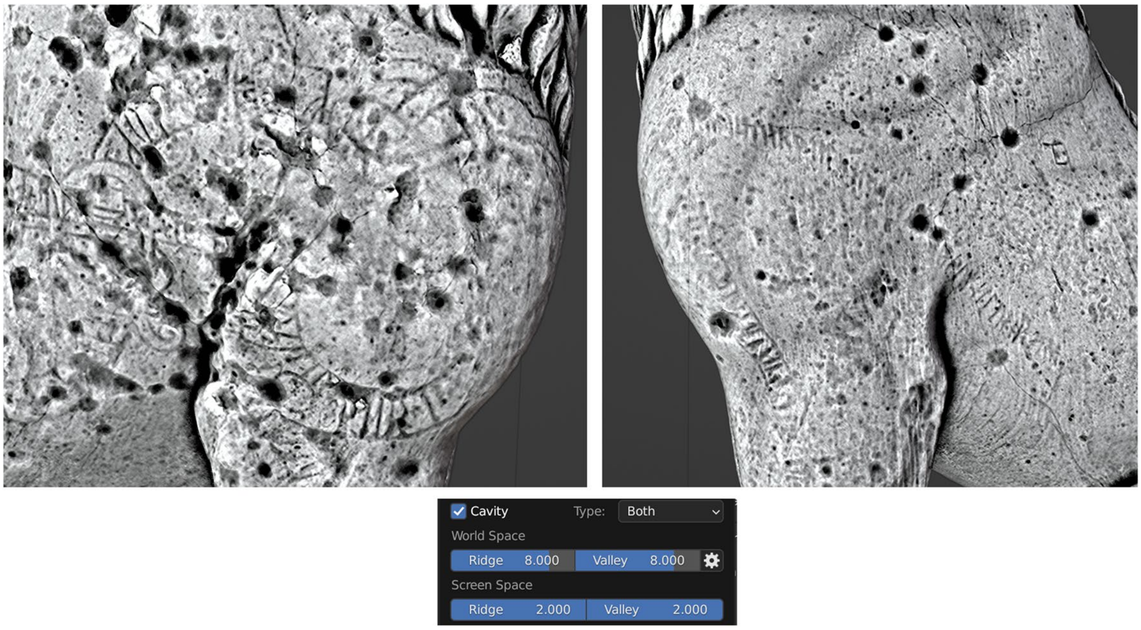

Fig. 11 Output from Blender using the cavity enhancement with settings shown below with the medium-resolution mesh

8,192 pixels) and shared as an entity for analysis in any software that can open 3D models with textures.

A further benefit of the *Substance Painter* workflow is that since the low-resolution model obtains similar levels of the curvature details to the high-resolution model, without the difficulty of having to work with a high-resolution model, it allows for the sharing of the mesh with those that do not have the possibility to use powerful hardware. Its smaller file size also makes sharing the model easier due to potential bandwidth issues. While this makes sharing easier, it must also again be stated that the low resolution model does not retain accurate measurements or micro-topographical geometry on the 3D model.

Substance painter also allows for the creation of "smart materials", which are essentially custom presets within the software. These allow the user to recreate the process above on other 3D models without having to go through all of the setup steps. It still maintains the functionality of being able to adjust the parameters (i.e. the levels histogram) and to add other filters if required, but makes it much easier to recreate results and process multiple models quickly.

Mari

Within *Mari*,[16] a colour layer was added as a base layer of a very light grey, followed by two curvature nodes, one set to convexity, the other to concavity. This was then followed by a levels layer and a brightness layer to allow for manual adjustment to enhance contrast in the result (Fig. 17). The textures were created at a size of 16,384 by 16,384 pixels to get the highest possible resolution and to show the greatest number of details.

Mari created too much "noise" to delineate the carvings in some places, particularly when viewing the mesh from further away. However, upon moving closer to the mesh, the carvings become somewhat clearer (Fig. 18).

The *Mari* user interface is rather more complicated and less intuitive than *Substance Painter*, though it does seem as though it could potentially be the more powerful alternative in the long run, especially since it allows for the creation of higher resolution texture maps (one of the key reasons for including Mari in these test). While Mari was able to run the high-resolution mesh and create higher resolution textures, this does come at a cost of requiring higher performance hardware.

Discussion

Using SfM as a documentation method overcomes several of the difficulties regarding first-hand readings of the inscriptions, including the inaccessibility of the sculpture (located in a naval base), the translucence of the material, and the sheer size of the monument. As the recorded model is completely digital, it is also possible to disseminate copies to researchers for comparisons of interpretations or application of further experimental techniques.

[16] https://www.foundry.com/products/mari accessed 15.08.2023.

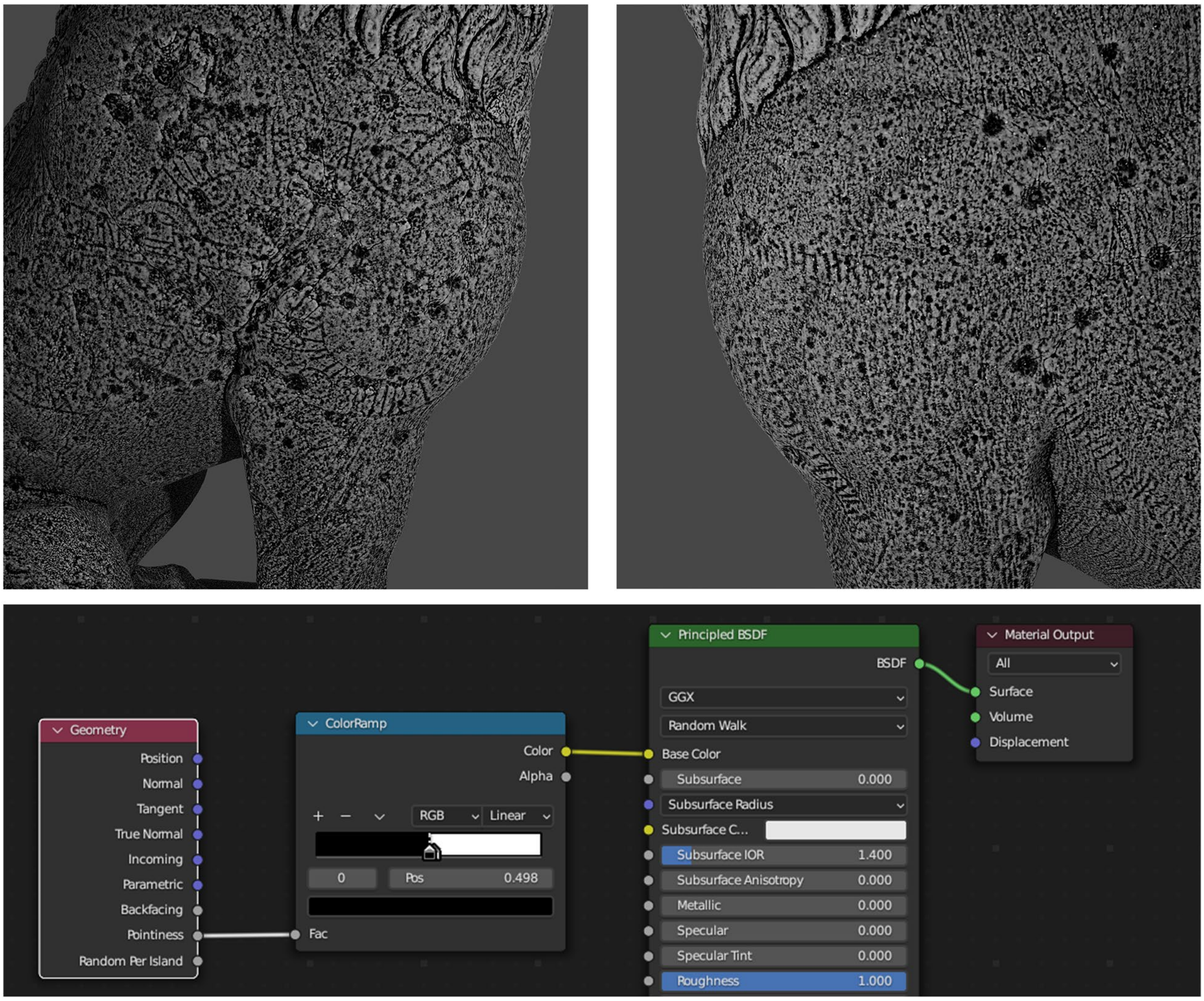

Fig. 12 Node graph from Blender and the result from both sides of the medium-resolution Lion

Another strength of the recording method is that no specialised equipment is strictly necessary, with regular digital cameras and reference cards covering all needs. The relatively low cost of the software and the accessibility of tutorials and user guides add to this, making the method versatile for the recording of inscriptions on a great variety of surfaces and materials.

The majority of the software used to create the visualisations presented here was generally relatively easy to use (though a number of issues arose from outdated software and file sizes), with very little effort required to obtain results once the methods were understood. In the case of *Substance Painter*, after the fill layer with the curvature and levels histogram was added, it is possible to create a template ‘smart material’ meaning that it could easily be applied directly to other models without needing to repeat the steps again. Along with the model, this smart material can be disseminated to other researchers, who would then be able to accomplish the same results consistently. Table one presents an overview of the above, as well as some of the benefits and pitfalls that each method has.

Using the aforementioned LRM method as an additional control step, it became clear that *Substance Painter* also highlights carvings reliably in rock art panels (Fig. 19). However, in the case of *Mari*, it was again evident that it was almost too detailed, meaning the carvings were less visible. The adjustability of *Substance Painter* also meant that it was easier to isolate the carved areas.

But how did *Substance Painter* compare to the other methods? In general, it produced a largely comparative or better result than the other methods (see Table 1). While the radiance scaling method produced a very good result,

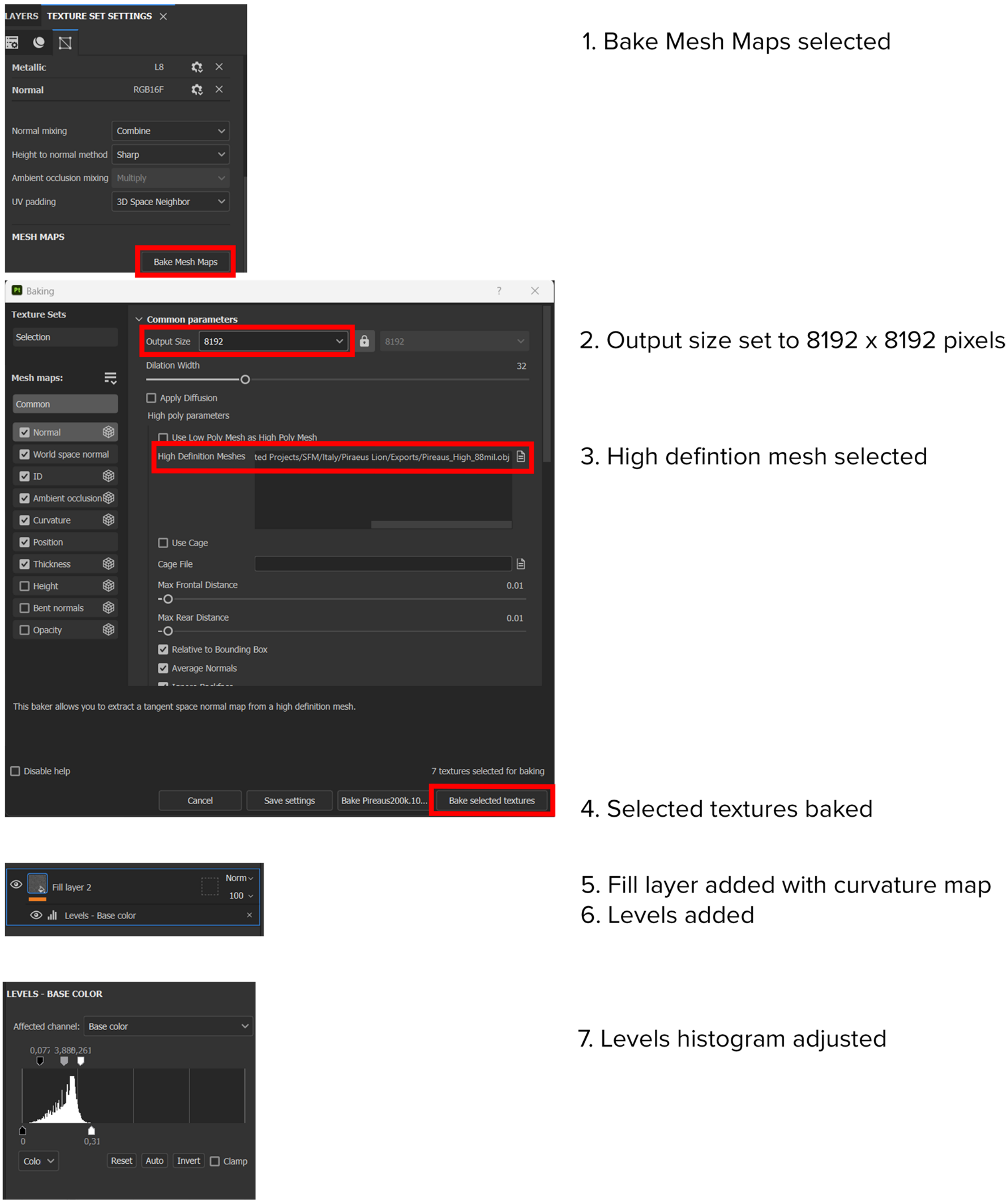

Fig. 13 Workflow of the Substance Painter method

it was limited by how contrasted it was, meaning that some of the shallower carvings were less visible (although still visible). This issue was solved by using *Blender's* viewport shading which creates a similar effect but allows for ramped up values. However, neither of these methods produce texture maps which can be passed on to other researchers as they only produce temporary effects. While they are quite easy to reproduce, for someone with no experience they can be a challenge.

Blender's texturing method using pointiness does allow for a texture to be produced, as well as both *Substance Painter* and *Mari*, but in this respect, *Substance Painter* is by far the easier method as there are significantly fewer

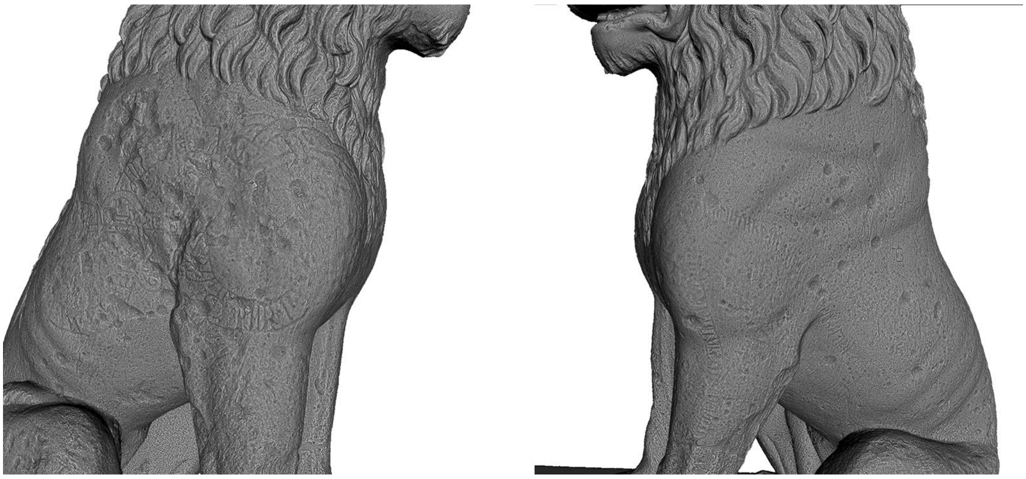

Fig. 14 Results from Substance Painter using the curvature method on the low-resolution model with the high-resolution model baked down to it

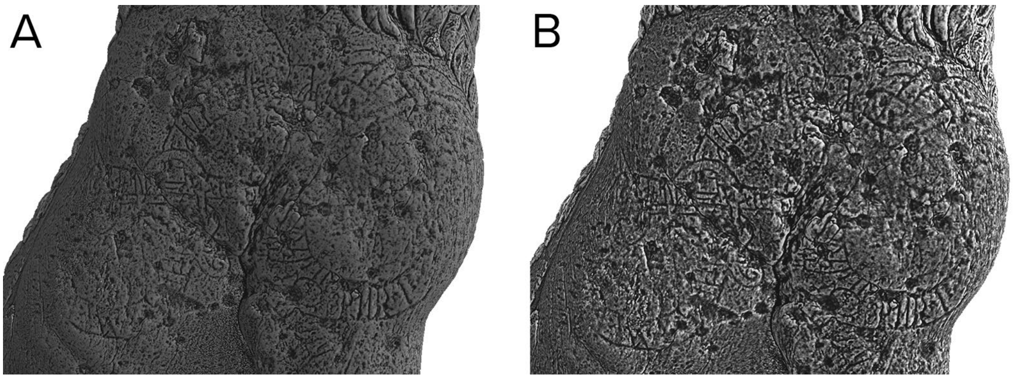

Fig. 15 Comparison between the low-resolution baked model (**A**) and the medium-resolution polygon model (**B**) after processing in Substance Painter

steps required, and the texture baking process is much simpler.

MRM and APSS were both quite suitable methods for this kind of work, as has been shown in the past. However, the methodologies required quite a significant amount of testing before they produced results, largely because there is so little published about how to actually run the processes. While the results are good, the processing times were high, and the histogram in *MeshLab* is not the most intuitive, stable, or user-friendly tool.

Xshade was limited by its capability to handle larger scale models, and while producing pleasing results from afar, the details were lacking when zoomed in. The same problem existed for displacement mapping in *Agisoft Metashape*, despite it being an adapted version of the LRM methodology.

In general, the high-resolution model proved difficult to work with in terms of processing time and moving the model to inspect different areas. The difference between the high- and medium-resolution model only varied a little, so it was not considered to be a major problem to proceed with the medium-resolution model, especially for these types of visualisations. The possibility of working with a small model, for example the low-resolution model created for *Substance Painter*, was preferable in terms of processing time, dissemination, and generally moving and rotating the model.

Substance Painter, *Mari*, and *Blender* all include the possibility to paint interpretations directly onto the model in a non-destructive fashion. This is a very useful feature since these annotations can then also be shared with other researchers. The was again more intuitive in *Substance Painter* than any of the other software.

While it is acknowledged that the majority of the methods presented here use free software, and *Substance Painter* and *Mari* are tied to subscription licenses, for the most part the cost of these licenses, particularly for educational facilities, is not overwhelming.

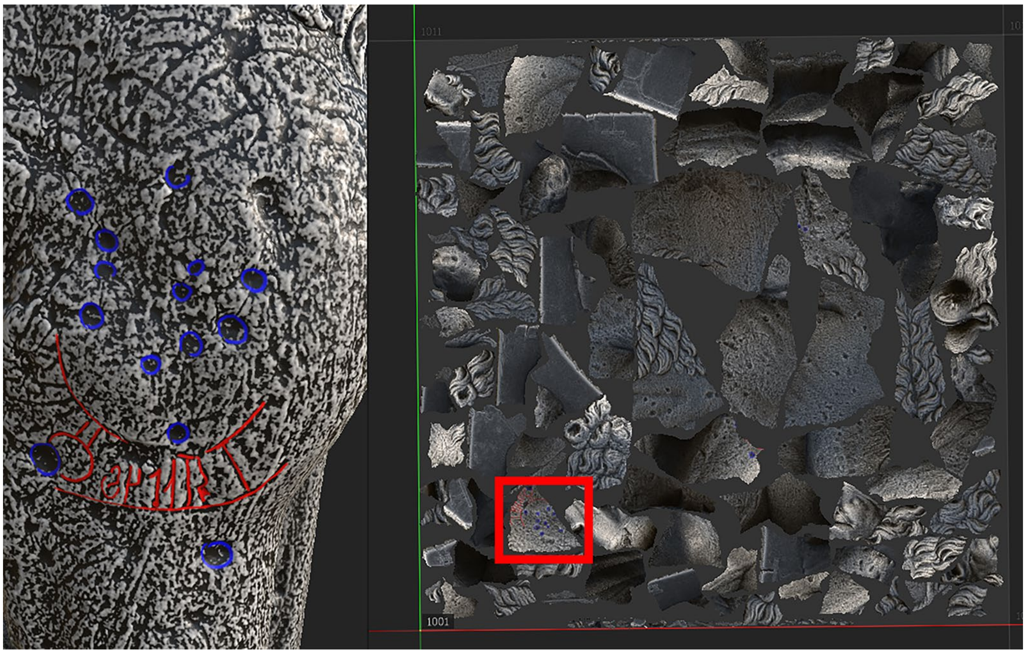

Fig. 16 Direct painting onto the model in Substance Painter with blue to denote damage and red to denote carvings. The image on the right the represents the UV map, note the highlighted section in the lower right, where the annotations are stored

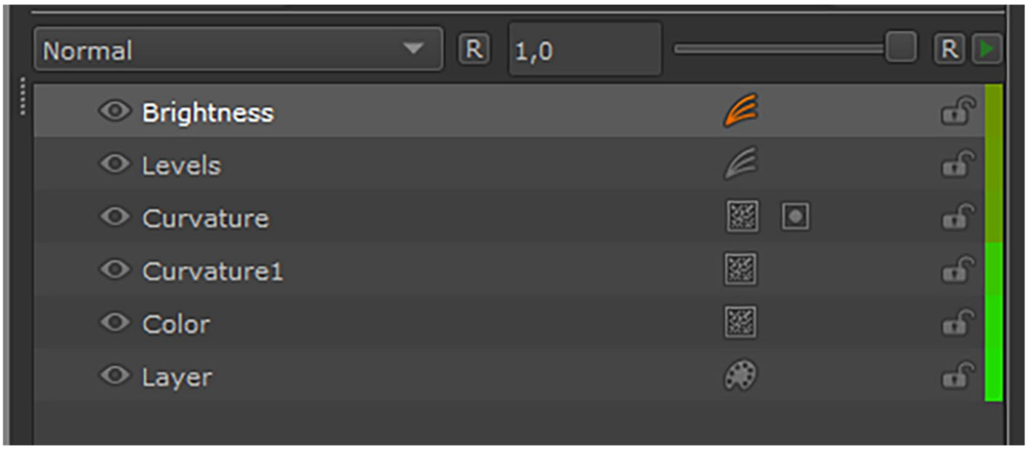

Fig. 17 The layer set up used in Mari

It was noticeable that all of the methods had their own individual strengths and weaknesses in various areas of the model. Most often, they struggled with areas that had less distinct carvings, particularly those on the sculpture's left-hand side. With the exception of APSS, both *Substance Painter* and Mari seemed to handle larger topographic variations in the sculpture better than most of the other methods, which seemed to highlight the larger contours. In this instance increasing the visibility of the larger contours was undesirable as it obscured the smaller carvings.

Overall, while both *Mari* and *Substance Painter* provided useable results, it was clear *that Substance Painter* was the better option of the two, both in terms of visibility of carvings, and ease of use. While the results were highly comparable to the other known processes in terms of highlighting carvings, *Substance Painter* provided a significantly quicker and more intuitive experience. The possibility to use a low-resolution model that

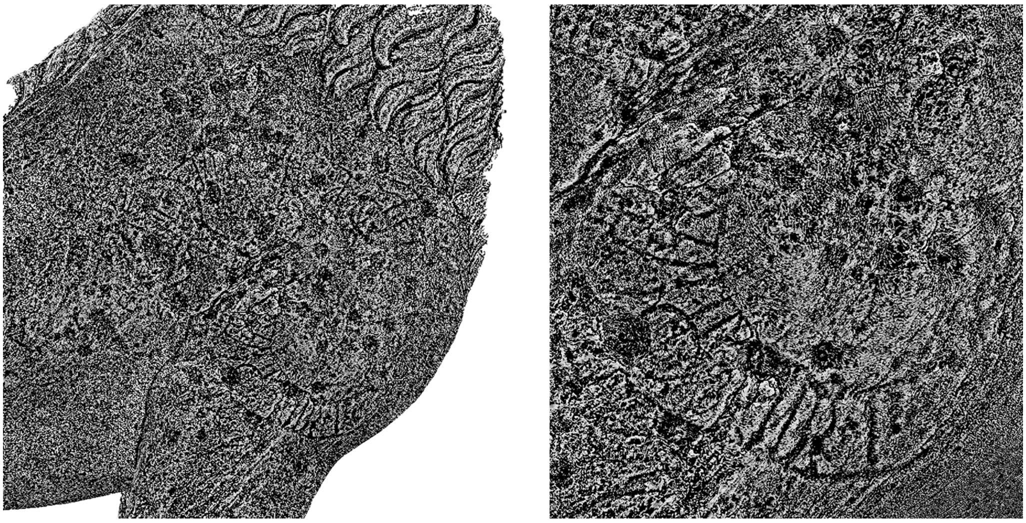

Fig. 18 The Results of Mari on the high-resolution mesh demonstrating that the level of noise detracts from the carvings

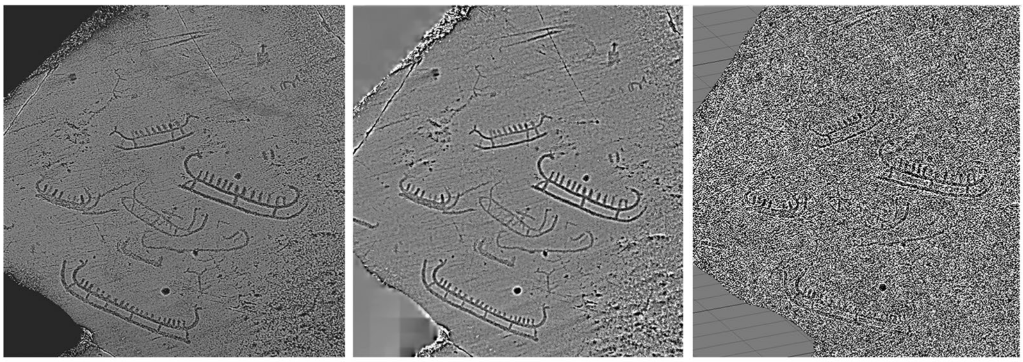

Fig. 19 Comparative verification step using an SfM of Brastad 5:1, a rock art site from Tanum, using Substance Painter, ArcGIS and the LRM Method, and Mari

can be disseminated with an annotated texture map is something that none of the other established methods can produce. Being able to share a "smart material" from *Substance Painter* also increases the reproducibility of the results.

While the low-resolution method does remove the 3D detail of the model, it allows for those with less hardware capabilities to both inspect, annotate, and view the entirety of the carvings in their original position and in the context of additional carvings around it. It also allows for the discovery of new carvings in areas that may not ordinarily be focused on, which can then be analysed in more detail using trimmed sections of the mesh with other methods. The high-resolution method retains all the original 3D information of the original mesh, but requires access to more powerful hardware.

Once the mesh is exported from *Substance Painter* it can be used as any other 3D model would be used, for example, for publication on Sketchfab, with its annotated surface as an additional layer of interpretation alongside the photorealistic texture. It is also possible to relight the carvings both with HDRI maps, and by rotating a light in *Substance Painter*.

The presented results have also shown that both *Mari* and *Substance Painter* are capable and useful tools for the initial investigation of carved surfaces, as well as for producing visualisations of carvings for dissemination.

As previously stated, no one method is a 'magic bullet' for uncovering all the information about any given carving [13]. It is worth restating that we do not advocate or present the use of *Substance Painter* or *Mari* as a method to be used at the exclusion of others, but instead

Table 1 Table showing the results and outputs of the tested methods

Method	Processing time	Full 3D model	Open source /free	Ease of using process	Output	Temporary or textures producible	Highest model level method worked with
Blender Viewport	Minutes	Yes	Yes	Simple, blender handles large models very efficiently	Carvings highly visible, but only a temporary lighting effect	Temporary	22 million
Blender Pointiness	Quick depending on hardware	Yes	Yes	Some effort required to set up nodes and adjust values. Requires powerful hardware depending on model size	Carvings highly visible, but user interface is complicated and node production is not the most intuitive to adjust	Textures maps producible	22 million
Substance Painter	30 min, mostly loading/baking time	Yes	No	Several easy steps,	Carvings highly visible, easy to adjust variables. Some learning curve to run process, but possible to make a "one click" smart material	Textures producible	88 million
Mari	30 min	Yes	No	Several steps, not the most intuitive to set up	Carvings are visible, but there is a lot of noise which makes them harder to see. High possibility to adjust variables	Textures producible	88 million
Xshade	Several hours	No	Yes	Easy once you understand the instructions. requires some knowledge of handling/splitting models	Poorly visible carvings due to necessity of low resolution of the mesh	Temporary	6 million
MRM	Under an hour	Yes	Yes	No known parameters make it difficult to get a good result	Carvings highly visible, but histogram in Meshlab is rather unintuitive to change variables. Larger curves are highlighted more strongly, which can have a negative effect on small carvings	Temporary, but saveable	88 million
LRM	Quick	No	Yes if using *QGIS*	Requires some GIS software knowledge, and handling/separation of 3D models	Carvings visible, but heavily affected by large undulations. Only works on one plane	Only a 2D surface produced	N/A
APSS	Several hours	Yes	Yes	Lots of trial and error, histogram produced is potentially unusable	Carvings are highly visible, but method takes a long time to process, especially on higher resolution models. Histogram in Meshlab not the most intuitive to work with when changing variables	Temporary, but saveable	22 million

Table 1 (continued)

Method	Processing time	Full 3D model	Open source /free	Ease of using process	Output	Temporary or textures producible	Highest model level method worked with
Radiance scaling	Quick, most time spent loading model, and moving into place	Yes	Yes	Easy, with a high-polygon mesh navigating round the model and moving lights etc. is a slow process	Carvings highly visible, but diminished by the low maximum level of enhancement	Temporary	88 million
Agisoft displacement	Relatively quick	Yes	No	Complicated as instructions limited	Has potential, but also requires a large amount of trial and error. Carvings visible but not very clear	Yes	22 million/50 k

as additional tools to aid the process of visualising and interpreting carvings on a 3D model. The best results for any documentation of this kind will always include traditional methods like frottage and tracing, as well as a multitude of digital methods for comparison [29].

Conclusions

This paper has shown that both *Substance Painter* and *Mari* are viable tools for successfully visualising, presenting, and disseminating carvings on different mediums. Comparisons to other established methods have demonstrated that it is possible to gain a reliable impression of small, incised details in stone on full 3D surfaces by using standard 3D texturing methods, with the additional benefit of being able to annotate non-destructively and work with smaller file sizes. Its suitability as a method has also been shown by its ability to bake the curvature of the mesh itself to a texture map, and then dynamically highlight the concave and convex features of the object.

Of the two software presented here, *Substance Painter* and *Mari, Substance Painter* was the most intuitive, easier to work with, and produced more interpretable results in this instance. While there are a host of features available in both *Substance Painter* and *Mari* which will likely further improve the visualisation of the inscriptions, this article has presented a fairly simple and reproducible method.

A full study of the Runic inscription recorded is in progress, and will be presented in a future article. We aim at employing the presented texture-based methods and the results as a starting point for which further experimentation can take place both within this project and others, especially those including rock art and epigraphy.

Abbreviations

MRM	Morphological residual mapping
RTI	Reflectance transformation imaging
vRTI	Virtual reflectance transformation imaging
SfM	Structure from motion
DEM	Digital elevation map
LRM	Local relief modelling
GIS	Geographic information system
APSS	Algebraic point set surfaces

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Author contributions
The project was devised by JW and RP. Permits and necessary permissions were handled by JW. Documentation was carried out by RP and RR. Analysis and visualisation were carried out by RP. The article was written by RP and RR with input from JW. All images were prepared by RP. All authors reviewed the manuscript.

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Availability of data and materials
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Declarations

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There are no competing interests to declare.

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Article ten: Bringing it all together: a multi-method evaluation of Tanum 247:1

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I was the main author of this publication. I wrote the majority of the article, created the SfM model, and performed a large portion of the analysis. **(overall contribution 75%)**

This article critically evaluates how useful using a combination of modern 3D recording techniques and the traditional methods are for documenting and understanding Scandinavian rock art. Within the article a case study is made on a rock art site in Bohuslän known as Tanum 247:1. The site has a relatively small panel with several Bronze Age carvings which include a crewed boat, two additional uncrewed boats, and several figures. The innovative combination of methods identified two hitherto unknown boats, a new human figure, and determined that one of the human figures was composed of two figures superimposed over the top of each other. It also improved the understanding of the figures crewing the populated boat.

The paper incorporates both historic and modern recordings to compare and contrast the effectiveness of various methods, including a newly produced SfM model. Areas where we found new carvings were confirmed by means of the creation of new frottage on a second visit, demonstrating that the best method of documentation is to record and visualise using as many overlapping methods as possible and collating the outputs to obtain an accurate result.

Bringing it all together: a multi-method evaluation of Tanum 247:1

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ABSTRACT

This paper presents the results of a photogrammetric survey of the rock art panel Tanum 247:1 in Kalleby, which revealed two entirely new boats and an additional partial human figure that were previously missed in a documentation history over 50 years long. Through the combined use of digital and traditional methods the results could be verified. It is therefore argued that collating documentations, both past and present, can help to create a better picture of Bronze Age rock art carvings. In addition to using new and traditional documentation methods together, panels should be recorded beyond what is known, both in terms of discovering unknown carvings, as well as creating better data for future researchers.

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Bronze Age; Rock Art; Scandinavia; Structure from Motion; Photogrammetry; Frottage.

Introduction

This paper focuses on a rock art panel in Kalleby (Tanum 247:1), upon which a photogrammetry survey revealed an entirely new boat that had previously been missed in over 50 years of documentation. The collection of 3D data using Structure from Motion (SFM) and Structured Light methodologies in Rock Art analysis has become a standard practice. However, rather than dismissing traditional methods of frottage and tracing, we want to demonstrate how both can fruitfully complement each other. Once 3D data has been recorded, there are a number of different ways in which the data can be processed and manipulated. Using a multi-method approach, including the traditional techniques, this paper examines how bringing the outputs of several documentation methods together may help to enhance the analysis and interpretation of rock art panels, including the discovery and verification of new carvings.

Kalleby is located in the UNESCO world heritage area in Tanum (Bohuslän, Sweden). The figurative Bronze Age rock art in Tanum was created by engraving, or pecking, patterns into the exposed granite bedrock, perhaps using stone or antler tools from a period of 1700 BC, or even already during the Late Neolithic to around 300 BC (Bengtsson 2013; Goldhahn and Ling 2013). The vast majority of rock art images are abstract in the form of hundreds of thousands of cupmarks (Tvauri 1999). Recently, conclusive evidence has emerged that the cupmark tradition began in the Neolithic (Iversen, Thorsen and Andresen 2021). Most of the figurative carvings appear to relate to figures interpreted as warriors, boats, weapons, and animals, though there are a wealth of other types of carvings as well (Bertilsson, Horn and Ling 2021; Ling 2014; Nimura 2015). The Bohuslän area is home to around 1500 such panels (Ling 2014, 5).

New discoveries, evaluation, and quality control are important aspects of rock art research and documentation, as such the recorded data should be as error-free and extensive as possible (Nordbladh 1981). All methods have specific and different advantages and disadvantages, which means they can be used to evaluate the results of different record-

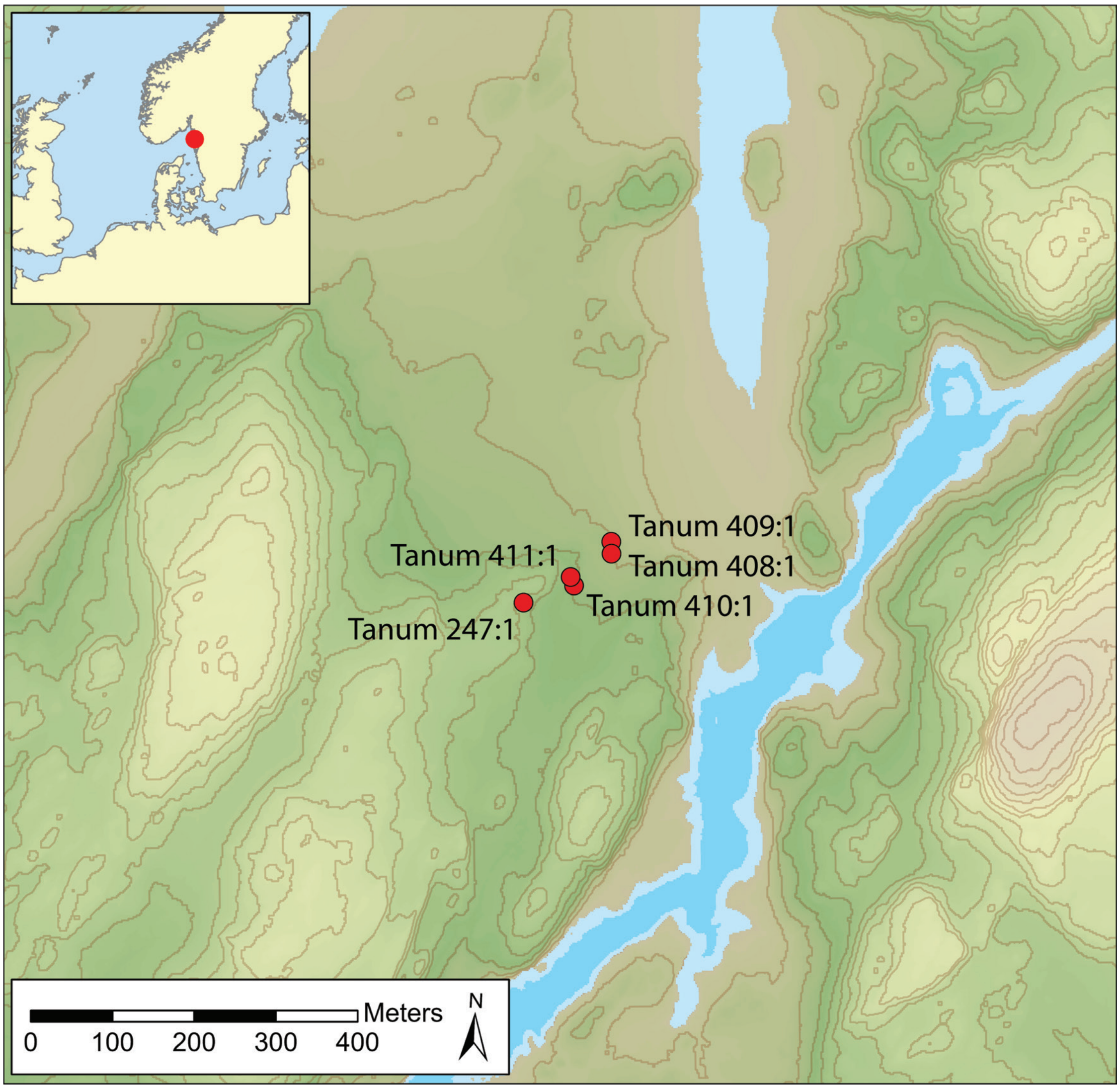

Figure 1. Map showing the locations of panels mentioned in this article (Base map: © Lantmäteriet).

ings of the same site. This paper seeks to utilise the results of digital and traditional visualisation methods to investigate how both can strengthen the interpretation of rock art sites and verify new discoveries. Furthermore, it is hoped that this case study advances best practice approaches to rock art investigation.

Site Description

Tanum 247:1 is situated on the border of a field in Kalleby, and forms a roughly straight line with four other rock art panels, Tanum 408:1, 409:1, 410:1 and 411:1 (Figure 1), which were also recorded using SFM in the same field session. Tanum 247:1 is located roughly 45 m above the sea level making it one of the higher laying panels: they generally seem to cluster around 18-25 m above the sea level. The panels in the area overlook a shallow valley which was likely dry, or perhaps a wetland during the Bronze Age. From higher points like Tanum 247:1, it may have been possible to see fjords that were a relatively short distance away.

The panel Tanum 247:1 was chosen as a case study because it was previously documented, as described below, but held high potential for a greater number of carvings than were previously known since it covered a large area, and was of a fairly uniform and high quality surface typically used for carving – although now lightly eroded. According to the national heritage database of Sweden (Fornsök), the panel measures 1.75 by 1.00 metres. It slopes down towards the east and descends at a fairly steady angle of 15 degrees. It is placed in an area of planted forest and is bedded in with grass and moss. The bedrock onto which the panel was carved is primarily Bohus Granite and features a small segment at the top which is from a quartz or pegmatite dyke (Figure 2, Mark Peternell (Department of Earth Sciences, University of Gothenburg), Personal Communication, 2021)

Previous Work

The rock art panel at Tanum 247:1 has previously been documented at least four times using traditional methods with varying results. The panel was inventoried in 1971 and described as having one ship, 1 metre long with a minimum of three 30 cm tall human figures, two cup marks - one above and one below the ship, and a 45 cm tall human figure at the bottom of the panel. The description mentions that the panel is highly eroded, a fact that every documenter has reaffirmed, and which can also be confirmed here (Fornsök).

The second documentation was made within the 1970s to 1980s by Torsten Högberg and was a frottage using industrial textile towels with blue carbon paper and no fixation. It was made of selected areas of the panel where rock art was recognized using a tactile survey (Figure 3a). The frottage clearly shows a boat that can be dated to period IV (Ling 2014, 105). Inside the boat there are a number of kneeling figures and potentially a lur blower, which could belong to period III, but they could also be later (Ling 2014, 103). There is also a larger figure above the boat, as well as one below which appears faintly and could point towards a Late Bronze Age dating. The strongly exaggerated calves, the curvilinear construction of the body, the belt-like empty space on the hips, and the weapon have been used as arguments for such a date (Fredell 2003, 2009), but recently new evidence has shown that the chronology of human figures may need to be reconsidered (Bertilsson 2015; Horn and Potter 2018; Ling and Bertilsson 2017). There appears to be a second boat over the cracked part of the panel, the dating of which is unclear. This second boat remained unrecognized in the original report, but was mentioned in a re-evaluation conducted in 2009 which will be discussed below.

Figure 2. An orthomosaic of the panel Tanum 247:1.

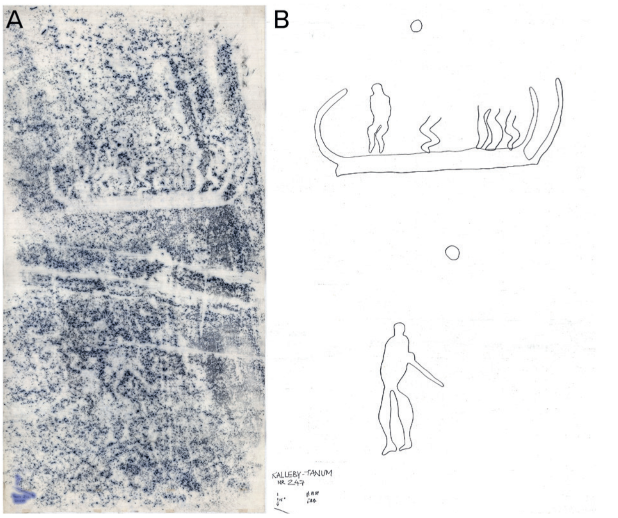

Figure 3. Frottage and tracing image of Tanum 247:1 by Torsten Högberg.

The third recording was a tracing taken in 1983 which missed some important features (Figure 3b). The legs of a number of the figures shown in the boat in the earlier frottage were present, but their bodies as well as the figure above the boat were

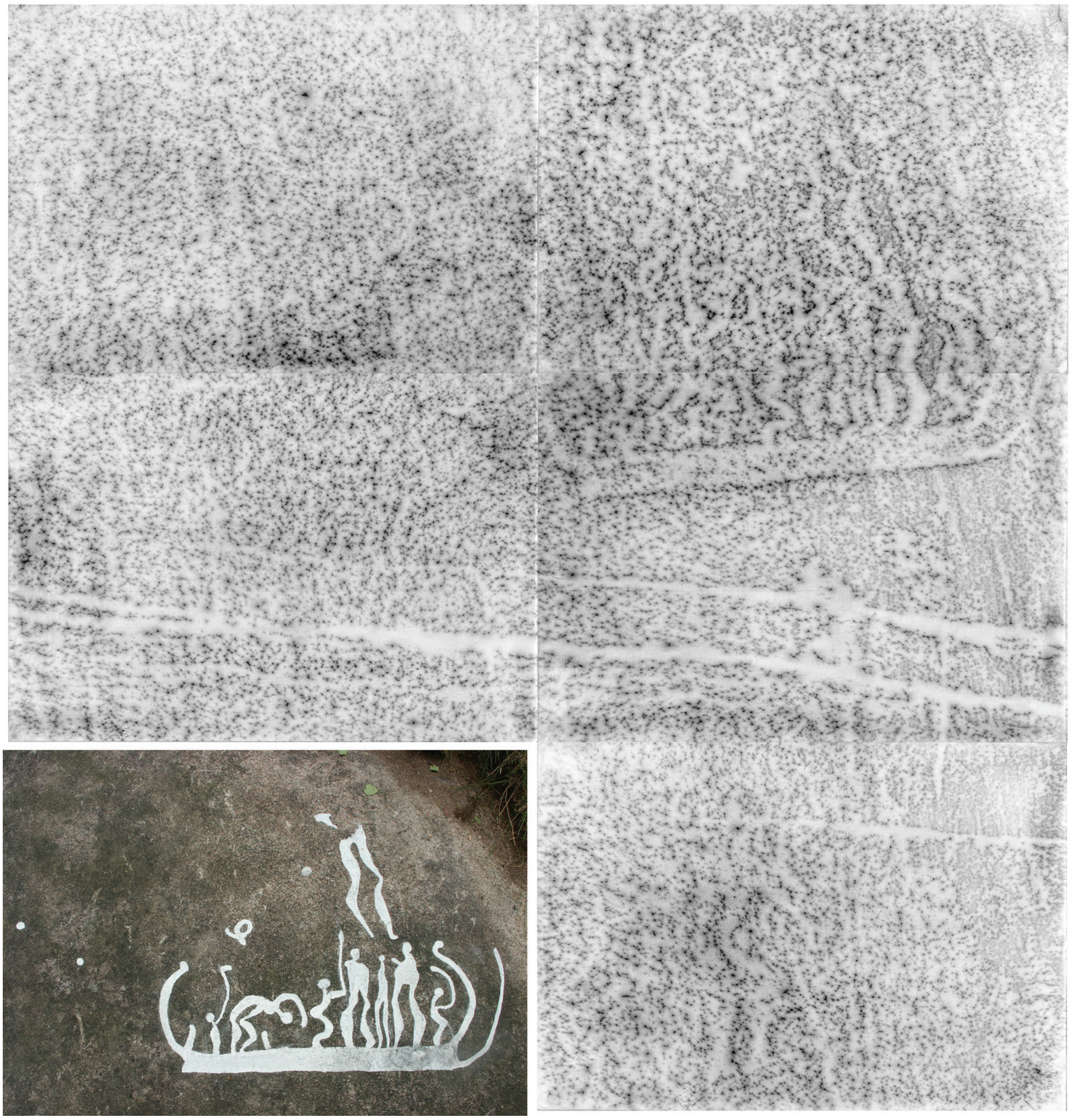

Figure 4. Frottage created by Tanums Hällristningsmuseum Underslös with photo of chalk painting created by Gerhard Milstreu, inset.

missing. It also shows a figure below the boat, but the exaggerated calves seem to be interpreted as thighs. The result lacks some key features on the prows of the boat which makes it seem like it dates to period III (Ling 2014, 105)

The photograph of a chalk painting by Gerhard Milstreu at Tanum 247:1 conducted in 2003 differs from the tracing from 1983. This documentation recognizes the boat with seven figures, including a lur blower. Furthermore, several cupmarks, a pair of legs with exaggerated calves above the boat, and a figure with exaggerated calves towards the bottom of the panel were recorded (Figure 4).

The most complete traditional documentation was created during the same field seminar as Milstreu's chalk painting in 2003. This shows the boat and the figures extremely well, and was used as the base point onto which the new results were overlaid. However, when this rubbing was conducted the lower left part of the panel was not documented, presumably because it was considered to be too eroded. A raking artificial light was used at night, and it was decided to only document areas where traces of carvings were visible.

Documentation Method

The new recording was conducted during fieldwork in the summer of 2021. The panel was captured using standard photogrammetric documentation methods, including structure from motion, which are discussed elsewhere (Cobaz and Jagersand 2003; Green 2018; Horn and Potter 2018; Meijer 2016). The equipment used was a full frame Canon EOS R5 in manual mode and a Canon 28-70 mm RF lens shooting at 28 mm. The panel was largely shaded and there was also minimal wind, so shooting conditions were ideal. The panel was initially lightly cleaned and loose material was removed so that the full panel could be recorded. A total of 913 images were taken, all of which aligned successfully in Agisoft Metashape. All photographs were manually masked prior to alignment and checked for quality to minimize erroneous points. The model was then processed in the software using high settings and accuracy throughout for the best quality result.

For the analysis of the panel, a variety of visualization methods were used. Firstly, a Digital Elevation Map (DEM) was created in Agisoft Metashape, imported into ArcGIS Pro, and processed using the local relief modelling (LRM) methods outlined in Horn, Potter and Pitman (2019). It was processed with the focal statistics tool using cell sizes of 90 and 250 and then subtracted from the original DEM and given a standard deviation of 1.5 to highlight the carvings better. This produced two visualisations of the panel, each highlighting different features in different ways, which were then used for comparison when the final interpretation was drawn.

The 3D mesh that was created in Agisoft Metashape was then run through a visualization tool called Topographic visualistion toolbox[1] (Horn et al. 2021). It was calculated using the full quality mesh with resolutions of 1, 10, 100, and 250. The best-looking output maps were selected for comparison.

The 3D mesh was then placed into a virtual reflectance transformation imaging (RTI) 'studio' created in Autodesk Maya, which moved the light with each frame and rendered out an image using a similar technique as described elsewhere (Goskar and Earle 2010; Goskar and Cripps 2011). These were then calculated in RTI builder and compiled based on the principles laid out by Cultural Heritage Imaging (CHI) (Cultural Heritage Imaging 2013). The result was investigated in RTI viewer using the specular enhancement rendering mode from various angles. The 3D mesh was also investigated in Meshlab using the radiance scaling shader and a moving light in line with standard analysis methods for rock art (Díaz-Guardamino Uribe and Wheatley 2013; Jones et al. 2015).

Comparative approach

Due to the erosion, some of the motifs were quite difficult to determine or were entirely missing from previous documentation attempts. In order to verify the results of the new documentation and to evaluate earlier findings, the output of a number of different visualisation techniques were overlaid, starting with the frottage created during the field seminar of Tanums Hällristningsmuseum in 2003, overlaying the LRM results. Older documentation like the frottage by Torsten Högberg was then used in the same manner. The tracing created by Gerhard Milstreu was used as a reference point, with the outlines from the LRM and Frottage being preferred as a baseline. The traditional recording methods were rectified to match the orientation and scale of the LRM in ArcGIS. These were then exported as TIFs and included in the analysis. The results from the methods were then compared using Adobe Illustrator. A final interpretation of the new 3D recording was drawn to create a better comparison.

Throughout the analysis and interpretative process, the orthophoto and textured 3D mesh created in Agisoft Metashape were consulted to make sure that natural features and damage were not misidentified as rock art. Once the initial investigation was completed using digital methods, we returned to the site and conducted a traditional rubbing on the surface that was covered by the 3D documentation to evaluate our findings (Figure 5).

Figure 5. A frottage being produced at Tanum 247:1 by Author.

Result

The LRM output provided the baseline for the interpretation as it produced a strong visualization of all the known features as well as new previously undiscovered images. The majority of the features were visible on the LRM directly, but we also utilised the results from the other methods to verify that what we were seeing was real, as well as to fine tune the results. The carvings are outlined in the figure below, and subsequently described.

Boat 1 (B1 on Figure 6) was updated by adding outward turned prows, suggesting that an Early Bronze Age boat was returned to and updated. The presumed addition on the prow becomes narrower where it meets the original prow, slots into the original carving, and the visualisation suggests that it is carved deeper, implying that it was created by another carver. This logic is also why other carvings in this paper are considered to be later additions (Horn and Potter 2018; Milstreu 2017). If the boat is considered prior to its update, then the prow design and the two Lur blowers may indicate a period III boat. The style of the stems after the update might be reminiscent of period IV or V. The boat features several other figures, three crouching, three standing. The deeper carved human figures may also be additions and it appears as though the prow may also have been extended. Although the rock above this carving is quite eroded, it was still possible using a combination of techniques to pick out the outlines of the figures.

Within the boat there appear to be two lur blowers, an acrobat, and at least five other anthropomorphic figures (Figure 7). There is potentially also

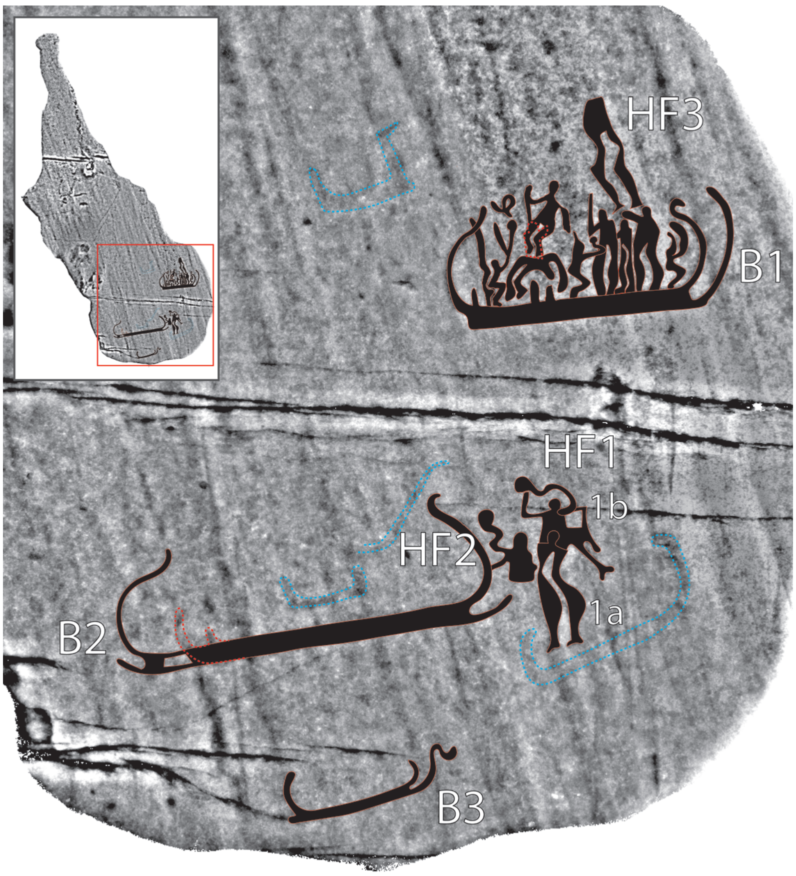

Figure 6. LRM view of the panel with interpretations marked. Motifs are labelled as they are described in the text. Red dotted lines indicated amendments to the carvings, or figures that are obscured by others. Light blue dotted lines denote features we felt might be present but were not sure enough about to confirm.

another figure hidden behind the acrobat. This, as well as the elevated figure whose legs are represented below the acrobat on the boat itself, suggest that some of the human figures were added later.

Boat 2 (B2 on Figure 6) features long outward curved stems, which can be compared to period V boats (Kaul 1998; Ling 2014, 105). The boat was originally a different length, or is intersected by another boat. The Late Bronze Age stem extensions seem to be updates to a boat that had much simpler stems, perhaps dating it to period III (Ling 2014, 105): an idea supported by the possible lack of crew on the ship. There is potentially at least one larger figure present in the middle of the boat which also seems to have been added later, but we were not certain enough to add it to our interpretation.

Boat 3 (B3 on Figure 6) is located below boat 2 on the panel and features outward curved stems which are elongated. There is no crew indicated on the ship. The stem design indicates a period V ship (Ling 2014, 105). However, given the observations so far, it may also be an updated earlier boat.

There are a number of other potential boats and features which may have been present, but they were heavily eroded, and it is not clear enough to be determined with any confidence whether it was in fact a feature, natural, or erosion/damage.

Human 1 (HF1 on figure 6) appears to be in fact two motifs superimposed on top of each other. The original figure (1a) is approximately half the height of the second figure (1b) and features exaggerated calves and a very short torso. Comparative examples of figures like this can be found on Tanum 410:1, approximately 65 metres away. The carving was later potentially extended, and a more anatomically correct version of the body was engraved. In its final form it features a sword sheath with a winged chape, which extends approximately from the head of the older figure (1a). The larger human (1b) appears to be holding a circular object and may also have a line going through its arm that curves round its head, which could be the representation of a lure, but the precise relationship is not certain. The larger figure may date to period V, as is often suggested based on the chape which resembles Central European examples (Fredell 2003, 2009). However, it is worth pointing out that the typological comparison is not an exact match (Pare 1991).

Figure 7. Detail image of Boat 1.

Human 2 (HF2 on Figure 6) is directly in front of human 1 and appears to be the same height as the original version (1a). It seems to only be the upper half of the figure and it seems to be holding something which could potentially be another lur. This figure is connected to the prow of boat 2.

Human 3 (HF3 in Figure 6) is located on top of boat 1 and seems to consist only of a pair of legs with exaggerated calves. It does not appear to have ever been completed, which is well-documented phenomenon in Scandinavian rock art (Fahlander 2021). However, the carving is also in a high erosion area, so it may have originally been a complete human body.

The boat originally mentioned in the inventory that was potentially visible on the original frottage was determined to most likely be natural damage or erosion, as although it appeared boat shaped in the original image, the panel itself did not hold a regular enough form to be considered rock art (Fig. 3a, 6). Part of B2 can be seen in the original frottage, to the left of the HF1, but it is extremely faint as the level of carbon that was laid down was lower in this area, suggesting that it was not an area of focus for the documenter.

Based on the observations in the older documentations, the new documentation using photogrammetry uncovered two boats (B2-3) and a partial human figure (HF2) that were previously unknown. The make-up of HF1 is also rather different than previously recorded.

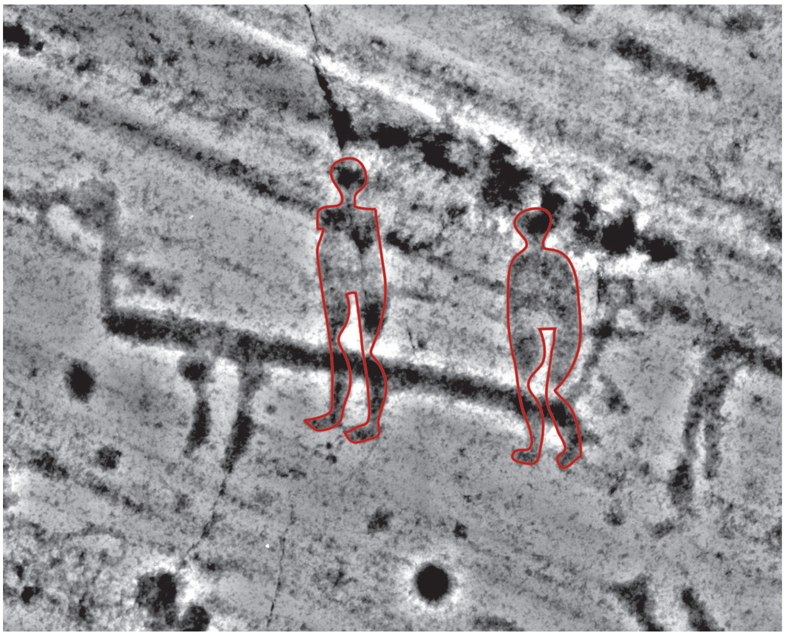

Figure 8. Illustration showing the two similar figures from Tanum 410:1.

The greatest enhancement using multiple techniques combined was on B1, as described above, where greater distinction of the figures was able to be determined. Overlaying our documentation with earlier ones allowed us to enhance the details on the boat crew of B1 as well as HF1 and 3. In addition it was possible to show that the human above B1 and the acrobat superimpose an older human figure. Our results also demonstrate that there is still room for improvement in the future. New, yet to be discovered, evaluative techniques will perhaps be capable of enhancing the visibility of areas on the panel where we felt there might be something, but were unable to accurately depict them with any confidence.

Discussion

There are four other panels in the local area which were also recorded using the same techniques. It is apparent that the carvings on Tanum 247:1 share similarities both in terms of the ship and figure design with Tanum 408:1, 409:1, 410:1 and 411:1, suggesting that some of the carvings were made contemporaneously, perhaps even by the same individuals. However, to establish this a more in-depth comparison is necessary.

There is also evidence of different carvers returning to the panel after generations and updating the images (Milstreu 2017). Two examples of this in particular are HF1 and B2. HF1 seems to be composed of one smaller figure with a torso added at a later date to make the figure taller. There is a comparable example of the smaller figure found on Tanum 410, some 60 metres away (Figure 8), which suggests that perhaps these two figures where carved at roughly the same time period, and it was then later extended with extra equipment added (the sword sheath and the possible lur).

B2 was updated at least once and made to be longer than it originally was. This is seen by the fact that there is an old shallower prow extruding from within the middle of the ship. It shows yet another kind of way in which carvers in the past re-engaged with previously existing images in addition to those already identified (Bertilsson 2015; Horn and Potter 2018; Milstreu 2017). It may be possible that the elongation of the boat has to be seen within the same context as the elongation of the warrior. This process was previously observed, although in a different way, in Finntorp which is within 6.5 km of Kalleby (Horn and Potter 2018).

From the panel at Tanum 247, it would have been possible to see the water in the valley which was a fjord during the Bronze Age which connected the area to the sea. Within the surrounding area there is a cluster of rock art which all contains maritime elements including boats and humans – some of which are quite similar in terms of the motifs that were carved upon them. This could indicate that the area was a natural harbour or landing site, which was potentially controlled by a local group. The local community may have carved the rock with symbols of maritime journeys and warriorhood during boat launching ceremonies, perhaps involving narratives of heroic journeys conducted by their ancestors which would also reaffirm their claim over this land (Horn 2019; Ling and Cornell 2017). It may well have demarcated the landscape and could have been used as such for a long period of time. At some point, carvers appear to have returned to the rock art sites and reemphasized and updated the boat images and the humans to make them fit better to changes in material culture and visual conventions with the aim to keep the images, narratives, and the memories linked to them relevant (Horn and Potter 2020).

Rock art and all of its potentially associated social functions, perhaps illustrating narratives, heroic stories, or myths, were important to the inhabitants of the Kalleby valley throughout the life cycles of the panels including making, viewing, adding, updating, and transforming images during the Bronze Age (Ranta et al. 2019; Redeí, Skoglund, and Persson 2020). They were perhaps a relatively frequently used aspect of life not only as images, but as a practice tightly interwoven into the social fabric that people not only viewed, but also actively engaged with. Their meaning and presence were probably curated to keep them relevant to changing social, political, economic, and ideological circumstances. However, since this was based on older carvings their meaning may have been kept within the same frame of reference, i.e., boats and warriors, making existing images places of memory that helped to keep stability and social cohesion (Horn and Potter 2018, 2020).

Conclusion

Using 3D documentation has revealed new carvings and unknown aspects of previously documented images in Tanum 247:1. However, it has also highlighted the need to evaluate these results with documentations derived from other methods. It was extremely useful to return to the site after the first data collection with SFM and create additional frottage sheets. This gave us the opportunity to confirm the results of the LRM and build a stronger interpretation of what we were seeing on the screen. This suggests that the best way forward is to record new finds as extensively as possible using a combination of new and traditional methods. While older methods are clearly reductive, and some are even more interpretative than others, i.e., tracings, they all have a value in highlighting specific aspects of engraved surfaces. It is also necessary to document at different scales with the new methods i.e., from full panels to individual images as well as close-up approaches like macro-photogrammetry. Ultimately, we need to utilise as many methods as possible together, both traditional and new, to create a fuller picture of what is represented by the carvings.

It was clear from this exercise that regardless of which technique is used to evaluate the results, it is important to redocument entire panels, rather than collecting only what is known. In the future there will undoubtedly be better techniques than presented here, so it will be crucial that the results we create now are as complete as possible so that they can be of more use to future researchers.

As this case study has shown, this incorporation of all of the available methods led to the discovery of several new anthropomorphic figures, and potentially two new boats on a panel that has a documentation history spanning over five decades. The results showed that images were added over time, revisited, and extended or otherwise changed. Using the proposed approach may help us to understand just how important carvers were and how deeply engrained rock art and the making of rock art were in Bronze Age societies in southern Scandinavia.

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Declaration of interest statement

There are no conflicts of interest to report.

Notes

1 https://tvt.dh.gu.se/

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Chapter five: Discussion

In the previous chapter, various methods of visualising rock art were discussed and some of the accessibility issues with methodologies were introduced. In the following this will be discussed in more depth with relation to how workflows and data management can be made more accessible to connected researchers as well as to an interested public.

While the majority of the theoretical discussion for this thesis is presented in the submitted article (Potter et al. forthcoming), a summary of democratisation and accessibility in rock art documentation is given below, with some conclusions about how rock art research can be improved starting with the naming of the panels, through to the dissemination of methods, data, and visualisation techniques.

5.1. Why digitally document rock art?

Now that the ”how” of rock art documentation has been introduced, the reasons behind why rock art needs to be documented digitally will be explored before the main discussion. This reasoning can be broken down into three main concepts, preservation and monitoring, dissemination, and community involvement.

5.1.1. Preservation and monitoring

One of the primary concerns of rock art documentation aside from research is the preservation and monitoring of rock art sites. Documenting rock art accurately and in high resolution generates a snapshot of the state of rock art at particular time points. These recordings can then be compared using various methods to see how the surfaces have changed over time, and how quickly they are deteriorating (Barnett et al. 2005; Horn et al. 2018, p. 82; Jaillet et al. 2017, pp. 16–17; Meijer and Dodd 2018, p. 288; Plets et al. 2012b; Sampietro-Vattuone and Peña-Monné 2021).

There are also environmental and conservational motives behind the documentation or rock art (Horn et al. 2018, p. 82; Milstreu 2020). As has been demonstrated by recent events where rock art has been lost/destroyed through vandalism and natural disasters in Greece (Rönnlund 2023),[34] Norway,[35] Russia (Plets et al. 2012b), and Australia,[36] as well as older events (El-Hakim et al. 2004, p. 344; Koenig et al. 2021; Kęsik et al. 2022, pp. 1–2),[37] rock art is an at-risk heritage. If panels are lost, as in the examples above, then at the very least, there is some record of the surface that is possible to work with (Wojcicki et al. 2022, p. 12).

5.1.2. Creation of corpus of material

Documenting rock art panels in 3D makes it easier to share visualisations and original documentation. This sharing of 3D models means that researchers far away from actual panels can experience the material in a highly tangible and interactive way (Jaillet et al. 2017, pp. 3–4; Morris et al. 2018, p. 55; Råmark 2022). While not quite the same as being at the panel (Huggett 2021, pp. 422–423), these models give a much clearer impression of the topography of the rock surface than 2D methodologies as they contain the third dimension, i.e. depth (Meijer 2015, p. 71; Monna et al. 2018, p. 117; Rolland et al. 2021, p. 36). As frequently stated, however, evaluation works best with a combination of multiple methods, both 2D and 3D (Potter et al. 2022).

34.https://www.keeptalkinggreece.com/2020/01/09/rock-carvings-vandalism-north-greece/ (accessed 20/07/23)
35.https://www.telegraph.co.uk/news/2016/07/31/norwegian-youths-who-ruined-5000-year-old-carving-could-face-pro/ (accessed 20/07/23)
36.https://www.theguardian.com/artanddesign/2022/dec/21/ancient-aboriginal-rock-art-destroyed-by-vandals-in-tragic-loss-at-sacred-sa-site (accessed 20/07/23)
37. http://www.ifrao.com/wp-content/uploads/2014/06/News_22-1.pdf (accessed 20/07/23)

Dissemination of documented rock art is also useful to quantitatively determine large scale patterns in the placement of rock art, for example geographic position, topographic position, and proximity to water. Amongst others, the SHFA in Sweden has been working to build an archive of rock art. Through this, researchers both locally and from further afield have shared their data, and have greatly increased the amount of comparative data that is available to researchers (Kansa and Kansa 2014). Sharing both 2D, 3D, and raw data helps researchers to compare stylistic carvings from a wider perspective and investigate carving techniques (Potter et al. 2022), and also offers more options for researchers to reprocess and evaluate results.

5.1.3. Community involvement

Documenting, sharing, and thereby highlighting rock art also offers another benefit. By promoting the importance of the rock art through accessible mediums like websites, popular journals, and short videos, people are more likely to take an interest in their cultural heritage: when it is presented in a way that the general public can experience, understand, and take part, people can become quite protective of the surfaces (Beale and Smith 2018; Råmark 2022; Westin et al. In Print), and can even help discover new carvings (Valdez-Tullett and Barnett 2021).

5.2. Why should we democratise rock art?

Democratisation in digital archaeology is here defined as the accessibility, transparency, and usability of methods and data to a wider range of researchers and the interested public (Fecher and Friesike 2014, p. 25). Building upon the tenets of open-science (Aspöck 2019; Fecher and Friesike 2014; Marwick 2022; OECD 2015) and the FAIR principles (FORCE11 2016; Wilkinson et al. 2016), this revolves around issues including how possible it is for non-specialists as well as specialists[38] to use

38. For want of a better terminology, those experienced in the methods will hereafter be referred to as specialists, and those who are newcomers will be referred to as non-specialists.

the techniques, both in terms of documentation, post-work, how accessible the results and raw data are, and the level of dissemination (Aspöck 2019).[39] Within the field or rock art documentation, this has implications for the documentation, visualisation, dissemination, and subsequent storage of the material collected.

Democratisation has a number of benefits for rock art research. In particular it leads to an increase in the amount of comparative data available (Gabriel and Jensen 2018; Grau González-Quevedo et al. 2021, p. 450; Valdez-Tullett and Figueiredo Persson 2023, pp. 16–17), projects getting unexpected input from non-specialists which improves methodologies (Beale and Smith 2018; Fecher and Friesike 2014, p. 23; Opgenhaffen et al. 2018, p. 77; Politopoulos et al. 2019, p. 173), existing methods being built upon, developed, and reused (Marwick 2017, p. 425), and openness with data both helping to improve specialists' data and preventing its loss when projects end (Kansa and Kansa 2014, p. 225). This openness can also help ensure that results are verifiable, have not been manipulated, and allow the assessment of their quality (Marwick 2017, p. 426).

Digital documentation has helped immensely with democratising rock art, and has led to a decentralisation of material since sites can be virtually accessed from anywhere and analysed without ever having to visit them in person (Huggett 1995, p. 23). Digital data is easier to disseminate than large format analogue documentation (Scopigno et al. 2017, p. 8), and there is also the added benefit of researchers being able to recreate results from raw data, controlling every step of the process outside of data collection (Huggett 1995, p. 24). Giving open access may also help to enhance the quality and organization of the data as it will be on display and open to evaluation from other specialists (Marwick 2022, p. 11).

Expert is avoided here as it implies there is nothing left to learn, and digital archaeology is a rapidly evolving subject (Valdez-Tullett and Figueiredo Persson 2023, p. 4).
39. For a more detailed discussion see (Potter et al. forthcoming).

As previously mentioned, the digital documentation of rock art is a field which is rapidly expanding. While rock art is a relatively niche topic, the implications of how we deal with the collection, processing, and dissemination of data have far reaching effects since the processes that we use have uses in other elements of archaeology, for example, epigraphy, archaeological excavation, artefact documentation, and use wear analysis. It is important to acknowledge and address issues within the digital documentation of rock art, as they can then be applied to the wider subject of archaeology.

The following will examine the steps, starting from the naming of the panels, right through to documentation, visualisation, data storage, and dissemination.

5.3. Naming of rock art sites

Specific to Swedish rock art is the way in which the panels are named. It is often the case that rock art panels on the same rock outcrop are given different ID numbers, which is both confusing for specialists and non-specialists alike. While it is acknowledged that they are obviously named on a first-come-first-served basis, there is no reason why panels that are on the same outcrops could not be named A/B rather than given different numbers. This would offer a spatial context for those not able to visit the sites, as well as those searching for perhaps overgrown sites when expecting two or more panels in proximity.

An example is found in a field in Kalleby where panels Tanum 408, 409, 410, 411, and 427 are located. It is not clear from this naming convention that 408 and 409 are located on one continuous rock panel within a metre of each other, that 410 and 411 are separated, or how far away Tanum 427 is in relation. Were these panels named, for instance, 408A and 408B, it would be clear that they were on the same outcrop, and that the others were separated. Should further carvings be discovered on the same outcrop, it would also be easier to update e.g. 408C. While it is of course

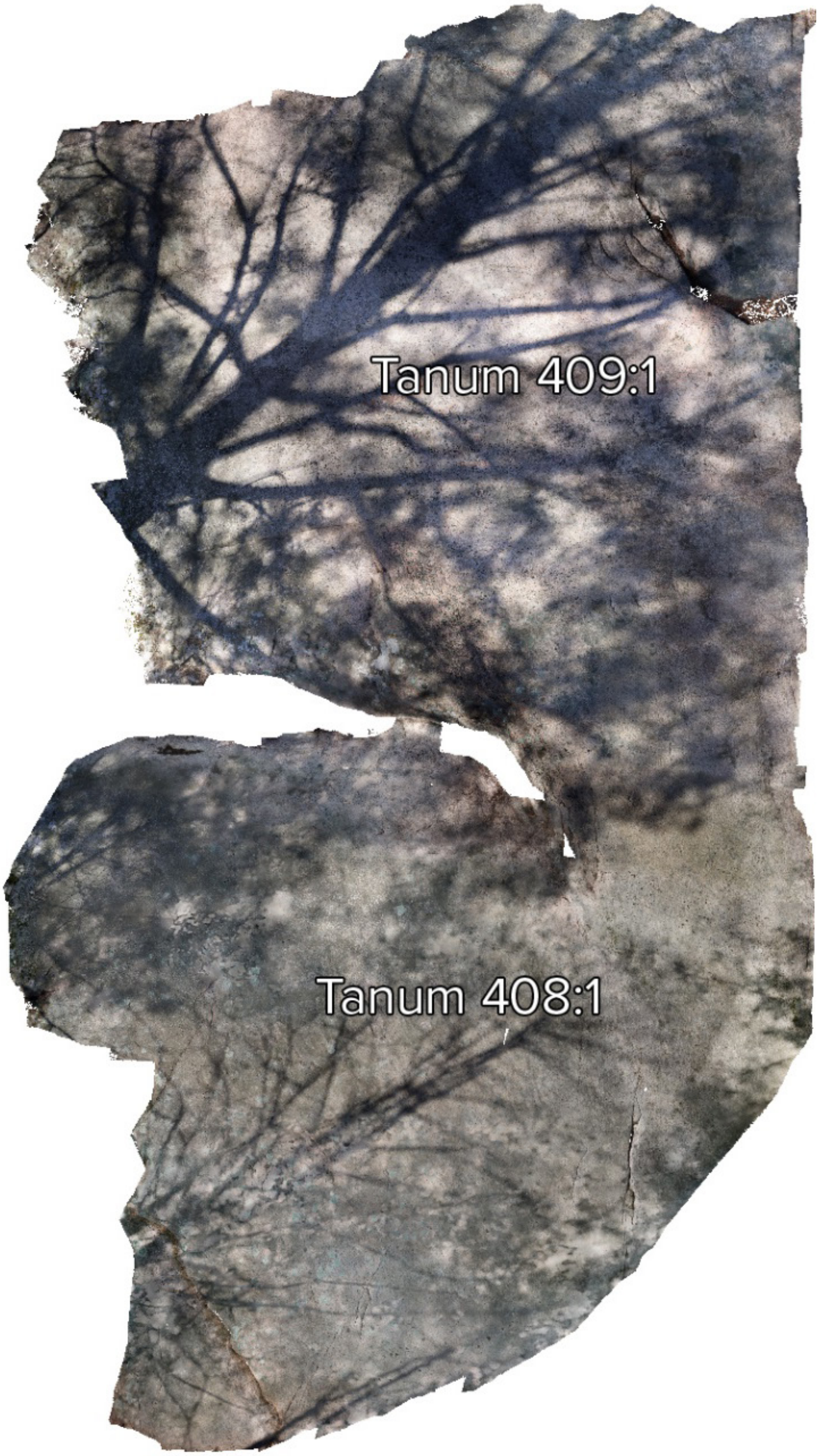

Figure 39: *Example of two panels on the same rock outcrop with different names.*

possible to locate these on a map, many of the GPS points that are documented in the Swedish sites and monuments record, Fornsök,[40] are low resolution which means that are not always placed in an accurate or fully representative fashion on the map. Naming them in the suggested fashion would make it much easier to read and write about the panels, as they would be named in a way that offered some insight into their spatial location.

5.4. Democratising documentation methods

There are already comprehensive guides for how the recording processes should take place for the three digital recording methods described in the previous chapter, both in video and text format (Agisoft LLC 2023; Cultural Heritage Imaging 2011, 2013a, 2013b; Meijer 2015; Scotland's Rock Art Project 2018a, 2018b). Laser scanning is somewhat under-represented here as in general you receive training upon purchase of the equipment.

A good example of accessibility in documentation is the comprehensive guides that the Scotland's rock art project (SCRAP) created. The project has opened up the documentation process of rock art in Scotland, making it accessible through guidelines both for collecting of digital and analogue data (Scotland's Rock Art Project 2018b, 2018c), and for processing SfM models (Scotland's Rock Art Project 2018a). There is even advice for how to upload the images to the Canmore archive and report new discoveries, which has proven successful (Valdez-Tullett and Barnett 2021).[41] In this way, SCRAP can be considered to have taken a curatorial role over the rock art, rather than claiming ownership of it (Gabriel and Jensen 2018). Asking the public to go and document rock art does not work everywhere however. For example in Sweden the public are not allowed to walk on rock art panels, and permits from Länstyrelssen (County Administrative Board for Sweden) are now required to work with rock art documentation (Gustafsson and Karlsson 2021, p. 32).

40. https://app.raa.se/open/fornsok/ (accessed 12/01/23)
41. https://www.rockart.scot/record/data-entry/ (accessed 20/07/23)

There is naturally an implied risk when allowing everyone to document panels that the data collected might be sub-standard, and therefore some suggest that it should be left to specialists (Dell'Unto and Landeschi 2022). However, it has been shown repeatedly that the documentation methods are easy to learn (Beale and Smith 2018; Derudas and Berggren 2021; Scherjon et al. 2019). This has also been demonstrated through courses within the University of Gothenburg, in which large groups of students with no experience making models learnt the method very quickly via online teaching and videos. Rather than blocking non-specialists from working with the material, we should instead make sure they have the necessary tools available to learn the methods to a high standard.

One way of achieving this is by offering information about how the result was achieved in the write up of the paper, for example a short statement with information about the equipment that was used, how many photographs were taken, and weather conditions can help other researchers and those new to the field to get a rough benchmark of what is expected of them to obtain a usable result (e.g. Potter et al. 2022, p.5, Potter et al. 2023b, p. 3). Where SfM is used, adding in a figure with the point cloud confidence from Agisoft Metashape is an effective way of giving an impression of the quality of the model that was used for analysis (Potter et al. 2023b, p. 4).

By opening up the documentation methods to more people, we, as researchers, will have more data to work with in the long run (Gabriel and Jensen 2018; Kansa and Kansa 2014). As the costs involved in the purchase of equipment for documentation processes go down, it should be possible for more local groups to get involved (Valdez-Tullett and Figueiredo Persson 2023, pp. 10–11). When non-specialists do get involved, the benefits can be seen both through developments in methodology (Beale and Smith 2018), and through the discovery of new sites (Valdez-Tullett and Barnett 2021).

5.5. Democratising visualisation methods in rock art

The examples below are intended to highlight aspects which can be improved in the publication of rock art visualisation methodologies. Although specific papers are named, they are not in isolation, and are only used to serve as an example of where processes can be improved upon. A general overview of what makes methods more or less democratic can be found in Potter et al. (forthcoming), but in short open methods can be considered to be those that are possible for non-specialists to reuse (Marwick 2022, p. 10).

An example of an inaccessible publication is Rolland et al. (2021). Although the presented results of the method are exciting and highly desirable, it is unfortunately not possible to reproduce the results, and even if it were, it would be highly inaccessible. This is down to a number of factors: the primary issue is that although a code file was uploaded to the journal it was published in, the main part of the code (which held the actual functions) was omitted.[42] Secondly, as the code was written in R, an interpretive language, and was therefore not compiled,[43] it is now outdated since two of the packages that it requires are no longer available, making it unusable.

Had the code been fully uploaded and the packages remained available, it would still have been an inaccessible method since it requires knowledge of the programming language R to operate. As well as having to install the R compiler, then install the packages required by the method, the code itself needs to be altered to process a model. As the code was uploaded without instructions other than R markdown, this would be nearly impossible for the vast majority of researchers (Angás et al. 2013, p. 3; Duineveld et al. 2013). As such, this method can be considered inaccessible as it prevents other researchers from using the method and therefore recreating the results (Marwick 2022, p. 10). It must be mentioned that other projects from the same authors have demonstrated that this was clearly an oversight, as they have

42. An email request to the corresponding author asking for the additional code remains unanswered.
43. Meaning that it was not presented in, for example, a .exe file that only requires the user to open it, rather than being a script that needs to be run through a software like r-studio.

shared both compiled programs, source code, and instructions of how to use their software (Monna et al. 2022).

Despite numerous papers stating that R code is an open and democratic method of publishing (Aspöck 2019; Marwick 2017; Marwick and Wang 2022), none seem to consider that not everyone is a coder or has the possibility[44] or interest in learning a new language to make their proposed methods work (Stienen-Durand and George 2014). As Marwick (a proponent of releasing R code) states, it took him three years to get to the point that he was comfortable with R (Marwick 2017, p. 441). While his suggestion that archaeology degrees should begin to teach languages like R is seemingly reasonable (Marwick and Wang 2022, p. 212), it must also be remembered that students of archaeology have opted to take archaeology courses and not computer science. Additionally, the impermanence of releasing code which cannot be compiled leads to the loss of methods when dependencies disappear and makes it less accessible for researchers when there is no intuitive graphical user interface. Projects written in python, for example, can be compiled with a user interface. In this sense, the method can be compiled into a black-box solution, and simultaneously released with the raw code (Marwick 2017, p. 434). This is not to say that R has no place in archaeological research, it is an extremely important, useful, and productive tool. However, caution should be taken when presenting it as an open and accessible tool, as this is not necessarily the case.

Black-box solutions are frequently held in contempt as they are seen as taking away a fundamental understanding of how the process works and preventing the development of projects. However, it is here argued that this is digital gatekeeping, as the majority of those who will use it will not wish to develop methods, nor will they have the desire to follow every step of the process. An example of this can be found in RTI builder/viewer.

44. For example, those with dyslexia -of which a significant amount of working archaeologists in the UK have (https://www.archaeologists.net/practices/equality/resources/disability/neurodiversity accessed 20/07/23) struggle with learning coding (Stienen-Durand and George 2014).

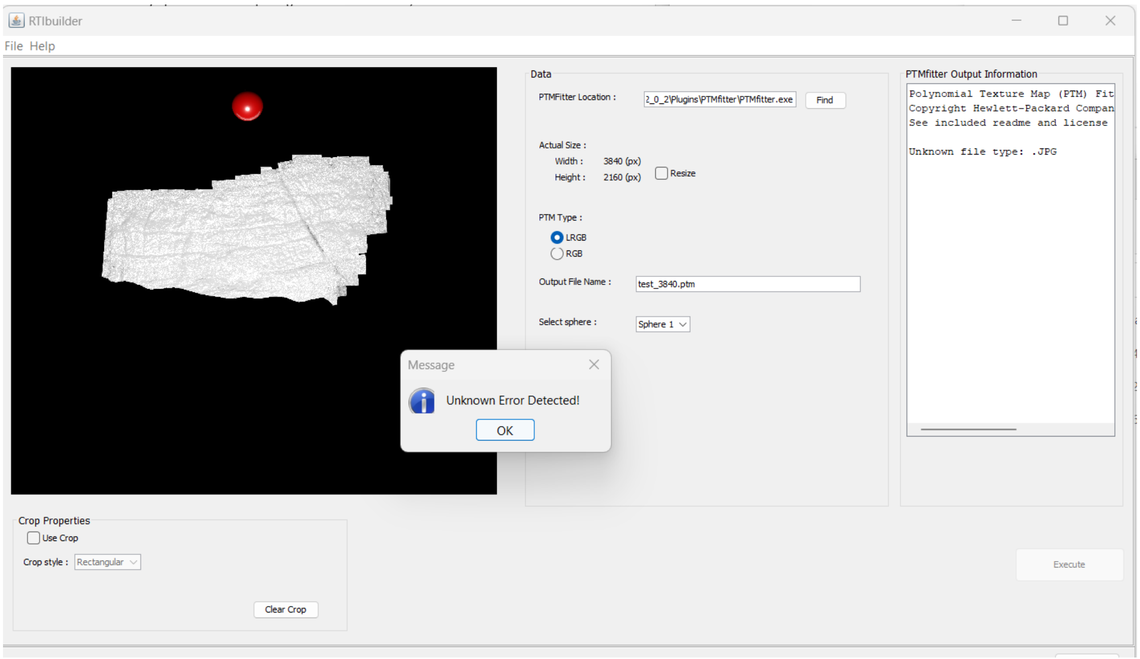

Figure 40: *The dreaded unknown error message in RTI builder.*

RTI was developed as a democratic and accessible software from the outset (Mudge et al. 2008, p. 5; 2010, p. 113), and was developed as a black-box software, i.e. that as long as the user understood and could validate the quality of the inputs and the outputs, they did not need to understand the processes that created the outputs (Huggett 2021, p. 425). As well as publishing their software free of charge, open-source, and maintaining access to it, Cultural Heritage Imaging (CHI) have also developed detailed instructions for the creation, processing, and evaluation of RTI documentation, but also made it possible to delve into the algorithms, if desired, through publications. However, there are some issues with the software that create inaccessibility. Primarily, it is the lack of updates and accessibility to the ptm.exe file (as discussed in chapter 4.1), which is causing issues for users of modern operating systems. Second is that the software can be somewhat challenging to use for new users, requiring a specific set-up of folders, and the use of specific file types (e.g. .jpg will work but .JPG will not work). The error message for using the wrong file type appears at the end of the process and reads “unknown error has occurred”, and “unknown filetype: JPG” which can be a challenge for those starting with the software, or those who do not know there is a difference between upper-case and lower-case file extensions.

Article five (Horn et al. 2019) presents a method which works within a software that is commonly used by archaeologists for mapping, ArcGIS, to create a visualisation of carved incisions on relatively flat surfaces. The method is clearly explained, with alternatives for QGIS, an open-source GIS software, for those who do not have access to ArcGIS (Horn et al. 2019, pp 4-5). This method is essentially a black-box, which requires little, if any trial and error, depending on the surface which you are working with. Similarly, TVT was also released as a black-box solution (Horn et al. 2022b).

Article nine within this thesis (Potter et al. 2023b) presents a number of visualisation methods, several of which were already documented by other authors. Throughout the process of writing this article several of the methods were found to be documented in a fashion that required a large amount of trial and error, and extensive reading around the subject before obtaining a usable result, in particular MRM and APSS. While these methods have been published fairly extensively, the actual process of the methods, in particular MRM, were difficult to find, and eventually found in an article written by someone other than the original creator. Article nine aimed to build upon this by being as open as possible with the presentation of these methods, even approaching other researchers to have them test the methods to make sure they were clear. This means that in the long run the methods presented have a better chance of being used in other projects, rather than quickly becoming obsolete.

From the above, accessible methods can be defined by

- Open-source or cheap software / equipment requirements
- Good instructions (for both usage and installation if required) and intuitive user interface
- Continuous software updates if not open-source
- Easy access without signup or licensing
- Makes use of familiar software

Whereas inaccessible methods will feature

- Incomplete or obfuscated methodology descriptions
- Digital gatekeeping
- Uncompiled or incomplete code presented without instructions through e.g. github
- Overly complicated steps, with jargonistic instructions and assumption of expertise
- An expectation that the user should be a coder
- Trial and error to obtain a usable result because of poor documentation

5.6. Data storage/dissemination of data

There are a number of benefits to sharing data, not least the increase in the amount of data that is available for comparative analysis, and the number of researchers in varying locations that can use the data (Huggett 1995, p. 23). Openly shared data also means that specialists can assess the data quality, and reproduce results themselves using parameters that they prefer, while also trying new visualisation methods rather than being presented with a static final result (Angás et al. 2013, p. 1). Sharing raw data will push specialists to produce better more organised data (Kansa and Kansa 2014, p. 225; Marwick 2022, p. 10), while also giving non-specialists the possibility to learn from the specialists and develop their own data collection process (Kansa and Kansa 2014, p. 226) potentially leading to an overall improvement in the quality of the data. This data openness must of course take into consideration the potential for misuse of the data, copyright issues, relevant laws, ethical issues, and cultural objections to its presentation (Marwick 2022, p. 10; Marwick and Wang 2022, p. 201).

There is some discussion about the authenticity and aura of digital documentations which needs to be addressed. Some researchers struggle with the aura and realness of digital models (Cardozo and Papadopoulos 2021; Gabellone 2015, pp. 112–113; Jeffrey 2015; Molloy and Milić 2018), despite being a valid concern, it is not within the scope of this thesis, and should not be considered as a factor in whether scientific documentation should take place (Valdez-Tullett and Figueiredo Persson 2023, pp. 11–12). However, the authenticity of the object is a more interesting challenge here. As discussed by Mudge et al. (2007), as digital surrogates there is some need to demonstrate that the captured digital documentation is an accurate representation of the object that was captured. This is again a problem of lack of openness with shared data, and is solved with the sharing of raw data, metadata regarding how the project was undertaken, and allowing researchers to start from scratch with raw data (Strupler and Wilkinson 2017). It would also be useful if non-core-data, and contextual information was added to the raw data. For example, as well as SfM photographs, and information about how the data was collected, overview photographs could be added to give a wider impression of the panels being recorded (Huggett 2015, p. 90).

One major long-running question that this brings up is how and where this data should be stored (Koller et al. 2009). Long term cloud data storage is still quite expensive and in general is not very permanent. With photo sessions of large rock art panels often exceeding 120 GB (for RAW and JPG photographs), this amounts to a large cost quickly. There are various databases already in existence (For example SHFA's database,[45] and the Global Rock Art Database[46]), but these are by no means permanent, and are highly dependent on third-party funding as direct funding through departments, faculties, and universities is generally minimal, and there are few public funds to maintain digital archives. At present there is no real solution to this issue, other than making it clear what data is available and supplying it openly when requested.

5.7. In conclusion

This chapter has sought to create a suggestion for how we can make rock art research more democratic and accessible. It concluded that in order for both documentation and visualisation methods to be accessible they need to be published in their entirety with

45. The SHFA database - https://www.shfa.se/ (accessed 20/07/23)
46. Global Rock Art Database - https://rockartdatabase.com/ (accessed 20/07/23)

detailed instructions, with code compiled into a form that requires no additional coding from the user, but with uncompiled code available on request, and should be made so that the majority can use it where possible (e.g. it should be given a user interface, with clear instructions given). This is not to say that complex solutions should not be presented or used, but rather that they should be created in such a way that the results can be reproduced in a scientific fashion by the majority. As exemplified by CHI, there is nothing wrong with using black-boxes and making it clear what the input and output of the process need to be: the complexities can also be presented separately.

Democratisation of rock art, both in terms of documentation and visualisation methods, and the dissemination of material, are an extremely important aspect of the field or rock art for several key reasons. Firstly, openness with documentation and visualisation techniques allows everyone to be on the same page, both with their understanding of how the techniques work, and what the input and output data mean. This leads to better documentation, and more consistent and comparable results/visualisations for research. Secondly, making data accessible not only leads to researchers having a larger comparable dataset to work with, but also means that there is an impetus on researchers to produce the best data that they can. This also makes it possible to learn from other researchers and find ways to improve one's own documentation, and advance methodologies. Thirdly, the open sharing of raw data means that other researchers can freely verify results, and can also experiment with larger datasets. This also includes researchers from further afield who would not ordinarily have access to this material due to limitations in their possibility to travel, funding, and other criteria.

Furthermore, results should be published with signifiers of quality of meshes, e.g. point confidence, and with metadata regarding equipment used, number of photos taken, etc. so that the reliability of the data can be assessed without having to recreate models. They should also be published in standardised formats that are usable by everyone (Bozia et al. 2014, p. 427). While it is understood that data storage is still an issue due to cost, raw data should be made available (even if only upon request) in order that it can be reproduced by non-local researchers as well as other interested parties.

A major stopping point of democratisation within the field of rock art appears to be that of perceived ownership of sites by researchers,[47] as well as that of unwillingness to share visualisation methods, presumably to maintain the status as the creator of a method. However, this in turn leads to other researchers using alternative methods, meaning that they become obsolete, or are superseded by other similar methods which are presented in a more open fashion. Unfortunately, researchers' perceived ownership is a persistent issue within the entire field of archaeology, and is difficult chain to break.

Taken together, being open with data and methods creates the possibility for specialists and non-specialists alike to recreate, reinterpret, verify, and build upon published works, while also leading to an overall improvement in the quantity and quality of available data which benefits everyone (Marwick 2022, p. 11).

A key issue is how data should be stored, as raw datasets are often extremely large. There are currently no viable long-term solutions to this, with the best option currently being commercial run storage services, which are often prohibitively expensive. Since they are privately run 'for profit' organisations, they should not be considered a permanent option.

47. It should be noted that this does not refer to the ownership of sites by ancestral groups who are linked to the creation and curation of sites.

5.8. Related Articles

The following presents two articles that are related to my work with democratisation. The first article was specifically written as a companion to this chapter, and is a more in depth discussion about the democratisation of digital methodologies. The second is a practical example of the democratisation of a method, using relatively cheap hardware and software to make tasks that would otherwise be expensive and time consuming be quick and easy. Each article is introduced in further detail, along with a description of how I contributed to them. For a more detailed breakdown of my contribution, see figure 1.

Article eleven – Everyone has to start somewhere: Democratisation of digital documentation and visualisation in 3D

Potter, Rich; Pitman, Derek; Shaw, Lawrence; Horn, Christian (in prep): Everyone has to start somewhere: Democratisation of digital documentation and visualisation in 3D.

This article was written as an extension of the scope of the discussion of this thesis. I developed the idea for the article, lead the research, and wrote the majority of the text. (**90% overall contribution**).

This article combines democratization, open-science, and the FAIR princples and applies them to digital documentation and analysis methods of rock art. Through this it is able to make several suggestions towards how the processes can be made more accessible. It suggests that established concepts like aura and authenticity can be adpated to help develop how rock art is presented to specialists and non-specialists alike, and that taking advantage of sharing data will improve both the amount of comparative material avialble, as well as its quality, transparency, and reliability.

This article is intended to spark a discussion around one aspect of a much larger subject, the democratisation of digital archaeology, rather than claiming to be a solution.

Everyone has to start somewhere: Democratisation of digital documentation and visualisation in 3D

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Abstract

Digital technologies have become a core component of archaeological and cultural heritage research and 'born digital' data sets are now commonplace within the discipline. Yet, despite significant efforts within the digital community there exists an increasing dichotomy between approaches that make information and data accessible to wide audience and user groups, and those that require a significant depth of specialism to access. Broadly speaking the latter falls into the data analysis and interpretation category, carrying a lag between innovation and adoption. Here we discuss the value of 'democratising' these processes. That is to say: how can we open complex digital approaches to as wide a user group as possible? Not to undermine specialisms, but to increase the amount of digital data that can be analysed and interpreted in novel ways. Using the documentation and analysis of carved rock art as a case study, this paper aims to stimulate a discussion about the value of democratisation within digital workflows. It defines key terminology and criteria that have an impact on the democratisation process and highlights the importance of self-reflection and 'future proofing' in how we publish methods. Ultimately this paper argues that everyone benefits from a broadening approach to digital data capture, analysis, and dissemination, and hopes to contribute to the ongoing discussions of 'digital affect' and methodological curation within archaeological research.

Introduction

Digital technologies can be identified as a medium for accessibility within history, cultural heritage studies, and archaeology. For the past twenty years numerous projects have used digital technology to document, analyse, and communicate research outputs and knowledge in innovative and diverse ways. Digital tools are easily used by archaeologists from a range of backgrounds and specialisms to share data and their interpretations and, arguably, considerable attention has been paid to making them accessible and democratic. Here though, we draw a distinction between passive (content consumption) and active (capture and analysis) engagement with digital technologies. This distinction is important because accessibility in digital technologies is focused on the passive, whereas there are significant advantages to improving access to the active. This is exemplified by projects including Citizan, Micro Pasts, Beacons of the Past, LoCATE and the New Forest Tree graffiti project which have all demonstrated the benefit of such approaches (Bollwerk 2015; Burnell and Woodhouse 2022; Gill 2019; Smith and Waterton 2012; Smith 2014; Smith 2010; Shaw Forthcoming; Turnbull 2022; Wintle and Morrison 2019) where democratised elements of data capture and analysis have vastly broadened the potential scope of the projects. More generally, aspects of digital data capture within the heritage sector have become increasingly accessible in areas such as field survey, 3D documentation, geochemistry, and aerial survey, albeit often developed within proprietary tools that are developed with specific project needs in mind. Conversely, analysis and interpretation of these data have become increasingly complex and less democratised, often relying on a detailed knowledge of coding, as well as financial resources to acquire increased computer power and highly specialist software. This is particularly true within the field of 3D documentation of rock art, where Structure from Motion (SfM)[1] has afforded a surge in digital recording.

1. Structure from Motion is a photographic documentation technique that involves taking multiple overlapping photographs and using a software to calculate a 3D mesh using common points extrapolated from the photographs. The output from this method can be a 3D mesh, a point cloud, a digital elevation map (a 2D black and white image where the grey value represents height), and an orthophotograph (for a more in-depth overview see Green 2018).

This paper assesses how developments in digital data processing and analysis can be used to 'democratise' the use of digital data, unlocking significantly more potential than the traditional analogue outputs. An additional aim of this paper is to stimulate wider discussion on the role democratisation can play in developing digital archaeology. Using the 3D documentation and visualisation of rock art as a case study, this paper demonstrates the value of developing the skillset of amateur and professional practitioners who have access to the techniques necessary to capture data, as well as analysing and presenting it.

What is democratisation/open-science/FAIR?

In this paper, we see the move towards being a more democratic subject as a process that makes research more accountable, transparent, accessible, and repeatable. This, in turn, allows the adoption and critique of complex processes to be accessible to general professionals and interested amateurs, rather than only to specialists. Building from Huggett (1995), democratisation in archaeology is here defined as the move to make the collection, processing, publication, and dissemination of research and research material available to as wide an audience as possible, both for specialists and non-specialists alike (Huggett 1995). Democratisation is inextricably linked to open-science and the FAIR principles. Open-science can be broadly be defined as "efforts to make the output of publicly funded research more widely accessible in a digital format to the scientific community, the business sector, or society more generally" (OECD 2015, p. 9). While there are a number of different outlooks on how open science should be achieved (Fecher and Friesike 2014), it is primarily intended to improve collaboration, through the openness of methods, data, and results (Aspöck 2019). The FAIR principles primarily refer to data management and are a set of guidelines to ensure that scientific data are findable, accessible, interoperable, and reusable through the sharing of raw-data and their associated metadata (FORCE11 2016; Wilkinson et al. 2016). In the interests of maintaining readability, throughout this article democratisation will be used as an umbrella-term for democratisation, open-science, and the FAIR principles. While none of these principles were specifically created with archaeology in mind, as a scientific subject -albeit one that incorporates aspects of the humanities, they should still be applied to all projects.

Terminology and criteria

In order to place approaches to the study of rock art into a democratic context, it is useful to define some key terms which can be used as criteria for the assessment of digital approaches.

Accessibility

Accessibility is here referred to in the general sense of "making things accessible." In the digital world this can relate to the capture of data, as well as its presentation, and the analytical/processing methods used being presented in a meaningful and understandable way which means that they are possible to use by both specialists and non-specialists. This means a preference for easy-to-use recognizable file formats that are readable in commonly used and easy to learn software (though not at the expense of innovation) (Angás et al. 2013, p. 3; Bozia et al. 2014, p. 427). Cost is a significant factor in how accessible a method is, since methodologies that require powerful computer hardware, expensive equipment, internet connections and other expensive consumables, will determine how many researchers have access to them (Angás et al. 2013, p. 3).

Dissemination

Dissemination relates to the distribution of data and publication of materials (Huggett 1995, p. 23). Open-access publishing refers to agreement between authors and publishers (usually for a price) to allow articles to be accessed freely by other researchers. Open-access publishing is seen as a benchmark of open-science as it allows for wider distribution of research, rather than it being behind a paywall or limited to research institutions that have an agreement with publishing houses (Aspöck 2019, p. 540; Huggett 2015, p. 90). This discussion has received a wider push with the emergence of Plan S in 2018 with which research funders attempt to mandate open-access publishing of scientific results for their grantees (Else 2021).

In the last decade, dissemination has also seen a step change with regard to non-academic content creation. Web resources and popular publications have allowed non-specialists to engage with and benefit from the results of often publicly funded research, or better appreciate their heritage which can otherwise be restricted through gate keeping (Bonacchi 2012, 2017) This recent trend is exemplified by the description and enumeration of public presentations, site visits, and non-scientific publications in excavation reports in Sweden (see for example, (Kihlstedt et al.)

For the purpose of this paper, as well as publication of results, dissemination also covers the need for researchers to release their raw digital data and code, so that both can be reused or validated independently (Aspöck 2019, p. 540; Marwick 2017, p. 426, 2022, p. 9). This will be discussed further below.

Reproducibility

Reproducibility is a consistency measurement in science guaranteeing a quality control of results of scientific projects, data capture techniques, analyses, and results. It means that other researchers should be able to follow any given methodology and be able to achieve the same results with the same data. This is strongly related to dissemination, as it provides the possibility for other researchers to understand the methodology and data that is presented (Marwick 2017, p. 426), which is essential to reliably reproduce scientific outcomes.

An important aspect of this is open-methods, which is the principle that methodologies should be described and published in such a fashion that they are reusable by the majority of researchers and interested parties (Marwick and Wang 2022). In addition to reuse and validation, open-methods offer the possibility for specialists to re-purpose and develop methodologies in innovative ways (Aspöck 2019, p. 541; Marwick 2022, p. 10). Where a methodology requires a bespoke software, it is advantageous to release the software as a packaged and executable black-box solution[2] because this increases its accessibility to researchers unfamiliar with coding. However, it is also beneficial to release a the software script simultaneously so that it can be developed further by others (Marwick 2017, p. 434).

Authenticity

There have been several researchers concerned with the authenticity of 3D model representation (Cardozo and Papadopoulos 2021; Eve 2018; Jeffrey 2015). While usually applied to objects that are documented for display, rather than for scientific analysis, it can be adapted to the documentation of rock art (Gustafsson and Karlsson 2008). Authenticity is typically defined as the qualities of the object that make it feel like a real object from the past (van Gerven et al. 2018).

Here authenticity is adapted to issues of using data that has been created by "digital surrogates" and how certain one can be that the model is accurate and an authentic representation of the original (Amico et al. 2018; Mudge et al. 2007, p. 1; Mudge et al. 2008, p. 3).

2. Black-boxes here refers to software where the user inputs data and obtains an output without understanding how the software processes the input data. For a full definition and overview of black and glass boxes, see Huggett 2021.

Figure 1: An example of a rock art from a site at Aspeberget in Bohuslän, Sweden.

How is rock art documented and visualised?

For this article, we focus on rock carvings in Scandinavia, specifically those located within the Bohuslän region. The discussion below, however, aims to be site agnostic and can be applied to any similar type of site regardless of location.

Created during the Nordic Bronze Age (1700-500 BCE) the rock carvings were produced through percussive pecking of bedrock panels using a variety of tools creating a shallow negative relief in the surface. The panels feature a variety of motifs ranging from animals to boats, to anthropomorphs, to cup marks. The bedrock upon which the rock carvings were usually smoothed through the movement of ice masses during the Ice Ages giving the panels a very fine polish (Horn et al. 2022b).

The carvings have historically been documented using traditional methods including frottage and tracings but are increasingly recorded using digital methods like photogrammetry and laser scanning. Once the panels have been documented they are typically processed further in order to make it easier to see the carvings on the surfaces: there are a number of techniques commonly used for this (Bertilsson 2017;

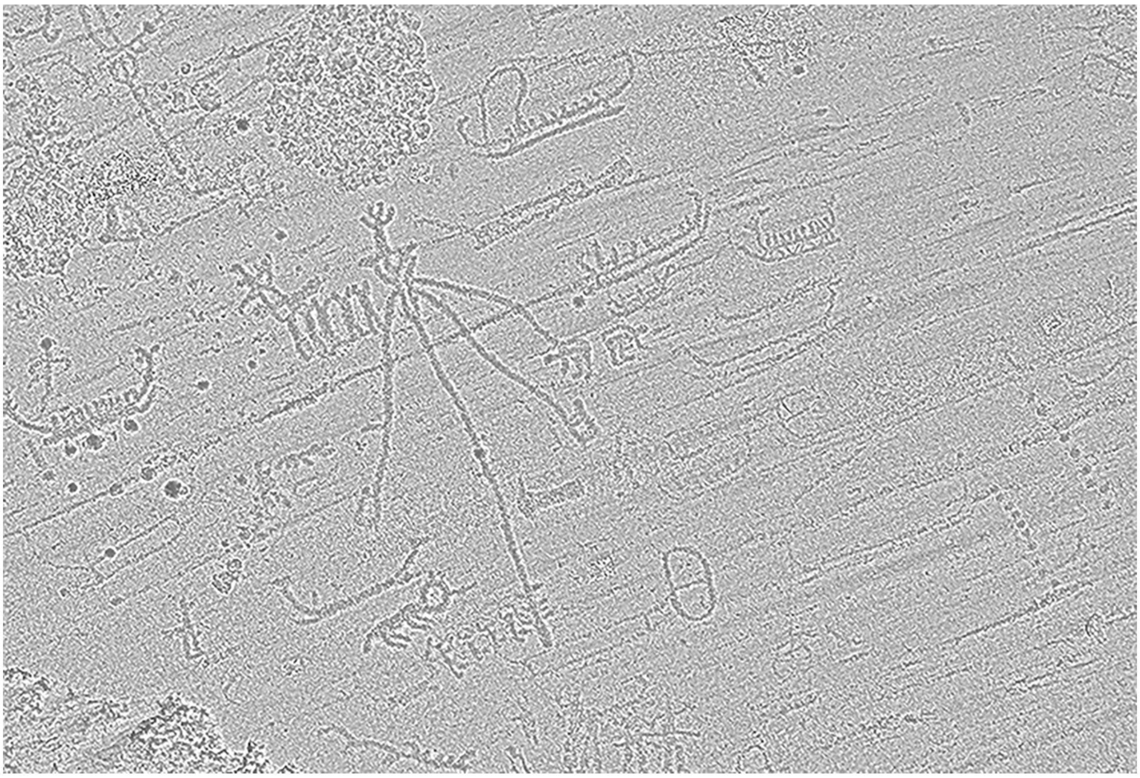

Figure 2: *A rock art panel in Bohuslän (Tanum 75:1) with rock art highlighted using radiance scaling, a technique that enhances the object shape based on the curvature of a surface (Vergne et al. 2010).*

Carrero-Pazos et al. 2018; Díaz-Guardamino et al. 2015; Horn et al. 2018; Horn et al. 2019; Horn et al. 2022c; Pires et al. 2014). A comprehensive overview of the rock art can be found in for example (Bertilsson 2017; Bradley 1997; Chacon et al. 2020; Goldhahn and Ling 2013; Horn et al. 2022b; Milstreu 2017; Sognnes 2011).

There are three digital documentation methods commonly used for recording of rock art panels: Reflectance Transformance Imaging (Mudge et al. 2006), Structure from Motion (Green 2018), and laser scanning (Trinks et al. 2005). RTI produces 2.5D .ptm files[3] which can be viewed in a free open-source software called RTI Viewer, the raw data is photographs. SfM produces 3D models, point clouds, orthographic photomosaics and Digital Elevation Maps (DEM)[4] from photographs taken on site.

3. 2D representations that appear to have characteristics of the 3D data that they represent. PTM = polynomial texture map.
4. A 2D representation of a topography which holds black and values for the lowest and highest points, with different shades of grey representing the height values in between.

Laser scanning produces point clouds and meshes (some of which can be textured depending on the equipment used). While RTI and SfM use equipment that most researchers and interested amateurs will have access to, i.e. cameras and tripods, laser scanning requires a significant initial investment. It is not feasible to use affordable laser scanners for rock art research (Horn et al. 2018), and although high-powered laser scanners are considered useful, they are also beyond the budget of most documenters. Conversely, RTI was specifically designed to be an open, accessible, and affordable, i.e. democratic method. However, while it is still maintained by Cultural Heritage Imaging, it has not been updated since 2012, and the ptm fitter it requires is no longer officially hosted by Hewlett Packard: both are factors severely impede its future sustainability and ease of access. For these different reasons, both methods will not be included in the following except as discussion points.

While there are several SfM workflows that are suitable for rock art panels and other 3D surfaces, all share the same basic approach to recording. As this has been explained in a several places in a way that is both accessible and easy to understand (Agisoft LLC 2023; Green 2018; Meijer 2015), it will not be covered in detail below.

The outputs created when recording rock art with SfM (usually the 3D mesh and the DEM) often require processing in secondary software packages to produce visualizations that bring out more details in the surface of the rock. The purpose is to empower visual analysis, improve publication opportunities, and enable further analysis (see below). Such visualization methods use either the mesh itself, or compare a high-resolution version to a smoothed lower-resolution version of the same mesh (for a full overview see Potter et al. Forthcoming). The results are usually then reduced from 3D to a 2D format ready for analysis and publication (Nobles and Roosevelt 2021, p. 591). These can be simply uninterpreted visualizations of whatever was recorded, but more often they convey the author's interpretation based on which angle the images is rendered, and how it is lit (Valdez-Tullett and Figueiredo Persson 2023, pp. 15–16).

Visualisation techniques are necessary, in part due to the difficulty of presenting 3D surfaces in 2D formats, i.e. images in a journal (Nobles and Roosevelt 2021, p. 591; Valdez-Tullett and Figueiredo Persson 2023, pp. 15–16), because they obscure as much as they reveal depending of the light direction and reflection. Additionally, they help to enhance the carved detail that is not necessarily visible to the naked eye. As has been previously demonstrated, visualising rock art also helps to discover currently undiscovered details about the rock art, as well as completely new motifs (Horn and Potter 2019; Potter et al. 2022). These visualisations are also useful in reducing the computing power required for the development of semi-automated system of rock art identification and classification (Horn et al. 2022a; Jalandoni and Shuker 2021; Melnik et al. 2022; Seidl 2016).

Democratisation in rock art studies

In the following, the terminology outlined above will be applied to examples of current practices, with suggestions of how we can add accessibility, authenticity, dissemination, and reproducibility to the existing workflow.

Accessibility in rock art:

A benefit of creating digital data is that it can be shared much more easily (Scopigno et al. 2017, p. 8). Large datasets, i.e. full rock art panels and extended areas around the panels, can be assessed near instantly by moving a 3D model, instead of needing to plan a trip to the site (Huggett 1995, p. 23). This is of course extended by the possibility to skip between datasets quickly, which may be in entirely different geographical areas, while traversing between the macro to micro level of detail.

The carvings, raw data, and outputs should be made available in accessible formats, e.g. obj, stl, jpg, tif (Angás et al. 2013, p. 3; Bozia et al. 2014, p. 427). and feature appropriate metadata (i.e. confidence maps, processing reports from SfM software) that can be used by the majority of people (Angás et al. 2013, p. 3), or even in print form (for example the extensive publications of carvings by Stiftelsen för dokumentation av Bohusläns hällristningar, a large number of which have also been made available online).[5] Whatever the method of access is provided by researches, it is un-deniable that advancements in technology have meant that the results of rock art documentation are more accessible than ever before.

Dissemination and reproducibility in rock art:

The internet has made the sharing of data significantly easier (Scopigno et al. 2017, p. 8), but there is still significant shortfall in the possibility of hosting large amounts of raw data with publications, and there are easily observable issues with projects running out of funding and their online presence subsequently disappearing: an issue which has long been considered (Koller et al. 2009). It should also be remembered that not everyone has equal access to the internet (Griebel et al. 2016, p. 295): while a file might be considered small to one group it might take several hours to access in another region. At present the internet is still often the best option for dissemination, but where it is not a possibility dissemination should be made available by means of disk upon request (Trinks et al. 2005, p. 132). Sharing data, while also allowing researchers to recreate models and perform their own analysis and quality control, encourages the original researchers to take greater consideration into how their data is collected, as their results will be on visible to others (Kansa and Kansa 2014, p. 225). In turn this also enables a better understanding of what works, and what does not, for non-specialists (ibid).

As opposed to the more traditional analogue methods of recording rock art sites, the SfM methodology makes it possible to share raw data files (i.e. photographs) so that other researchers can go through the processing stages and recreate and validate the results independently (Angás et al. 2013, p. 1). This not only removes

5. https://hallristning.se/

any potential bias from the original researchers (which is already reduced through the use of digital techniques), but also makes it possible to oversee the quality of the raw data. An additional benefit of this is that sites can be reinterpreted using completely different and potentially new methods from the published raw data, rather than only having access to one static output (Huggett 1995, p. 23). This also opens up for the possibility to use the raw data for entirely other processes than initially intended, for example, creating a vRTI from SfM material (Bryan 2009, p. 8; Trinks et al. 2005, p. 132). Sharing datasets also reduces the risk of potential loss of data when projects end or run out of funding (Kansa and Kansa 2014, p. 225).

An unfortunate reality is that when project funding disappears, this also tends to mean that the data archives that they have created disappear with it (Huggett 1995, p. 24). A number of archives are already attempting to remedy this problem with long term funding e.g. Ariadne, SHFA, but the question still remains as to what will happen to them should that funding run out. A commonly used tool for the display of rock art panels and cultural heritage objects is Sketchfab, which currently serves as an archive tool of sorts, even catering specifically for museum and cultural heritage institutes (García and Aláez 2021, p. 85; Scopigno et al. 2017, p. 4). However, it cannot be considered to be a permanent resource as it is owned by a commercial company.

Authenticity in rock art:

While it is useful to be able to disseminate the information following a site recording, the work on site must not be forgotten or undervalued (Meijer and Dodd 2018, p. 294; Valdez-Tullett and Figueiredo Persson 2023, p. 24), particularly the non-digital recording methods and physically experiencing the site for oneself (Meijer and Dodd 2018, pp. 290–291; Potter et al. 2022). There are several ways in which the authenticity of the panels (as defined above) can be improved. Although for scientific analysis the researcher’s impression of the panel is not strictly necessary, it does help to have some sense of how the panel is placed within a wider context, particularly in relation to the landscape. We here suggest that to give the carvings context, efforts should be made to record the entire panels in one large model to see how the motifs are placed, both in terms of their proximity to other motifs, as well as their placement within the topography of the rock panel. Where two panels are joined together, i.e. two differently named sets of carvings on the same surface which are considered to be from different panels, the entire surface should likewise be recorded including the empty space between. In addition, contextual photographs that should also be taken which show the panel as a part of the wider landscape, either with a drone, or terrestrially. Where possible, high-resolution textures should be included with 3D models, so that details of the surface can be seen clearly and used in analysis. As with all raw data, metadata should be supplied for these contextual additions.

Moving forward to democratize 3D data Documentation and visualization of rock art

Documentation methods can be made inaccessible through high startup prices or running costs. Examples of this in the rock art domain are laser scanning, which gives a highly accurate results but has a very high startup cost due to the necessary purchase of the scanner, laptop, batteries, and target points which can easily amount to over 50,000 €. In comparison, other methods like Structure from Motion (SfM) only require a camera and software. While SfM results depend on the quality of the photographs, and good dSLR cameras can incur considerable costs, it has been demonstrated that scientifically useful results can be obtained using cheaper equipment (Espinosa et al. 2021, p. 168; García and Aláez 2021, p. 89). Continuously falling costs of the equipment required for these processes make it possible for smaller scale, lower budget projects and community groups to make use of these digital methods (Beale and Smith 2018, p. 175). While the price of professional software for SfM can be quite expensive -especially for non-educational institutions, there are open-source alternatives available, like VisualSfM or Meshroom. However, they often require additional steps and may have less comprehensive instructions (Green et al. 2014, p. 173).

Results from laser scanners can be reproduced by using the same equipment, similar conditions, and the skillset of the documenter. The same can be said for SfM which will reliably reproduce previous documentation results with the use of the same camera type, the same conditions, and a similarly skilled photographer. Laser scanners may be somewhat more forgiving in that recording is direct whereas photographs for SfM can easily be accidentally blurry, which, given the volume of photographs taken in a session, can potentially only be noticed when the model is being processed. However, in addition to affordability, SfM models are based on an easily shareable raw data, i.e., photographs, which aids openness. Therefore, surfaces documented with laser scanners should additionally be documented using SfM since this makes independent reproduction more open. This requires visualization methods to be democratized in the sense that they need to be interoperable using data from laser scanners and SfM meshes. It is typically also possible to record larger areas using SfM than laser scanners (see authenticity in rock art above).

Democratising the documentation of rock art makes it possible for community groups to participate in the documentation and visualisation of rock art. Opening up to working with communities of “amateur” archaeologists can lead to an increased amount of data, as well as innovations and developments within existing methods that can be of benefit to both amateurs and professionals alike (Beale and Smith 2018; Gabriel and Jensen 2018; Harkema and Salt 2018, p. 188; Opgenhaffen et al. 2018, p. 77; Politopoulos et al. 2019, p. 173). The potential for extra data collection in a shorter time period is not only because there are additional helpers, but also because because the majority of digital documentation skills can be taught quickly, and subsequently passed on to others, as demonstrated by the “Re-reading the British Memorial project” (Beale and Smith 2018). Another example is through the Scotland’s Rock Art Project, who’s openness with methodologies (Scotlands Rock

Art Project 2018a, 2018b), and encouragement toward non-specialists to record and report rock art has led to the important discovery of a new sites (Barnett et al. 2021; Valdez-Tullett and Barnett 2021; Valdez-Tullett et al. 2023). An additional benefit is that the addition of community groups to projects can help add to the authenticity of the recordings (Jeffrey 2015).

Method development, coding, and the problem with current practices

While methods of collecting data are well documented, especially in the field of rock art documentation (Meijer 2015; Scotlands Rock Art Project 2018a, 2018b), quite often the descriptions of how post processing methods are actually achieved fall short, or use software and terminology that is not possible to understand as a non-programmer or IT-professional. There has been a general trend amongst open-science articles to suggest R as a good tool for the presentation and dissemination of methods (see refs). R is a programming language with a strong open-source environment frequently used for statistical and graphics computing that has also become popular in the humanities. However, they rarely take into account that not everyone is familiar with R, or has the possibility[6] to learn code (Stienen-Durand and George 2014). Marwick states that it took him three years to become a confident R coder, and suggests that R should be taught during the undertaking of an archaeology degree (Marwick 2017, p. 441; Marwick and Wang 2022, p. 212). While it is generally a good idea to offer archaeology and other students of cultural heritage related fields the opportunity to learn transferable skills, the proposal fails to consider that many students opted to take archaeology as a degree, not computer science. In addition, there are many other transferable skills students may wish to learn and the variety makes it impossible for everyone to learn everything. Furthermore, professionals, researchers, and interested amateurs rarely have adequate time allocations required

6. For example, those with dyslexia -of which a significant amount of working archaeologists in the UK have (https://www.archaeologists.net/practices/equality/resources/disability/neurodiversity) struggle with learning coding (Stienen-Durand and George 2014.

to learn the coding associated with these methods. Since R is an interpretive language, it is difficult to compile in a way that would be possible for someone with no experience of code to use, especially when dependencies[7] are required. Therefore, a very large portion of the public, researchers, or otherwise, will be excluded from its use. It is also a concern that libraries can be removed from CRAN (the main pathway for installing dependencies through R-Studio) meaning that they essentially disappear for those not skilled in R, reducing the longevity and sustainability of the methods developed in R and solely published in raw code.

Some visualisation techniques are made accessible by using software that is already common to archaeologists such as GIS applications, reducing the learning curve (Horn et al. 2019). Others make use of free or open source software like MeshLab or xShade with, in part, sustained development histories and a reasonable documentation (Carrero-Pazos et al. 2018; Cignoni et al. 2008; Pires et al. 2014). A third group uses code to produce their own open-source software, and compiles it into standalone programs (Dubinsky et al. 2023; Horn et al. 2022a). By developing tools in software that the majority have or can gain access to, they become more accessible to a wider audience. The raw code or scripts should be stored in open-source repositories allowing those interested to engage with it, while others can simply use the applications. This enables the creative use of the software for the potential inclusion of new data, for example, the new cuneiform script found on the burial stones of a 3D model of the megalithic tomb in Züschen, Germany (Hansen et al. 2021). Releasing the script enables further method development and, while there is no question that this beneficial, it is problematic to suggest that only releasing the script is the best way forward. Even the inclusion of considerable annotations and comments in the script will be impenetrable to some, and exclude researchers from reusing a method.

7. External libraries of code that are required to make the main code run.

The benefits of the black-box

Black-box solutions are frequently held in contempt as they are perceived as taking away a fundamental understanding of how a process works (Huggett 2021, pp. 425–426; Marwick 2017, p. 434). However, we argue that this contributes to digital gatekeeping, as the majority of those who will use it will not want or be able to develop the methods, nor will they have the desire to follow every step of the process due to a variety of constraints such as time, skill, and knowledge gaps.

A good example of this can be found in RTI builder/viewer. RTI was developed as a democratic and accessible software from the outset (Mudge et al. 2008, p. 5; Mudge et al. 2010, p. 113), and was developed as a black-box software. The user only needs to understand the principles of use and be able to validate the quality of the inputs and outputs. They do not need to understand the processes that created the outputs (Huggett 2021, p. 425). To facilitate its use RTIbuilder/viewer were published free of charge, open-source, and access was maintained. Cultural Heritage Imaging (CHI) also developed detailed instructions for the creation, processing, and evaluation of RTI documentation (Cultural Heritage Imaging 2011, 2013a, 2013b). In addition, for those interested it is possible to delve into the algorithms through their detailed publications.

It is simply neither important, nor realistic, that the user understands every single black-box process, but it is highly important that the user understands the inputs and outputs of the process (Huggett 2021, pp. 424–426). Expecting every person engaged in research to understand the code of every software or the mathematics behind every algorithm they use is unrealistic. The majority of archaeological methodology is something that is learnt from the ground up by practice and it is the same for digital methodologies. It is therefore the responsibility of those who develop the black-box software to offer detailed and ground-level instruction in what the expected input and outputs should be and why.

Democratization through teaching

For the field of rock art studies nearly all documentation and post processing methods can easily be taught openly and accessibly through the medium of simple instruction texts or videos tutorials that can be presented online (Scherjon et al. 2019). We have experienced this in our own teaching at the University of Gothenburg with large groups of students with no experience being able to quickly create their own 3D models. Online lectures, workshops, and videos proved extremely effective in helping the students to gain knowledge of SfM, post-processing visualization, and analysis of the outputs.

There are obvious perceived downsides to democratisation of methodologies, in that non-specialists are likely to make mistakes when collecting data, and do not have the experience to acquire data as well as those who have worked with the procedures for a long time (Dell'Unto and Landeschi 2022, p. 16). However, there are ways in which this issue can be mitigated, primarily through the sharing of data and reprocessing of raw data. Specifically for SfM, there are several tools, for example point confidence in Agisoft Metashape[8] which gives a colour scale demonstrating how accurate the data is, which can be used to assess how well the data was collected. It is also usually clear how well the data was collected based on the quality of the mesh and textures/orthophotos as well as by checking the initial photographs. A lingering issue however, is that there is no possibility of controlling exactly how the data was collected, especially if metadata[9] is not available (Huggett 1995, p. 24). While it is clear that those considering themselves to be experts probably have more expertise than beginners, it is more productive that non-specialists are taught how to collect and process data correctly, rather than preventing them from starting at all (Gabriel and Jensen 2018).

8. A software used to process SfM datasets. https://www.agisoft.com/
9. Information that describes the data, for example lens type, focal length, ISO, etc. for a photograph.

Everyone has to start somewhere: Developing and teaching black-box tools means a greater number of engaged users and an increased amount of comparative data for projects. Being open with material and methodologies allows beginners to understand how they can improve their own data creation, and black-boxes give access without the necessity to understand the coding behind them. Simultaneously releasing code also empowers those that want to learn and develop to methods to understand the principles of the tool. This widens the user base by including both groups and reducing reluctance to engage with digital methods perhaps perceived as being too complicated. This is not to suggest that we should “dumb down” our methods or processes to the lowest possible level, but that we should make them as open and accessible to as many as possible. It is not just the practitioners who are enriched by specialists sharing their skills.

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Article twelve: Cost-effective, rapid decorrelation stretching and responsive UAS mapping as a method of detecting archaeological sites and features

Potter, Rich; Pitman, Derek; Manley, Harry; Rönnlund, Robin (2023): Cost-effective, rapid decorrelation stretching and responsive UAS mapping as a method of detecting archaeological sites and features. In *Heritage Science* 11 (1). DOI: 10.1186/s40494-023-00931-6.

I was the main author for this paper. My work included the conception and the majority of the writing, the entirety of the survey with help from Pitman and Manley, and the processing both in Agisoft Metashape and DStretch, as well as the work in ArcGIS. **(Overall contribution 80%)**

This article presents the results of the use of DStretch as a quick and cheap remote sensing method using drone based orthophotographs. Having noticed that the shallow archaeology at the archaeological site of Vlochos was causing the plants on the top surface to brown following a rather warm spring, we undertook a number of drone surveys and used DStretch to bring out the brown soil and vegetation in contrast to the green of the healthier plants. This enabled us to map the shallow archaeology underneath the surface very quickly and discover new areas of potential archaeology in parts of the site that we had previously not been able to access geophysically due to magnetic scrap, buildings, and a spoil heap. We confirmed our results by comparing them to the previously completed magnetometry, resistivity, and GPR survey. While this article is not strictly related to the overarching theme of Scandinavian rock art, it is included as it utilizes many of the same methods, and demonstrates their interoperability, as well as how the democratisation concepts can be applied unilaterally to other types of digital documentation.

Heritage Science

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Cost-effective, rapid decorrelation stretching and responsive UAS mapping as a method of detecting archaeological sites and features

Rich Potter[1*], Derek Pitman[2], Harry Manley[3] and Robin Rönnlund[4,5]

Abstract
Approaches to aerial photography and remote sensing have become increasingly complex, can rely on opaque workflows, and have the potential to be published with inaccessible language. Conversely, aerial capture has become increasingly accessible with affordable, user-friendly unmanned aerial systems (UAS) now being commonplace in the field-archaeology toolkit. This means that considerable amounts of data are being produced by diverse projects, yet only a limited quantity are subject to advanced processing techniques. This paper aims to address this imbalance through a low-cost, accessible workflow that pairs frequent (multi-temporal) surveys with straightforward, out of the box processing. The results are comparable to more complex methodologies without the need to invest in expensive hardware (although a fast computer will make processing quicker) or abstract workflows. The detail and depth are still available if needed, but the aim is to make the interpretation of a wide range of imagery easier, rather than focus on the mechanics of the phenomena. The results demonstrate an effective, inexpensive and user-friendly workflow that requires only limited computational skills, but which offers robust, highly interpretable results.

Keywords Drones, DStretch, Remote sensing, Structure from motion, Archaeology, Accessibility, NDVI

Introduction

This paper presents an approach to aerial photography in archaeology, which combines rapid, affordable and reactive survey using unmanned aerial systems (UAS) with image decorrelation-stretching techniques commonly used in rock art studies [1–3]. The approach is explored through a case-study at the multi-phase Archaic to Early Byzantine (500 BCE to 800 CE) site of Vlochos in Thessaly, Greece (Fig. 1). This approach uses UAS derived images processed with DStretch, a relatively inexpensive plugin for the open-source software ImageJ, which highlights subtle colour bands in RGB (Red, Green, and Blue) imagery. The results from this approach are compared to those from alternative archaeological prospection techniques such as Normalised Difference Vegetation Index (NDVI) imagery and geophysical survey, which were carried out in tandem at the site.

While aerial photography itself is commonplace in archaeology (see [4] for a concise summary of the approach in Europe, and [5] and [6] for detailed background) the ability to survey on multiple occasions in a variety of lighting and weather conditions using UAS has been relatively under-explored. The flexibility and frequency of UAS flights has created opportunities for significant developments in methodological approach. Additionally, the ubiquity and affordability of UAS technologies means that accessible workflows for the analysis

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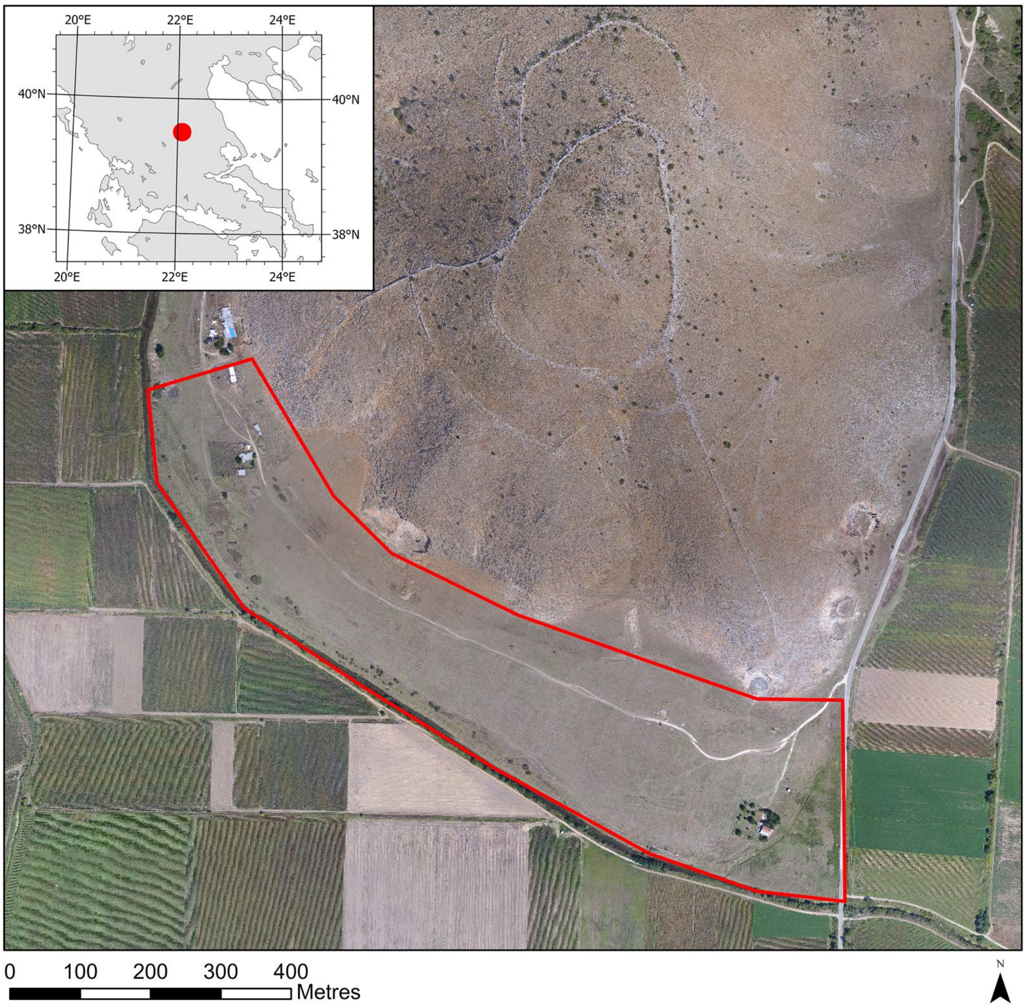

Fig. 1 Map showing the extent of the UAS survey and the gradiometry survey in the Patoma area of the Vlochos site

of aerial data are required to unlock the full potential of the dataset. Complex image analysis workflows have typically been reserved for highly specialized remote sensing projects (*cf.* [7, 8]). However, as argued here, if affordable and more accessible workflows can be established, then significant amounts of interpretative detail can be unlocked from the corpus of newly generated UAS data. Ultimately, the combination of affordable aerial capture tools and accessible image processing techniques can add significant value to the use of modern aerial imagery in archaeology.

Within the disciplines of landscape archaeology and archaeological prospection, visible light aerial photography has been supplemented/superseded by alternative techniques such as Light Detection and Ranging (LiDAR), multi-spectral image analysis, and landscape-scale geophysical survey [9–11]. However, the flexibility afforded by UAS photography has seen the technique become more widely used again, as reactive aerial imagery can now be captured routinely on projects when conditions are at their best [12]. This advantage can clearly be seen in the results from Vlochos [13, 14], where snow marks, only visible for a few hours, were captured and mapped using a standard, commercially available UAS, revealing numerous previously unidentified structures. In this paper, we explore this potential in combination with the use of decorrelation stretching, using affordable and accessible tools developed for rock art studies: the DStretch plugin for ImageJ [1]. This paper also considers the wider use of UAS survey in archaeological prospection and seeks to draw on the strengths of the approach, notably its affordability and rapid deployment, to increase the potential for identifying and characterizing archaeological features.

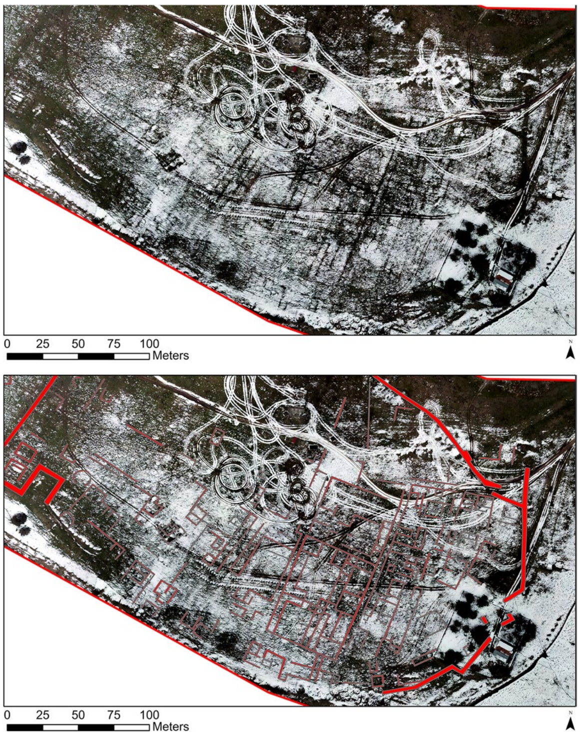

Fig. 2 Underground structures shown by melting snow (Photograph by Lawrence Shaw)

Background

The adoption of UAS survey has accelerated in recent years with projects at all scales routinely using low-altitude aerial photography (i.e. under 120 m) to survey sites as well as to produce digital surface models via Structure from Motion (SfM) [15–17]. However, this is typically employed within field methodologies as part of a like-for-like replacement for traditional aerial photography/LiDAR rather than as a more integrated/reflexive approach [11]. While it is starting to be discussed more in archaeology, recent publications such as [18], focus on the technical and economic aspects of UAS mapping in archaeology rather than the methodological affordances of the technique. Outside of archaeology, the advantages of this approach have been noted in environmental science (e.g. [19]) where there has been a steady adoption of advanced image processing and non-visible light-based approaches.

In terms of image decorrelation stretching, the approach was initially developed for aerial prospection with multiple case studies applying it to satellite remote sensing [20], but it has recently found other uses in archaeology (see below). This is largely down the development of an 'out of the box' plugin for ImageJ which allowed an accessible, open-source workflow to be developed. When decorrelation stretching has been used in archaeological and other types of prospection, it tends to be focused on highly quantitative image analysis rather than more qualitative image appraisal [21]. While the former is of clear value, the vast majority of uses of aerial photography in archaeology focus on the rapid prospection and characterization of sites, similar in scope and interpretive techniques as terrestrial geophysical surveys [22]. Overall, the methods tend to fall into two categories: large-scale approaches focused on automated (AI-based) feature recognition, and more site-specific appraisals that are handled by individual projects. The latter is significantly more routine in modern archaeology, despite the former attracting the bulk of funding and discussion.

Additionally, projects that focus on automation of data processing using machine learning, AI and crowd sourcing [23–25] tend to use relatively unprocessed RGB or multispectral imagery, rather than detailed image processing that aims to extract subtle, archaeological specific elements within aerial imagery.

The site used in this case study is commonly referred to as Vlochos (Fig. 1), and features the remains of a series of urban settlements of classical antiquity currently under investigation by the Palamas Archaeological Project (PAP). The project has produced a large amount of geophysical data, employing gradiometry,

Table 1 Table showing the details of all of the flights taken during the surveys

Survey date	Type/resolution	Photos taken	Height	Ground resolution
8th May	RGB (12mp)	875	49	1.8 cm/pix
9th May	RGB (20mp)	781	49	1.4 cm/pix
	NiR (1.1mp)	133	49	5.7 cm/pix
11th May	RGB (12mp)	601	60	2.1 cm/pix
13th May	RGB (12mp)	686	60	2.1 cm/pix
16th May	RGB (12mp)	999	60	2.1 cm/pix
	NiR (1.1mp)	540	60	5.7 cm/pix
18th May	RGB (12mp)	618	60	2.1 cm/pix
19th May	RGB (12mp)	620	60	2.1 cm/pix
20th May	RGB (12mp)	626	60	2.1 cm/pix
	NiR (1.1mp)	611	60	5.7 cm/pix

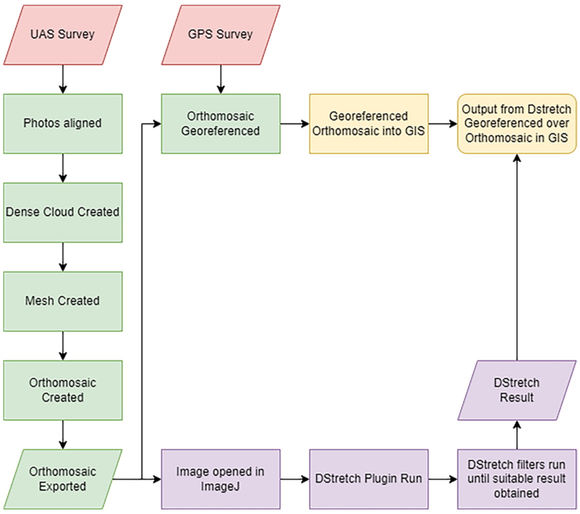

Fig. 3 Flow chart showing the creation process of the DStretch data

ground-penetrating radar (GPR), earth resistance, and a range of additional survey methods [13, 14, 25]. Excavations have also been carried out at the site in 2021 and 2022 [11]. The site has both deep and shallow archaeological features associated with substantial urban remains, including walls, cobbled roads, domestic and public buildings, etc., and represents an ideal test-bed for remote sensing approaches.

UAS-based aerial photography has been part of the package of methods used at Vlochos since the project inception in 2016. The initial aim was to use a combination of orthographic photomosaics, digital elevation models (DEM), and geophysics to map the site non-invasively and acquire an integrated digital dataset that could be used to explore the breadth of urbanization. Four techniques were used in total: gradiometry; earth resistance; GPR; and electromagnetism (EM) [13, 14, 25].[1] Each approach revealed different sub-surface features to varying extent. The gradiometry identified the full urban layout, but the spatial resolution was comparatively coarse. As such, GPR, earth resistance and EM were used in specific locations to reveal higher spatial resolution architectural details. However, some of the most detailed architectural results were revealed by the serendipitously captured snow marks (Fig. 2; [14]). The clarity of the results highlighted the potential of aerial photography as a prospection tool in itself, and a programme of seasonal RGB and Near Infra-red (NiR) photography was initiated. Both approaches were piloted in 2021 and initial results from NiR/NDVI were promising [14] with clear structured variation visible in the data which correlated with geophysical anomalies.

Study area

The study area at Vlochos has never been cultivated and consists of periodically grazed rough pasture-land covered in dense thistles and chamomile. As with cereal and legume crops, the differential growth of this vegetation during spring and early summer can be used as proxy for buried, near-surface archaeology. As such, the UAS surveys presented here were carried out in May 2022, when the vegetation at the site was just beginning to grow following an extended colder and wetter period in early spring followed by a period of warmth. This resulted in vegetation growing over near-surface archaeological features to dry out and turn brown. In certain areas, a simple visual appraisal of vegetation colour-differences indicated the presence of archaeological remains below the ground, but in other areas, the details were more ephemeral and could not easily be distinguished from either ground-level or from the unprocessed orthographic photomosaic.

Method: UAS image capture

Aerial surveys were carried out at the site every second working day to evaluate if the changing levels of soil moisture would affect vegetation growth, and in turn indicate buried archaeological features.

For the initial drone survey, a total of 865 photographs were captured using a Mavic 2 Air from a height of 49 m (though further surveys were conducted at 60 m) with 15 ground control points (GCPs) measured using an NRTK-GNSS unit included in the imagery. The survey area of interest consisted of approximately 25.5 hectares. (details of each flight can be found in Table 1, note that some flights included additional areas and may include extra photos). The survey took about 35 min, including setup time and programming of the flight. Photographs were taken at a speed of 5 m/s with an overlap of 75% front overlap and a 70% side overlap. The images were processed into a mesh in Agisoft Metashape[2] using a standard Structure from Motion methodology [26–28]. Following photographic alignment, a dense point cloud was created and points with too low an alignment confidence value (in this case, points with a confidence below three) were removed. The dense cloud was then

[1] Earth resistance uses an electronic signal to detect variation in moisture beneath the surface and is often used for mapping buried walls and foundations. Ground penetrating radar uses radio waves to detect buried features. Electro magnetism uses an electromagnetic field to identify contrast in conductivity in the soil. Gradiometry uses the earth's magnetic field to detect subtle variation in magnetism in buried deposits. The latter is the quickest technique and therefore gives extensive coverage. More details about these methods and how we employed them can be found in our previous publications [13, 14, 25].

[2] There are also open-source options available to process Structure from Motion models, but since we are experienced with Agisoft Metashape we chose to use this software.

Fig. 4 Un-processed RGB orthographic photograph of the site from May 16th 2022

calculated into a mesh which was georeferenced using the NRTK-GNSS control points. From this mesh, a georeferenced orthophoto with a high spatial resolution (0.05 m) was produced. The orthographic photomosaic was then processed using a decorrelation stretch process as outlined below. An additional UAS fitted with a Sentera High-Precision Single NiR sensor[3] was used to simultaneously capture standard RGB and NiR imagery.

Decorrelation stretching

Decorrelation stretching is a tool that was initially developed for processing aerial photography and satellite imagery [29] within general earth observation systems. It has been used most extensively in archaeology in legacy and archive imagery [30], though similar work with UASs has previously demonstrated its effectiveness when combined with other processing techniques [31]. The process has, however, been successfully and routinely applied to rock art identification and interpretation [32–34]. While decorrelation workflows can be complex (e.g. [21, 35], here we drew on the previous work by De Reu et al. [31] by using a simple tool called DStretch. DStretch is a plugin for the image processing software ImageJ, commonly presented as a tool for the evaluation and enhancement of poorly visible or pigmented paintings and rock art (e.g. [1–3]).

Within the plugin there are a number of different colourspaces: a specific subset of the colour spectrum, limited by the software [1]. While De Reu et al. [31] successfully used Lab and LRE colourspaces, there are also a number of other options, the details of which can be found in the plugin documentation [1]. It is important to note that this technique is highly condition dependant. Numerous variables can influence the choice of best colourspace such as the time in the vegetation cycle, ground cover, vegetation type as well as a range of localised conditions such as agricultural practices. The most straight forward approach to this is to experiment with each colourspace to identify the most effective for any given conditions (see [3] for an in-depth description of decorrelation stretching).

Within our suggested workflow, an orthographic photomosaic was exported from Agisoft Metashape as a jpeg-file (as ImageJ cannot natively open tiled tifs and

[3] More information about the sensor can be found here: https://sentera.com/wp-content/uploads/2022/08/Sentera-SingleSensor.pdf

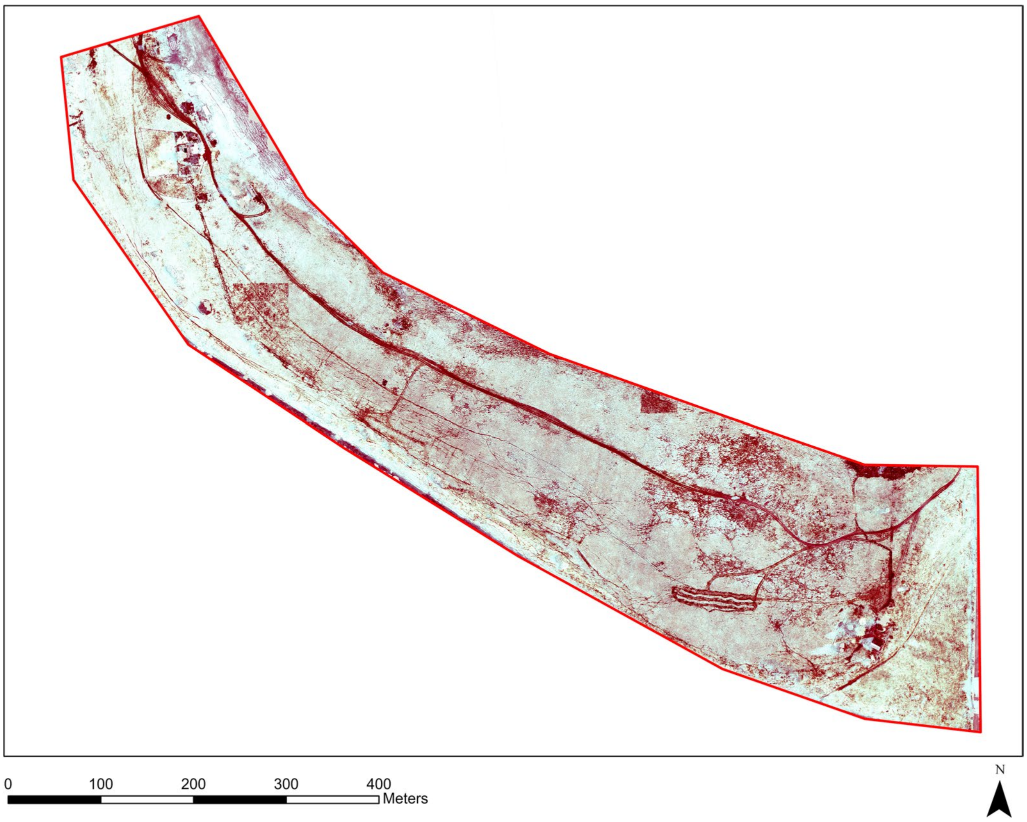

Fig. 5 Decorrelation stretched image from May 16th 2022, same extent as Fig. 4

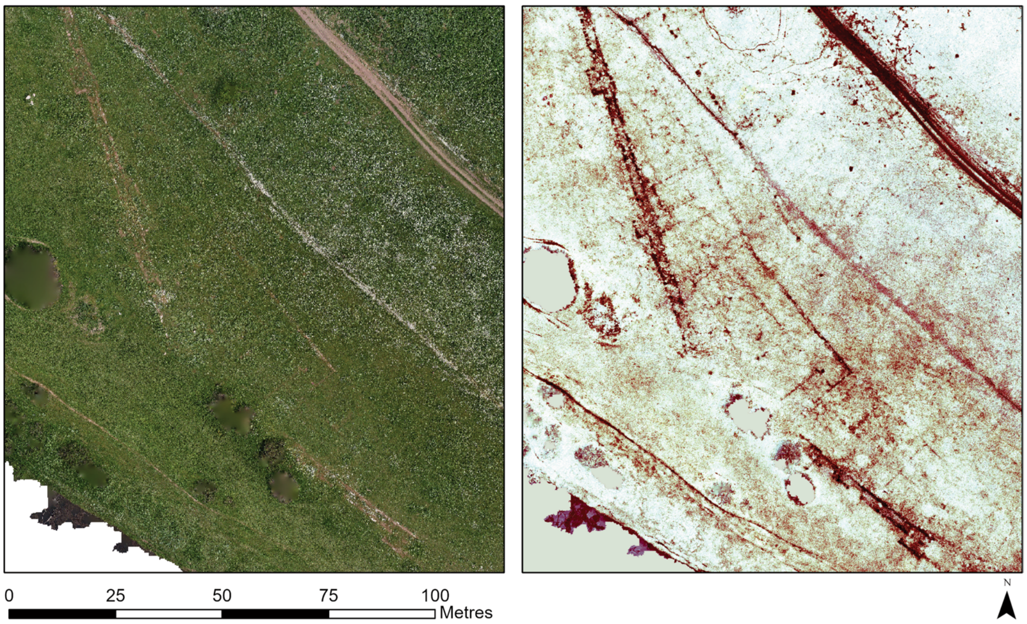

Fig. 6 Detail of the area containing a probable stoic building (at centre), showing the difference between unprocessed RGB imagery and decorrelation stretched data

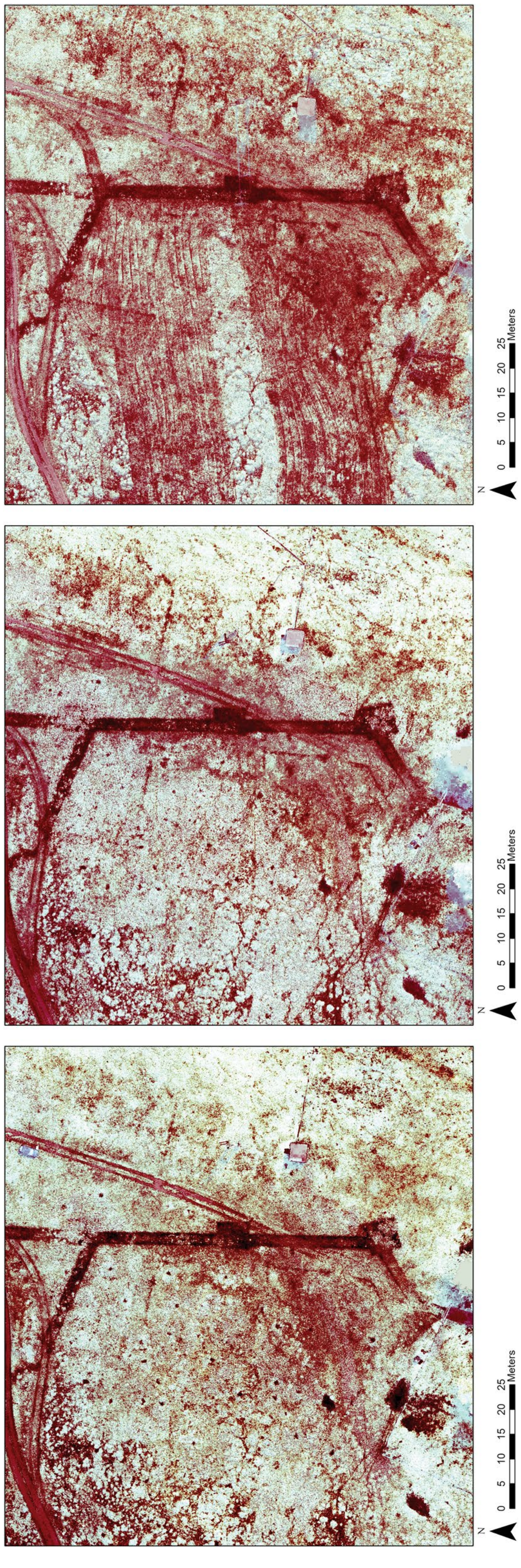

Fig. 7 Series of decorrelation-stretched aerial captures over the two-week period progressing from left to right. Buried fortifications are clearly visible. There are more wheel tracks on the latest image as the field had recently been mowed

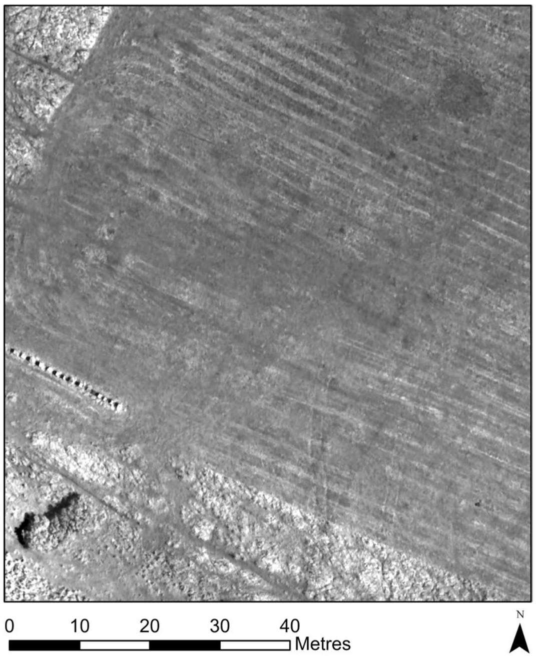

Fig. 8 Data from the NDVI survey

struggles with larger files), and imported into ImageJ and processed using the DStretch plugin (Fig. 3).

Once the images were imported into ImageJ, we applied each colourspace in turn. Each colourspace offers a slightly different output, which can be used interchangeably depending on the type of data analysed and the features sought. In this case, the "YRE" colourspace (which enhances and draws out red in the images) proved the most effective (see results below). This is perhaps not surprising given the red channel in a RGB composite is indicative of vegetation health, i.e. through drier plants or sparser vegetation cover. By enhancing the areas within this band, the influence of near-surface archaeological remains on plant health could be used as an indicator of buried archaeology. Other colourspace filters were less effective at enhancing sub-surface features in this case. However, since the results are dependent on the type of visible phenomena, they may prove useful on other types of sites.

Results

Overall, the results from the DStretch-processed images were promising. Numerous features that were visible in the geophysics were also clearly visible in the DStretch-processed UAS data. Crucially, very few of these features were visible in the raw data (Figs. 4 and 5). The data also indicated several new areas of archaeological potential that were previously unidentified by the geophysical survey due to both terrain constraints and magnetic "noise" from adjacent pasture buildings at the eastern end of the site.

Over the course of the field season, with continued warm and dry weather, the details of buried features became more and more visible from the DStretch-processed orthographic photographs. However, the best results came following a night of rain before the penultimate survey. This made the soil slightly darker which provided more contrast in the YRE filter.

In addition to the drying-out of the site, work was also carried out to remove some of the higher vegetation. While this helped to enhance the results to an extent, it also meant that more of the soil became visible, which actually reduced the contrast of the DStretch data. Conversely, the NDVI data in the freshly mowed areas of site became clearer (Fig. 6).

Its notable that the use of multiple flights revealed subtle changes throughout the season. As can be seen in Fig. 7, the levels of contrast improved in some areas towards the end of the season. This reinforces the argument for taking multiple captures throughout the season/year where possible. This again is a clear advantage of rapid UAS photography. Similarly, the impact of mowing can be seen in the DStretch-processed imagery with some features becoming less clear in the mowed areas. This is contrasted with the NDVI data, which conversely became clearer in these mowed zones (Fig. 8).

Most importantly, in the context of the case study, the approach revealed new features in areas that were inaccessible to other techniques (Fig. 9). Extramural areas that have significant metallic contamination (making gradiometry survey-techniques difficult) can be clearly seen to contain structural remains (Fig. 10), and buried foundations of monumental architecture can be seen in areas previously thought to have been truncated by modern quarrying activities.

Discussion

Each technique used in this experiment led to the identification of apparent archaeological features. Given that the site had already been surveyed in detail using geophysical survey methods later confirmed through targeted excavation, it was possible to appraise the aerial imagery data rapidly.

Both the decorrelation stretching and the NDVI approaches identified features previously seen in the geophysical data, yet the DStretch approach revealed details that were previously unknown. In addition, where features appeared in both the geophysical and newly obtained datasets, the DStretch data displayed a sharpness and clarity that was lacking in the extensive gradiometry data, and which could only be identified geophysically through much slower techniques such as

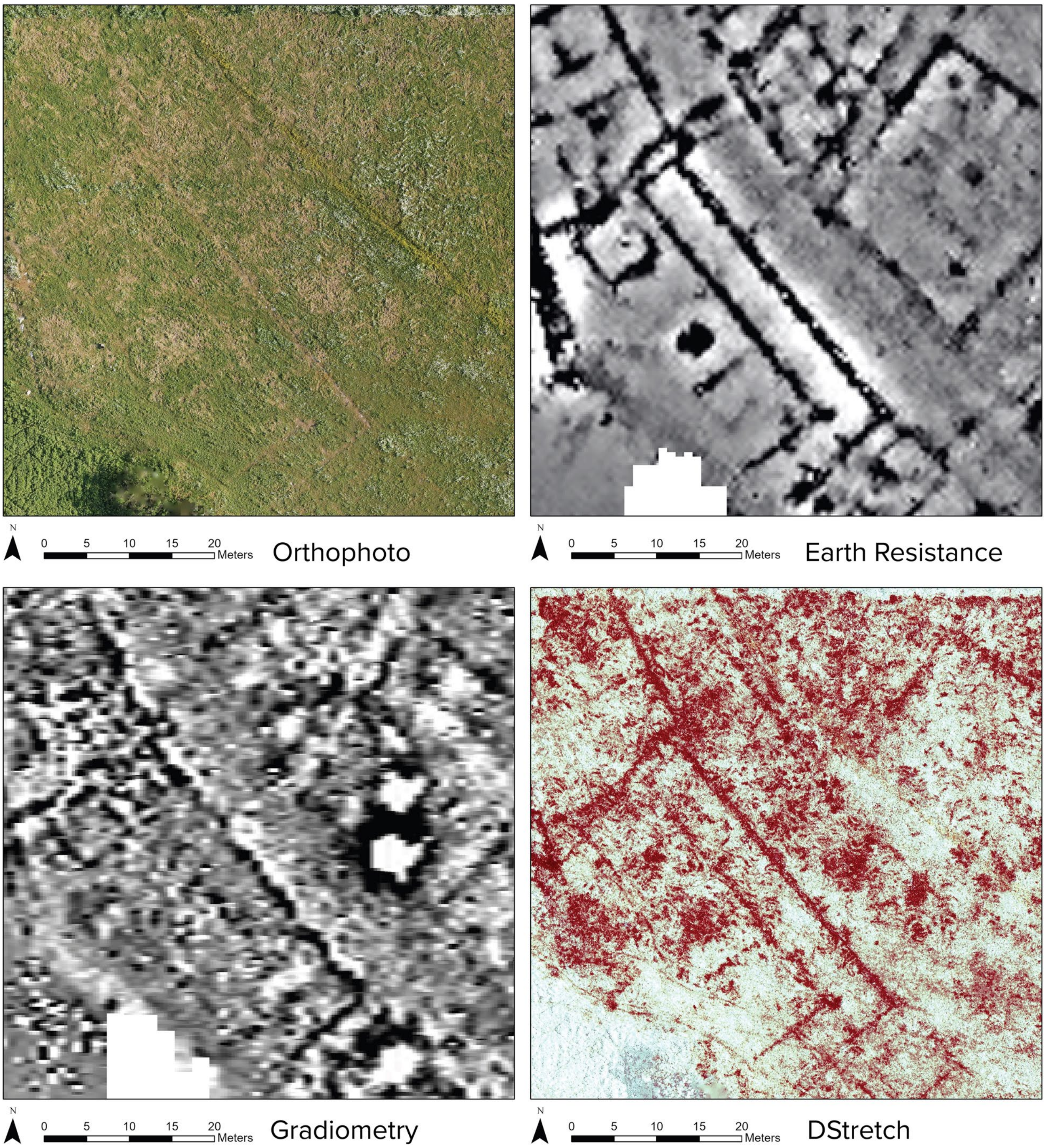

Fig. 9 Comparison between multiple techniques (Earth resistance: black = high resistance, white = low resistance. Gradiometry: black = low magnetism, white = high magnetism)

earth resistance and GPR. This means that significant portions of the site can now be understood at a much finer spatial resolution than before, with far less investment in terms of both time and funds. The use of multiple flights during the field season allowed for subtle variations in sub-surface architecture to be revealed in a way that would not have been possible with only a single flight.

The results presented here highlight the value of the responsive nature of UAS photography. Different

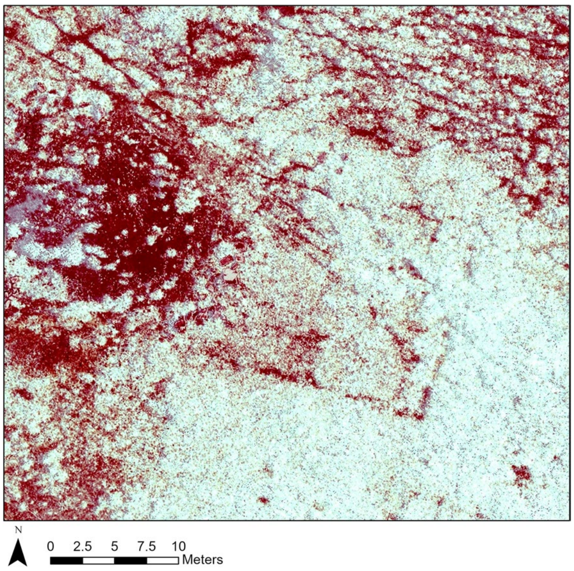

Fig. 10 Area within the ancient urban settlement which was unavailable for geophysical surveying, but which appears to show architectural remains

features, and different areas of the site varied in clarity day by day and under different weather conditions. While it has long been acknowledged that aerial photography is highly condition dependent [22], the ability to survey on multiple occasions—which is afforded by UAS technologies—has the possibility to revolutionize site prospection and characterization. The data presented here demonstrates that there exists an affordable and relatively user-friendly workflow for the processing and interpretation of the vast quantities of aerial data that are currently being produced by projects worldwide (Fig. 11).

It is important to acknowledge that the DStretch method worked especially well with this site because of the shallow buried archaeology (which we have found through excavation to range from surface to 30 cm deep [14]) and because the vegetation was in exactly the right phase of growth. The method will consequently not be useful at all sites. However, due to the low cost of the DStretch software, the wide occurrence of crop marks, and the fact that a large number of archaeological projects have access to UAS systems, we would argue that this method offers an excellent first step when assessing

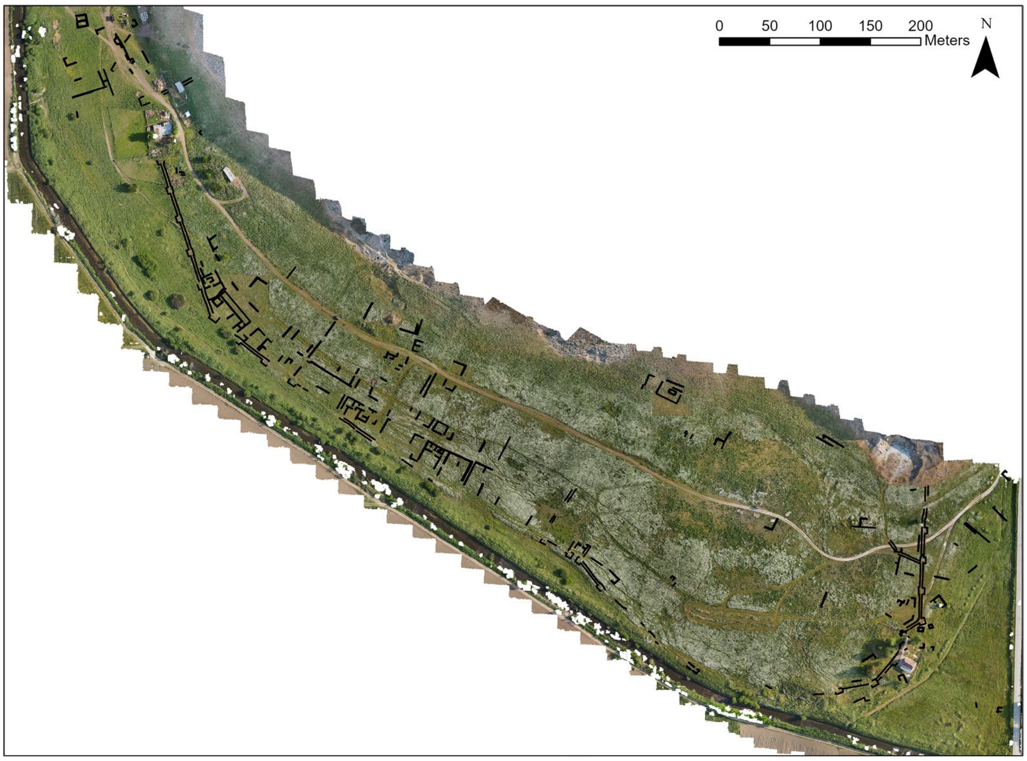

Fig. 11 Interpretation of results from UAS survey from the site

the location of new sites, or when attempting to get a good overview of the archaeological remains. This is especially true given the fact that UAS techniques can be deployed at relatively short notice when conditions are optimal for visible cropmarks.

Conclusions

This paper has shown that decorrelation stretching, using the DStretch plug-in, offers a viable tool for highlighting archaeological features in aerial imagery. The method demonstrated is inexpensive, easy to use, rapid, and provides results that can be used as a precursor to geophysical surveys or as a cost effective and rapid alternative/compliment to traditional terrestrial surveys. Employing it at the site in Vlochos, we were able to identify new archaeological features in areas that we had not been able to cover geophysically due to terrain constraints or magnetic contamination. It is hoped that this method can be developed further in the future and be used as a rapid evaluation tool for archaeological projects prior to the application of expensive geophysical surveys and other more intrusive methods. As most archaeological field projects are (or at the very least should be) using aerial survey as a recording tool, it would take very little effort to adopt the DStretch image analysis process outlined above to the wider survey method.

Abbreviations

UAS	Unmanned aerial systems
NDVI	Normalised Difference Vegetation Index
RGB	Red, Green, and Blue
SfM	Structure from Motion
LiDAR	Light Detection and Ranging
DEM	Digital Elevation Models
GPR	Ground Penetrating Radar
EM	Electromagnetism
NiR	Near infra-red

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Author contributions

All authors contributed to the writing and production of the article with Rich Potter taking the lead. Drone fieldwork was carried out by Rich Potter and Harry Manley. All authors critically reviewed the paper.

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Availability of data and materials

The data was generated by members of the Palamas Archaeological Project, and can only be acquired with permission from the Greek Ministry of Culture and Sports.

Declarations

Competing interests

The authors have no relevant financial or non-financial interests to disclose. The authors have no conflicts of interest to declare that are relevant to the content of this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article. The authors declare that there are no known competing interests.

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Publisher's Note

Chapter six: Conclusion

This thesis has demonstrated that I have positively contributed to rock art studies, digital archaeology, and our understanding of Scandinavian rock art. My research has contributed methodologically, thematically, and intellectually to the discipline, both through publication and my ongoing work at the University of Gothenburg. By introducing RTI to the department of historical studies, I brought in a new way of looking at the rock carvings which gave us the possibility to gain a greater understanding of the carvings and how they were produced in both the Kivik tomb and the Bohuslän area, as well as supporting the argument that carvings were reused and recarved (Bertilsson et al. 2017; Horn and Potter 2018; Horn et al. 2018). Additionally, I used RTI to determine that several "blind" Iron Age picture stones did in fact have carvings on them on Gotland, Sweden (Andreeff and Potter 2014). I was also involved in the introduction of handheld laser scanners at Gothenburg University, and their use and testing in Kivik and Finntorp (Horn et al. 2018). I have used SfM extensively in the field, and developed a documentation methodology that consistently creates high quality reconstructions which we now teach at both a Bachelor and Master's level. Through these reconstructions I have developed and helped develop various visualisation techniques that bring out the detail in rock carvings (Horn and Potter 2019; Horn et al. 2019; 2022b) and used these as a discussion point in the understanding of rock art creation and use (Horn et al. 2022d; Horn and Potter 2020). I have also applied these methods to projects which are external to Scandinavian rock art (Potter et al. 2023a; 2023b; Vaïopoulou et al. 2022). Throughout these publications I have aimed at presenting workflows that have been possible to be reused by external researchers by using software that is standard to the typical archaeological workflow (Horn et al. 2022d; 2019; Potter et al. 2022; 2023a). This has been further consolidated by a discussion article relating to the democratisation of rock art studies (Potter et al. forthcoming).

This thesis began with a brief introduction to the primary material that the documentation methods cover. Firstly introducing the Bronze Age, it moved onto an overview of Scandinavian Bronze Age Rock art, a maritime based tradition in which varying motifs were pecked into bedrock surfaces along the shoreline.

From there, traditional non-digital methods were introduced, including some that are no longer used i.e. plaster casting, and a number which are still commonly used, i.e. rubbings, tracings and squeezes. Some of the benefits of these methods were described (high detail, ease of creation, understandability), as well as some of the issues that working with analogue methods creates (physical space requirements, creator bias, creating 2D documentation of 3D surfaces, potential damage to rock surfaces – Chapter 3).

Following this, the current digital methods were introduced. Firstly RTI, a method which involves a static camera and a moving light and creates PTM files (highly detailed 2.5D images have the possibility to interactively move a light and adjust parameters like specularity). Secondly, laser scanning, a technique which uses expensive scanners (either static or handheld) to create high resolution point clouds and 3D meshes. Thirdly SfM, a photogrammetric method that creates 3D models from series of overlapping photographs taken at a site. Within each introduction, a general overview of how the documentation methods are applied to rock art was given, and some of the benefits and problems with the methods were stated. Once recorded, the documented rock art panels are then visualised in order to better show where carvings are, and to evaluate and analyse factors including carving style, motif type, and to find previously unknown carvings. A description of how the outputs of the field documentation are processed and visualised within the field of rock art concludes the chapter (Chapter 4). It is clear that there is no one correct way to document rock art carvings, since each has benefits and flaws that the others do not i.e. laser scanning is the most accurate but expensive, RTI gives the best detail but is only 2.5D, and SfM is the most versatile, but easiest to get wrong. Since visualisation methods similarly bring out individual details in different ways, with some areas being more visible than others, it is clear that a combination of both documentation and visualisation methods is best way forward. It has been demonstrated that digital approaches to documenting rock art surfaces are an extremely valuable resource both in terms of the quality and versatility of the results and through the potential to take the results further by processing them using techniques which can be adapted to the type of surface recorded.

Finally, an introduction to democratisation and accessibility issues in the field of rock art was given, in connection with an article focusing on digital democratisation as a supporting document. From here suggestions about how rock art research can be democratised from the initial naming of the sites to the dissemination of the raw data and the results of visualisations, as well as in terms of how the methodologies should be described and published were offered (Chapter 5). Building upon Open Science and the FAIR principles, it was determined that as well as being open with data and results, the presentation of the methodologies used for both recording and visualisation could be improved upon. One of the key suggestions was that, while complex visualisation methodologies are to be encouraged, since they are often innovative and groundbreaking, it should be remembered that not everyone is competent at coding – even in open-source languages like R. As such, and in the interest of longevity of methods, code should be compiled before it is released if possible, and released in such a fashion that it can be used as a black-box where only the inputs and outputs need to be understood. This thesis has demonstrated that while there should be no limitation on the complexity of a method in how it creates visualisations, for it to be of any practical use it needs to be accessible to the majority, and presented in such a way that it has some longevity and is usable without training. Ensuring that methods are democratic not only enables more research from an outward perspective, but it also improves the status of the presenting researcher, as people continue to use, develop, and build upon their work.

This thesis examined the current documentation methods and investigated to what extent digital methodologies have made rock art documentation more democratic, and what this means for researchers and the general public. It is clear that in comparison to the traditional analogue methods, that the digital methodologies are far more democratic and accessible, primarily because of the mediums in which the documentation is created. By its very nature, digital documentation is easily transmissible via digital means, i.e. the internet and other storage mediums. There are however issues with this, including the requirement for internet access and the cost and availability of storage. Data storage is the main issue that we currently face within digital archaeology. As technology improves, the file sizes that we can work with get bigger and the processed models increase in size and detail, leading to the requirement for larger storage. There is no clear solution to this at present.

Of the digital documentation methods described, SfM is seemingly the most democratic in terms of the data that is collected and the possibility to process the output further. However, the lack of viable open-source software for processing is an issue. RTI does not have this software issue, but the output is limited to 2.5D documentation and only being viewed in the specific RTI viewer. Laser scanning is clearly the least democratic method based on its high-cost.

In terms of visualisation, no one method can be claimed to better than any other as each have their own qualities and surface types that they are useful for. The most important factor is presenting the methods in an easy way which can be replicated by other researchers, and consideration of who will be able, and have the need, to use the method.

In addition to making the data more accessible to archaeological researchers, there are also benefits had to making data more accessible to other fields of study and the general public. An example of this is our current work with geologists, who have helped us gain an insight into the processes of rock formation, and as to how the rocks may have been carved. By making research accessible to the general public, there is a greater likelihood of additional discoveries, and unexpected advancements to techniques from the inclusion of specialisms that would not normally be associated with archaeology.

The thesis was supported throughout by article submissions that have primarily been published in ranked peer reviewed journals. Based on the above, these submissions demonstrate that I have made a significant contribution to the field of Scandinavian rock art which is more than equivalent to that of a traditional PhD. These submissions have also shown that while starting off primarily as a junior researcher working with documentation, I have progressed to developing and working on my own projects from start to finish (See figure 1). This is something that I hope to continue in the future. While the overarching theme of these papers has primarily been that of rock art research in Scandinavia, a key takeaway from them has been that the majority of the techniques included within them can be applied to multiple aspects of archaeology, as demonstrated in article 12. While the subject here is relatively niche, the concepts of democratisation that are applied to the documentation, visualisation, and dissemination of the work within this thesis can easily be applied to nearly all aspects of archaeology.

6.1. Future Work

In this final section, planned future work will be discussed. It is obviously my intention to continue working within the field of Scandinavian Rock Art research. There are a number of projects that are already in the pipeline including an app for identifying similar rock art motifs, and a larger landscape based project in the Bohuslän area. These are introduced below.

Already in production is an application which I have designed and which is now being developed within the SHFA. The application is intended to allow researchers to upload outline images of motifs they are interested in and discover sites which have highly similar motifs based on an automated comparison of the shape. This will allow researchers to find comparative material, as well as find patterns relating to both the placement and relationships between panels and motifs on panels as well as within the landscape. The application is currently being developed by Ashely Green (University of Gothenburg) and will be released free of charge via the university website.

A second project relates to an area that I have already begun to work with in Bohuslän, Sweden. When the Bronze Age water levels determined by Ling (2014) are applied to a DEM map of the Bohuslän area with the known rock art locations marked, it becomes apparent that there is an area in Källeby which seems to be relatively isolated from other rock art in the region. Within the area there are over eighty rock art panels of varying sizes and shapes, and the intention here is to document them all, digitize them, and analyse them in terms of production, content, and similarities between panels. As well as a close-up analysis of the panels, there will also be a more zoomed-out analysis of the area. Using the Department of Historical Studies, Gothenburg University, LiDAR drone, I plan to capture a high-resolution DEM of the landscape and analyse the location of the sites based on water flow (Horn et al. 2022d). Additionally, the area will be evaluated from a landscape perspective, and in loose comparison to neighbouring areas. The hoped output will be a monograph on the area and the potential discovery of some new panels.

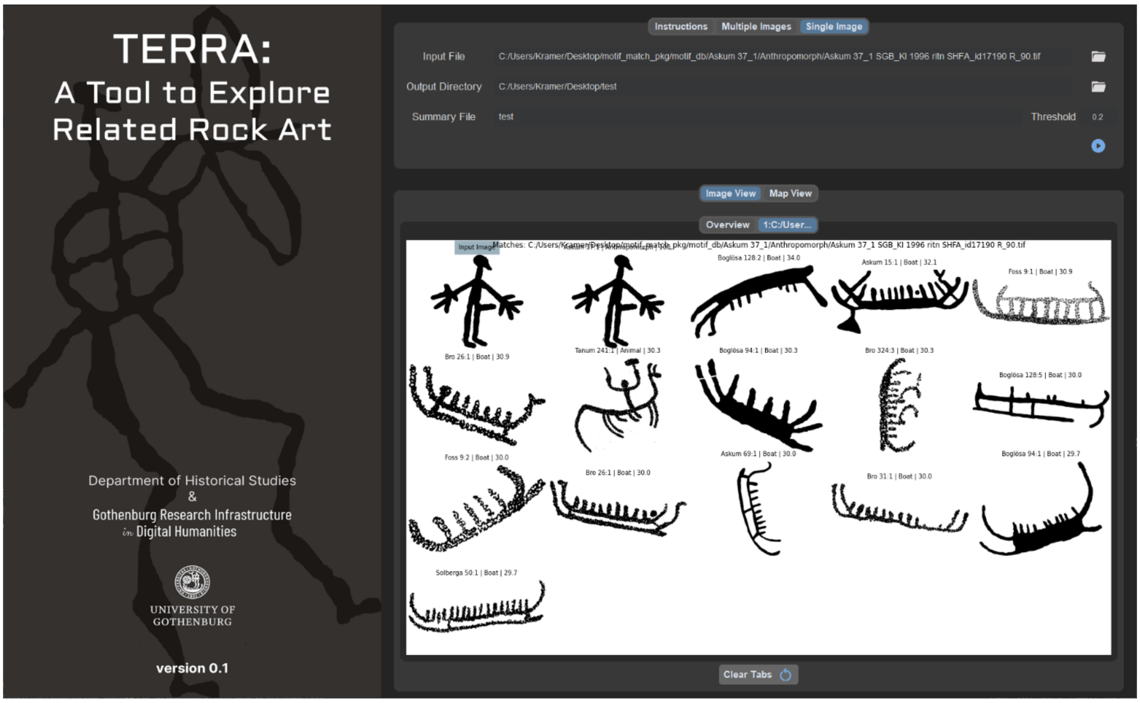

Figure 41: *Screenshot from reverse image search application (Created by Ashely Green)*

I have also just received funding to create a study on how various lens types affect the quality and possibilities of creating SfM documentation. The primary purpose of this study is to determine how much of a difference the lens makes, as well as to compare the results to various qualities of camera, including smartphone cameras, to determine what the absolute base requirement is for detailed rock art studies. This will include the real-world practicalities of taking up large surfaces, rather than what is best on paper.

Having obtained funding from Epic Megagrants to set up a digital Master's Course in collaboration with Christian Horn, we were able to create a digital archaeology laboratory as well as two successful courses in digital archaeology: one at an introductory level, and the other at Master's level. Given the laboratory's success in helping digital based projects at the department, we have decided to develop this into a research cluster for digital and natural scientific archaeology. This will allow us to build a network of practitioners and researchers in method development to collaborate within innovative projects, and hands-on teaching. Our goal is to raise the profile of the laboratory and the department by increasing our research output and level of teaching.

Should this submission be successful, having a doctorate would enable to me to apply for larger funds, for example Riksbankens Jubileumsfond[48] and Vetenskapsådet.[49] It will also allow me to confidently expand my current network, and apply for smaller funds to run my own projects both in Sweden and Internationally.

48. Riksbankens Jubileumsfond – www.rj.se (accessed 20/07/23)
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