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University of Bergen Archaeological Series

The Stone Age Conference in Bergen 2017

Dag Erik Færø Olsen (ed.)

UNIVERSITY OF BERGEN

12

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Preface

This anthology is based on contributions presented as part of *The Stone Age Conference in Bergen 2017 – Coast and Society, research and cultural heritage management*. The conference was co-organized by the Department of Archaeology, History, Cultural Studies and Religion (AHKR) at the University of Bergen and the Department of Cultural History at the University Museum of Bergen (UM). The organizing committee included Dag Erik Færø Olsen (leader) and Tina Jensen Granados from AHKR, together with Leif Inge Åstveit and Knut Andreas Bergsvik from UM.

The Stone Age Conference in Bergen 2017 was the third instalment of the "Stone Age Conference" series to be organized in Norway. The first conference was held in Bergen in 1993 (Bergsvik *et al.* 1995) and the second in Molde in 2003. The purpose for the 2017 conference in Bergen was to gather archaeologists with common interest in the Norwegian Stone Age and from all parts of the national Stone Age community. Several prominent research communities exist in Norway today and representatives from all University departments and from the majority of the County Municipalities was gathered to share current results and to discuss common issues and strategies for future research.

Since the last conference in 2003, the cultural heritage management in Norway has made large quantities of new archaeological data accessible for research. Such extensive new data has provided new methodological and theoretical challenges and opportunities which is reflected in the scope of research published within the last 20 years.

The Stone Age Conference in Bergen 2017 wanted to reflect the new empirical, theoretical and methodological diversity, and to highlight how these developments could be integrated into the cultural heritage management and within future research. The conference was structured by current themes and approaches and divided into five main sessions (including a poster session) and seven session themes (see Sessions and papers at the end of this volume).

An increasing association with the *natural scientific approaches* was one important theme of the conference focusing on research on climate change, aDNA and new and improved methods for analysis and dating. Related to this was the general theme *technology* were studies on raw material and technological studies are used in mobility- and network analysis.

Managing and utilizing the large quantities of data generated over the last two decades was the basis for the themes *demography* and *subsistence changes*. The theme *methodological developments* included increasing digitalization and how this is used in rescue archaeology, with challenges and new possibilities. The conference also wanted to explore aspects of *ritual communication* where various forms of expressions, such as rock art, could elaborate and increase our understanding of several of the other main themes mentioned.

During the three days of the conference a total of 46 15 minutes presentations addressed various topics and aspects within the seven session themes. All sessions were led by session leaders and three of the conference sessions were introduced by key note speakers.

After the conference, it was decided to publish an anthology, inviting all participants to contribute including the poster participants. The publication was to be in the University of Bergen Archaeological Series, UBAS, and with Dag Erik Færø Olsen as editor of the anthology. Ten papers were submitted from all the sessions and is representative of the topics presented and discussed during the three-day conference. The papers included in this volume are organized mainly geographically starting with Northern Norway moving southwards.

Kenneth Webb Vollan focuses on housepit sites in Arctic Norway using radiocarbon dates for distinguishing reuse or occupational phases. He presents a method for analysing dates following the Bayesian approach and shows that the housepits were reused to a much larger degree than previous acknowledged.

Skule Spjelkavik and *Axel Müller* explores similar topics in their paper about quartz crystal provenance. By using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) they were able to compare debitage from the Early Mesolithic settlement site Mohalsen I at the island Vega with samples from 19 known sources in Norway. This is especially interesting since there are no known quartz crystal occurrences at Vega and was consequently brought from the main land or other areas. This study shows the potential for using this method, even though no clear parallel to the Mohalsen debitage could be identified in the analysed material.

Jan Mangerud and *John Inge Svendsen* explores colonization processes from a geological perspective. They document how an ice sheet margin presented a physical barrier across the Oslofjord preventing human immigration until the onset of the Holocene, providing an interesting backdrop for discussing aspects of colonization processes in the Early Mesolithic.

Arne Johan Nærøy discusses the use of tools and behaviour patterns based on use-wear analysis of quartz assemblage from the site 16 Budalen in Øygarden, Hordaland County. He is able to distinguish two individuals operating at the site suggesting spatially segregated work operations. Nærøy shows through this study the potential for functional analysis of lithic material from settlement sites.

Astrid Nyland, Kidane Fanta Gebremariam and *Ruben With*'s contribution represents both the new technological and methodological developments and the interdisciplinary nature of archaeology today. This paper explorers the potential for using pXRF for regional provenance analysis of greenstone adzes in western Norway. This study revisits an older interpretation of the division of this region into two social territories in the Middle and Late Mesolithic. The results show that the method is robust and well suited for studying green stone and the authors can also largely confirm the original interpretations based on distribution networks of Mesolithic adzes.

Birgitte Skar discusses the early postglacial migration into Scandinavia based on aDNA studies on two Early Mesolithic Norwegian skeletons. Skar's results confirms the recent interpretation of a second migration into Norway from the Northeast thus contributing to the overall narrative of the colonization of Norway.

Almut Schülke revisits the topic of Mesolithic burial practises in Norway based on new data from recent excavations. Schülke highlights that human remains are often found at settlement sites, opening for discussions of various relationships between the living and the dead and human-nature engagement.

Krister Eilertsen presents results from an excavation of an Early Neolithic hut in Rogaland, Southwestern Norway. He discusses classical interpretative challenges where the lithic material and ^{14}C-datings are not comparable. Eilertsen emphasise the importance of not dismissing difficult results but rather try to find an answer to the differences in light of a wider analysis of the area including various natural and cultural processes. He is thus able to explain the contrasting data and provide new insight into settlement patterns and economy at the start of the Neolithic.

Dag Erik Færø Olsen reviews the rock shelters in the mountain regions of Hardangervidda and Nordfjella. The previous interpretation of these settlement sites as primarily from the Late Neolithic and onwards is discussed based on a reclassification of archaeological material. The results show that rock shelters have been used from at least the Middle Mesolithic and in some cases with an intensification and stronger continuity after 2350 BC.

Gaute Reitan discusses the chronological division of the Mesolithic based on new data from excavations the last 20 years. Reitan presents a revised chronology for the Mesolithic in Southeast Norway dividing each of the three main phases into two sub-phases, adding two new phases to Egil Mikkelsen's original from 1975.

Acknowledgements

On the behalf of the organizing committee, we would like to thank all participants of *Steinalderkonferansen i Bergen 2017* for sharing their knowledge and for the discussions that followed at the conference. We also want to express our gratitude to the conference key note speakers, Prof. Kjel Knutsson (Dep. of Archaeology and Ancient History, Uppsala University), Assoc. Prof. Per Persson (Dep. of Archaeology, Museum of Cultural History, University of Oslo) and Prof. Charlotte Damm (Dep. of Archaeology, History, Religious Studies and Theology, The Arctic University of Norway) for introducing three of the conference sessions. This gratitude is also extended to five session leaders, Assoc. Prof. Arne Johan Nærøy (Museum of Archaeology, University of Stavanger), Prof. Marianne Skandfer (The Arctic University Museum of Norway), Assoc. Prof. Birgitte Skar (Dep. of Archaeology and Cultural History, NTNU University Museum), Prof. Hans Peter Blankholm (Dep. of Archaeology, History, Religious Studies and Theology, The Arctic University of Norway) and Prof. Almut Schülke (Dep. of Archaeology, Museum of Cultural History, University of Oslo).

During the three-day conference the committee received assistance from voluntary students from The University of Bergen and they provided valuable help during the conference.

We would also like to thank the following institutions for their generous funding:

Bergen University fund (UiB), University Museum of Bergen (UiB), Museum of Cultural History (UiO), Museum of archaeology, University of Stavanger (UiS), The Arctic University of Norway (UiT), NTNU University Museum, Department of Archaeology, History, Cultural Studies and Religion (UiB), and the Directorate for Cultural Heritage (Riksantikvaren). Without this support it would not have been possible to organize the conference. The Museum of Cultural History also contributed generously towards the production of the book.

The editor of this anthology would further like to express gratitude to all the anonymous peer reviewers whose valuable comments and insights has made this publication possible.

Last, but not least, thank you to the authors of this anthology for the patience and work on the papers that make out this volume.

Dag Erik Færø Olsen and Tina Jensen Granados – Oslo 2021

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Astrid J. Nyland, Kidane Fanta Gebremariam and Ruben With

Challenging an old theory – Portable X-ray fluorescence (pXRF) analyses of greenstone adzes in Rogaland, southwestern Norway

Abstract

The first large scale regional provenance analysis of greenstone and diabase adzes in western Norway was undertaken forty years ago. The study identified two social territories, which have been central in Norwegian archaeology ever since. Concerns have later been raised regarding the validity of the results due to the dominance of descriptive macroscopic methods, mostly based on visual examinations, used to identify the different rock types. To evaluate the older study, we have undertaken portable X-Ray Fluorescence Spectroscopy (pXRF) analyses of greenstone adzes distributed in Rogaland County, southwestern Norway. However, there are also challenges pertaining to this type of surface-confined analytical technique, such as effects of patination, surface depositions, surface geometry and spectral interferences. Methodological rigorousness and proper documentation are thus vital in order to produce valid data suited for inter- and intra-group comparative lithic provenance studies. Acknowledging the concerns raised, we describe our procedure, including the process of selecting suitable parameters and measures taken regarding the computation and replicability of the measurement results. Our preliminary results suggest that pXRF is indeed a capable non-destructive method for studying the provenance of greenstone adzes. It may also prompt further research into the exploitation of rock, place and identity in the Mesolithic.

Introduction

Was the region of Rogaland in southwestern Norway really a part of a larger southern social territory in the Mesolithic? In the early 1980s, Asle Bruen Olsen and Sigmund Alsaker (1984) argued the existence of two social territories along the west coast of southern Norway. They based their theory on a primarily visual-based provenance study of about 1000 adzes made from greenstone and diabase from two particular quarries (Fig. 1) (Olsen and Alsaker 1984). Our paper presents the preliminary results of a pilot study utilizing portable X-Ray Fluorescence Spectroscopy (pXRF) to analyse 80 Mesolithic adzes from Rogaland County in order to confirm or refute the hypothesis presented in the 1980s (cf. Olsen 1981, Olsen and Alsaker 1984, Alsaker 1987). The central source in the suggested southern social territory was a large quarry at the islet Hespriholmen, 2 km west of the island Bømlo, providing greenstone for adze production in the region of Hordaland and Rogaland counties. In the northern territory, the quarries 'Stakaneset I–V' at the headland Stakalleneset 200 km further north in the county of Sogn and Fjordane, provided rock in a similar manner. The notion of two coexisting social territories has since been central to the understanding of the Mesolithic and Neolithic on the western coast of South Norway (e.g. Olsen 1992, Bergsvik 2002, 2006, Bergsvik and Olsen 2003, Bjerck 2008, Nyland 2016, 2017). However, since most of the identification of rock types was done macroscopically, concerns have lately been raised as to whether the greenstone distribution pattern is indeed valid and as wide as suggested (Bergsvik 2006, p. 120).

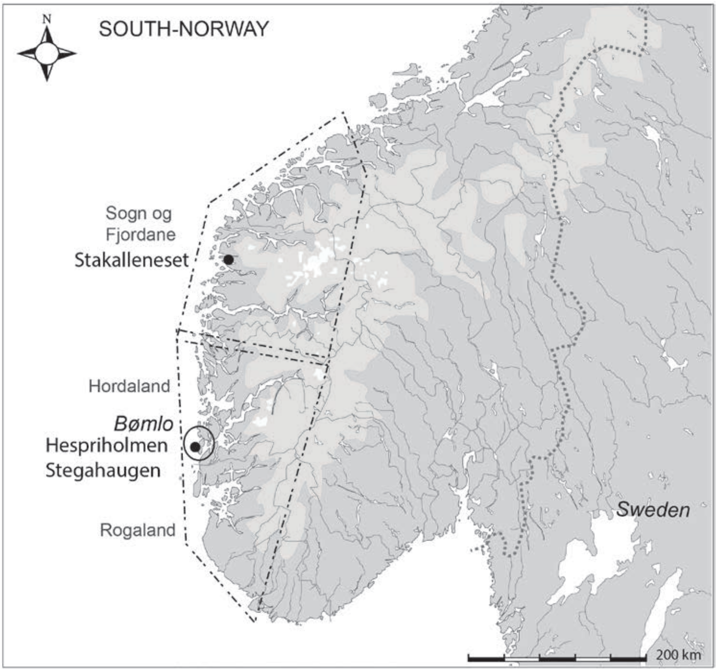

***Figure 1**: Map with place names mentioned in the text and the two suggested social territories by Olsen and Alsaker (1984). Illustration: Astrid J. Nyland.*

Visual methods are often criticized for being too subjective and unreliable (e.g. Crandell 2006, Gauthier *et al.* 2012a, Olausson *et al.* 2012). To address this, pXRF, a fast, non-intrusive and non-destructive method was applied to identify the geochemical signature of the greenstone from the quarries at Hespriholmen and Stegahaugen, another quarry located on the nearby island of Bømlo. In turn, this method was used to re-examine the greenstone adze distribution in the southwestern part of the southern social territory, i.e. focusing on the county of Rogaland (see Fig. 1). The determination of the multi-elemental composition of lithic objects is vital for studying provenance and exploitation of raw material sources. Among the successful analytical techniques for such analyses are inductively coupled plasma mass spectrometry (ICP-MS), neutron activation analysis (NAA) and electron microprobe analysis (EMPA) (Luedtke 1979, Cackler *et al.* 1999, Frahm 2012, Speer 2014a, Speer 2014b, Simpson and Dussubieux 2018). Nevertheless, the need to access advanced instruments, combined with the time required for analysis, the cost incurred and the destructive nature of some of the methods have limited the number of objects studied, but this has also encouraged the development of more accessible and non-destructive methods (cf. Tykot 2016). The pXRF approach has thus given us the means to examine more objects non-destructively, in a relatively short time and at low cost. Our study is the first large regional provenance study of Mesolithic adzes using portable X-Ray Florescence Spectroscopy (pXRF) in Norway.

Multi-elemental analysis based on pXRF can thus potentially be a very useful tool. Used in provenance studies, results could have wide-ranging implications for our understanding and interpretation of prehistoric social relations and societal organization (e.g. Pétrequin 2017, Simpson and Dussubieux 2018). However, there are challenges pertaining to surface-confined analytical techniques like pXRF, such as the effects of patination, surface depositions, surface geometry and spectral interferences. The determination of light elements and the need for matrix-matched calibration are also often encountered difficulties. Methodological rigorousness and proper documentation are vital in order to produce valid data suited for inter- and intra-group comparative provenance studies on lithic materials. For example, an ongoing debate questions whether it is a reliable method for provenance studies at all (e.g. Hancock and Carter 2010, Grave *et al.* 2012a, Frahm 2013, Frahm and Feinberg 2013, Speakman and Shackley 2013). One also asks whether such studies are reliable if they only produce self-contained data for isolated research projects, only internally compatible, and thus non-replicable (Speakman and Shackley 2013). Due to the noted problems with variation in accuracy, sensitivity and precision of employing pXRF, the necessity of methodological rigorousness has been advocated to make sure one produces valid data suited for comparative studies in general (Tykot 2016). Moreover, since pXRF is a non-intrusive method, efforts should be made to explore the potential for applying the method, as it offers possibilities to analyse prehistoric artefacts without destruction. Continuous testing including a wider range of measured rock types contributes to consolidating the method. Besides obsidians (e.g. Frahm 2012), pXRF has also been applied in provenance studies on mafic stones and cherts (Gauthier *et al.* 2012b, Grave *et al.* 2012b, Mehta *et al.* 2017). The selection of heavier elements for the analysis has provided promising results in some of the cases where weathering and patination on the artefacts is a factor that can affect the measurements considerably.

The tacit contract of archaeological interpretation is that we trust in each other's data. Acknowledging the concerns raised to the validity of pXRF data, establishing a sound procedure for our measurements was thus an objective in the pilot study presented in this paper. In the following, we will therefore describe our procedure, including the process of selecting suitable parameters to maximize the validity of the data and replicability of our results. We will present our preliminary findings and some implications that can be further explored in future research. However, we will commence by outlining the older study as an explanation and contrast to our study and results.

Research history – the background to the pilot pXRF study

The greenstone discussed in this article is a metamorphic igneous rock with a massive fine-grained texture, lacking slate structure, phenochrysts and gas voids (geologist H. Furnes in Olsen and Alsaker 1984). In the greenstone at Hespriholmen, 0.1–1 mm epidote lines are visible in the deposit (Fig. 2), yet the rock is relatively homogeneous. Its greenish hue is derived from its content of chlorite, epidote and/or amphibolite. The greenstone investigated was mainly procured at Hespriholmen but also at Stegahaugen, located on the main island of Bømlo. Both quarries tap into a larger greenstone deposit surfacing in more than one place within the Bømlo area but made during one geological event (described by geologists as deposits of 'pillow lava'). There is greenstone at the other islets surrounding Hespriholmen too, but the texture is too coarse and the stone contains too much epidote to be suitable for making adzes (Kolderup 1925). The islets have also been surface-surveyed but no traces of prehistoric quarrying were found (Alsaker 1981, 1987). The sites are located about 13 km apart as the crow flies, yet the quarry on the islet of Hespriholmen was by far the most intensely exploited. Based on topography (measurements of the depth of the scars on the rock face), and the remaining waste piles on the islet and on the sea floor just below the main quarries, Alsaker (1981, 1987) estimated that around 400 m^3 greenstone had been quarried at the site.

***Figure 2**: Picture of the greenstone with epidote lines in the quarry at Hespriholmen. Photo: Astrid J. Nyland.*

The potentially wide range of distribution of rock from Hespriholmen was discovered in the early 1940s. At this time, the geochemical signatures of rock samples from the quarry, alongside two adzes found at Lego in Rogaland about 93 km south of the Hespriholmen quarry, were found to match (Fægri 1944). In the 1960s, Graham Clark (1965) pointed out the vast potential that lay in an extended provenance study of greenstone in western Norway. Following up on this in the late 1970s, Sigmund Alsaker initiated a large-scale study of adzes from the southwestern coast (Alsaker 1982, Olsen and Alsaker 1984, Alsaker 1987). Alsaker's study is the present study's point of departure, and his methodological choices are our reasons for retesting the older hypothesis.

Sigmund Alsaker initially selected adzes and flakes for sampling based on the artefacts' visual appearances. According to Alsaker (1987, p. 33), four visual criteria characterize greenstone from Hespriholmen: the rock has to be homogeneous (1), be without voids from gas bubbles, or phenocrystals (2), the colour should be close to 'Munsell 4.2/1 – olive grey' (3), and the rock should contain hair-thin lines of epidote (4). Altogether 86 samples of greenstone from various contexts were then geochemically analysed for trace elements using XRF (Alsaker 1987, p. 15) (Fig. 3). Forty of these came from adzes found at sites on the west coast and fjord landscapes of southern Norway (Alsaker 1987, p. 57–58). Nine of the 40 adzes came from Rogaland County. Twenty-four of the 89 samples came from flakes from workshop sites located at the island of Bømlo. The rest of the samples came from four other greenstone deposits in Norway, located further south and north on the western coast, in central and northern Norway (Alsaker 1987, p. 37). The results were presented in triangular discrimination diagrams portraying the content of Titanium (Ti), Yttrium (Y), and Zirconium (Zr) (Alsaker 1987 (with references)).

***Figure 3**: Picture of adze with drilled holes after sampling nearly 40 years ago. Photo: Astrid J. Nyland.*

Together, these samples created a frame of reference, identifying variation between greenstone sources and the signature of greenstone from the Bømlo area, from the quarries of Hespriholmen and Stegahaugen. Compared to the sampled adzes, the analyses demonstrated that these clustered within the same area in the Titanium-Yttrium-Zirconium (Ti-Y-Zr) discrimination diagram. Based on this, Alsaker (1987, p. 58) argued that his visual criteria were verified, and with that, their applicability to identifying greenstone through a visual analysis. Hence, out of

2209 visually inspected adzes from the Mesolithic and Neolithic, 736 were visually determined as greenstone from Hespriholmen. Pertaining to our investigation of adzes from Rogaland County, 268 adzes (32 %) allegedly originated from Hespriholmen (Alsaker 1987, p. 55). The distribution of these adzes supported then the interpretation of a social territory covering Rogaland, Hordaland and parts of Sogn og Fjordane in the Mesolithic and Neolithic. Due to the intrusive nature of the sampling procedure (Fig. 3), it is understandable that the number of sampled Mesolithic and Neolithic adzes was kept to a minimum. Nevertheless, that only nine of these adzes were geochemically analysed is potentially problematic. Since then, the developments in the X-ray detectors, optics and associated electronics have progressively also improved leading to ever-increasing sensitivity of pXRF to the elemental determinations even when compared to benchtop XRF instruments used in the 1980s and later. Although smaller samples are now required for benchtop XRF, pXRF enables measuring without any intrusive sampling at all.

In the early 2000s, Knut Andreas Bergsvik (2006) pointed out some problems with Alsaker's analyses. For one, the results had not been sufficiently described and presented, making it hard for later researchers to evaluate them. Secondly, some of the previous identifications were proved false by an isotope study of the content of Strontium (Sr) and Niobium (Nb) isotope levels. Bergsvik (2006, p. 121–23) had thus selected 12 Neolithic adzes from Hordaland and Sogn og Fjordane counties, as well as samples from the two mentioned greenstone quarries, to test the listed visual criteria for greenstone from Hespriholmen. However, the results showed that only two out of 12 tested adzes actually originated at Hespriholmen, or rather, Bømlo. Testing other adzes macroscopically, too, and examining the slate structure of the rock in particular, Bergsvik (2006, p. 120–22) demonstrated that using visual criteria was not a fail-safe method to identify greenstone from Hespriholmen. Consequently, doubts arose as to whether the distribution analysis of adzes in Rogaland could be trusted. Hence, the current pXRF project, measuring the trace elemental composition of 83 adzes and adze fragments from the county of Rogaland, was undertaken. These include several of the Mesolithic adzes previously classified as greenstone by Alsaker, as well as artefacts from newer excavations.

Methodology

The rock and tested adzes

The adzes selected for this study are from the collections of the Museum of Archaeology, University of Stavanger, Norway. They are all typologically classified as Middle and Late Mesolithic adzes with rounded cross-sections and pointed or butted necks. The surface preparation of the adze bodies varies between being fully or partly pecked and ground, but the edge is always carefully ground and polished. The rock type in all of the adzes had previously been recorded as greenstone in the museum's database. As noted earlier, visual and macroscopic identification is challenging, so some of the adzes could have been misidentified in the first place. Moreover, even if all the adzes are greenstone, they may not originate from the same quarry or source.

The surface of greenstone is highly susceptible to post-depositional weathering processes. When exposed to soil acidity, water, sun or air, the greenstone will start to weather, that is, to shed minerals and develop a patina. This is an obvious problem when measuring surface properties of ancient artefacts. The pXRF depth of penetration is affected by the sample matrix's elemental composition, its density and the applied X-ray energy of excitation, often within a range of a few micrometres. Therefore, a selective sampling strategy of the adzes measured has been adapted with a wide range of tests, including measurements to demonstrate the variation found between non-weathered and weathered samples collected at one particular source (Fig. 4). Furthermore, to reduce the possibilities of variation due to weathering, which could affect measurements, mostly polished parts of the adze, which are relatively less affected by patina formation, were measured in our study. In addition to the adzes investigated, measurements were taken on reference samples, including both weathered (W) and non-weathered (N), directly from sources in the Bømlo area, from Hespriholmen, Stegahaugen and a now destroyed workshop site called Løvegapet, located directly east of Hespriholmen. We could therefore establish a solid frame of reference for comparison with the results from the adze measurements.

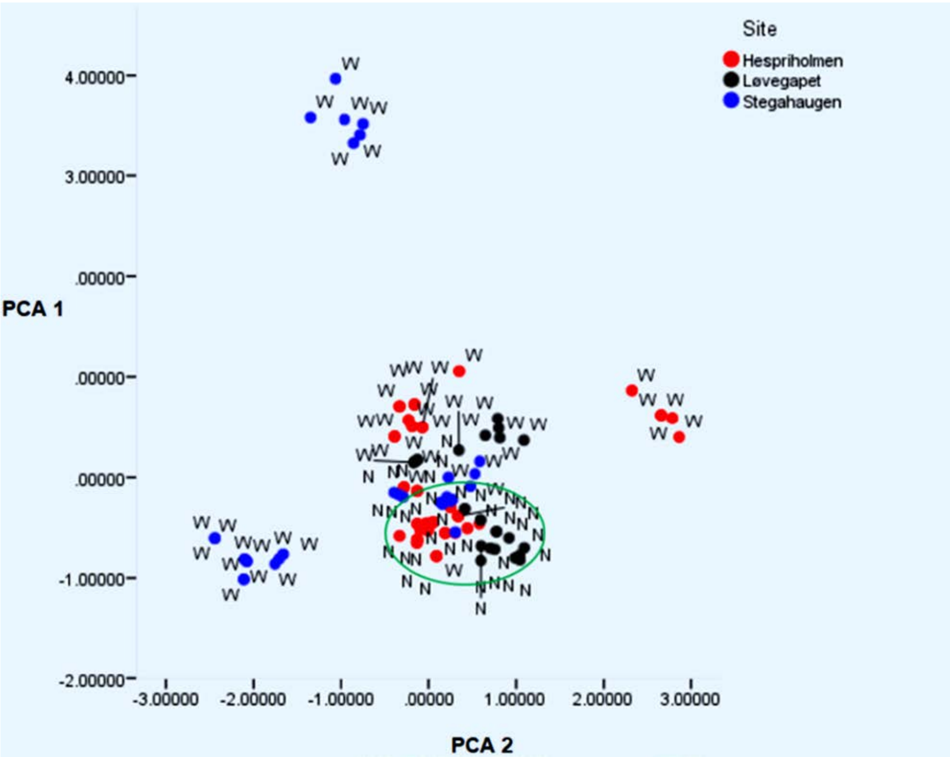

Figure 4: *Score plot diagram showing weathered (W) and non-weathered (N) samples from Bømlo area (Hespriholmen, Stegahaugen and Løvegapet), PC1 (56.5%) and PC2 (21.8%). Illustration: Kidane Fanta Gebremariam.*

Instrumentation

A Bruker Tracer III-SD portable XRF instrument was used to carry out the measurements. The instrument is fitted with a silicon drift detector (SDD) that allows fast and sensitive measurements. It has a Rhodium (Rh) anode (2W tube) and can allow an application of a maximum of 30μA current at 40 kV voltage and 55μA at 15 kV. The operator has the option of manually inserting one out of four different filters or none at all, depending on the elements of interest being targeted. Count rates of more than 100,000 cps can be acquired, allowing the detection of trace concentrations of even light elements up to magnesium. The resolution is 145 eV at FWHM (full width at half maximum) for Ka of manganese. The alloy calibration can be tested using a stainless steel duplex 2205 check sample supplied by the manufacturer, but it is not straightforward to calibrate the instrument for the intended lithic analysis as it demands matrix-matched standard materials. Data correction schemes and calibration may vary between devices from different manufacturers, even between devices of different series. This can produce non-compatible measurements. We therefore employed the same instrument for all our measurements, and in this case, we analysed the net count, raw data that was not calibrated to an external standard. A primary focus in this paper is thus the testing of the capability of the semi-quantitative data collected from a portable-XRF for the aforementioned greenstone provenance study.

For this study, S1PXRF (version. 3.8.30) was used to control experimental parameters (voltage, current, time) as well as for spectrum collection and storage ARTAX (version 15) was used for processing of the spectra collected, such as element identification, peak deconvolution using Bayesian method, net peak area calculation, and export of the computation results. To present the semi-quantitative data from the pXRF measurements, a relative percentage based on the net peak areas was used after element identification and deconvolution. The relative percentages computed for the sample measurements based on the net peak areas were used to numerically compare elemental concentrations and employed in the multivariate data analysis. This approach is intended to simplify the conversion to more problematic quantitative units. It is applied in the context of non-obsidian lithic material studies that can be affected by surface weathering similar to the samples we have examined (Grave *et al.* 2012b). Our results are, therefore, only internally comparable, but at a later stage, the results will be calibrated with closely matrix-matched standard reference materials. That will make it possible to make comparisons of the data with measurements taken by other researchers working with similar objects.

Method and procedure

As mentioned, concerns have been voiced against the application of pXRF in provenance studies. The critics point to variable accuracy, precision and, in particular, the difficulties in measuring heterogeneous materials (e.g. Frahm 2012, Tykot 2016). Testing archaeological artefacts without intrusive methods is well worth exploring, but needs a stringent procedure. The precision and accuracy of spot testing on the surface of an artefact, employing pXRF is naturally lower than laboratory-based testing on bulk samples with sampling and subsequent sample preparations. Bulk sample testing provides the general elemental composition of the homogenized material of the sample in question, covering representative components of the sample from all parts, not only those confined to the surface. However, spot testing does give us the average elemental composition of the measured areas subjected to the possible weathering and heterogeneity of the artefact surface.

Before starting the study, measurements were undertaken with a variety of filters and without a filter to experience how to maximize the detectability of selected elements. Parameters such as durations of measurements were considered, too. We then chose to measure smooth, flat surfaces with as little weathering as possible and homogeneous texture. In order to partly make up for variations arising from any other heterogeneity and surface confinement, we chose to take five to six measurements per stone adze or flake, increasing the accuracy and precision of the analysis. All samples were measured at 40 kV and 30μA current, without the use of filters, and vacuum for an acquisition duration of 120 seconds. This gives enhanced sensitivity to heavier elements that can be used as geomarkers, while also allowing for measurement of lighter elements. The spots where measurements were taken were all documented on photographs to ensure the replicability of the measurements (Fig. 5).

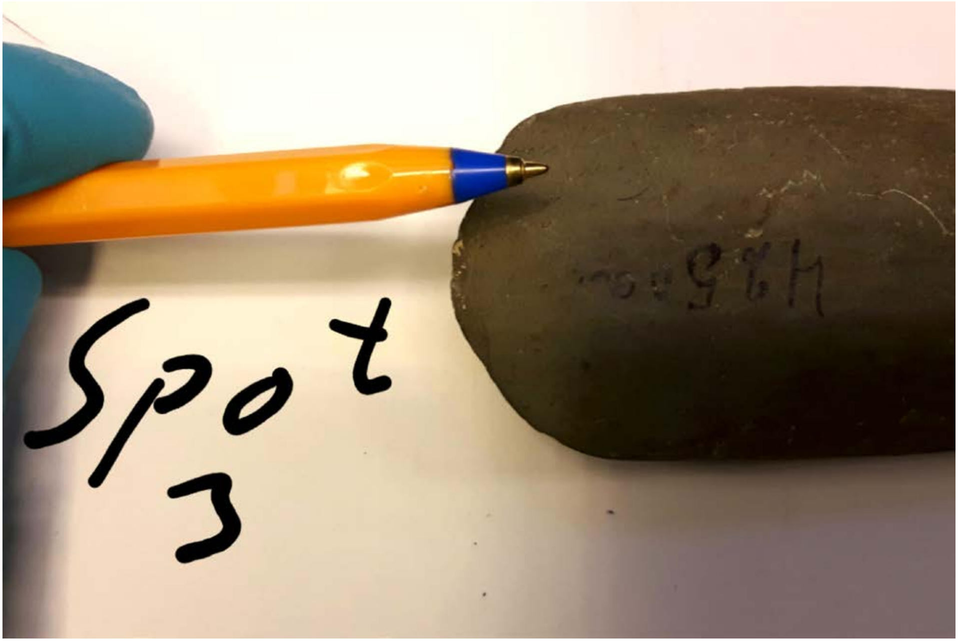

Figure 5*: Photo documentation of test spots. Photo: Ruben With.*

Some sample measurements were repeated in order to check whether the measurements changed over time, and to assess the effect of time on the measurement of elements from different samples. As to the latter, differences in the effect of prolonging the time on the intensities of the elements on different samples were noted, though there is a generally increasing trend with time (Fig. 6). The enhancement with extended time was more predominant for strontium and zirconium in both samples tested compared to that of yttrium, rubidium and niobium. With regards to the sensitivity of the method, these can imply and reflect the accuracy and precision of the measurements.

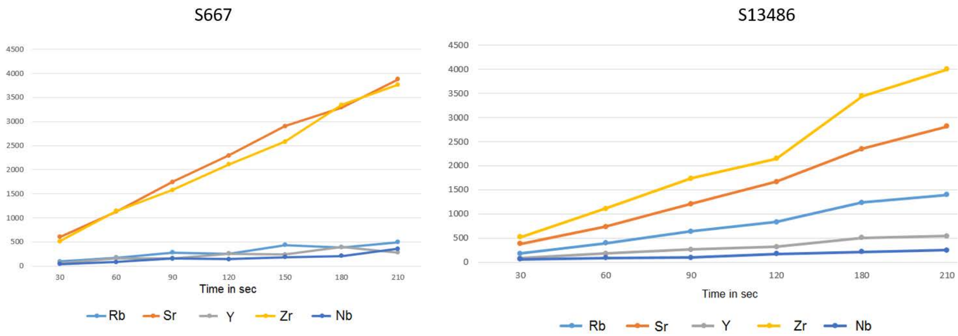

***Figure 6**: Effect of time of measurement on the intensities of pXRF peaks for some of the elements used in the provenance study. The sample used in this case are S13486 and S6667. They show clear variations in the pattern of peak intensities for the five elements, and thus their respective computed net peak areas, are observed for the different samples. Illustration: Kidane Fanta Gebremariam.*

There is variation in the precision of the measurements from sample to sample. A mean value of the elemental composition of each object was therefore computer generated from the five to six measurements, based on the peak areas of the respective detected and selected elements (listed below with their element symbol and number). Net integrated peak areas of potassium (K, 19), calcium (Ca, 20), titanium (Ti, 22), vanadium (V, 23), manganese (Mn, 25), iron (Fe, 26), copper (Cu, 29), zinc (Zn, 30), gallium (Ga, 31), rubidium (Rb, 37), strontium (Sr, 38), yttrium (Y, 39), zirconium (Zr, 40), niobium (Nb, 41), tin (Sn, 50) and lead (Pb, 52), were calculated with ARTAX software and later converted to relative percentages. The quantitative results were then subjected to multivariate analysis (Principal Component Analysis (PCA)) using Statistical Package for the Social Sciences (SPSS) software version 25. Non-rotated PCA was used in the analysis. This has been instrumental for analysis of the data and visual display of the results in a simplified manner.

Results

Ti, V, Rb, Sr, Y, Zr, and Nb were used in the PCA of the greenstone adzes, as most of them are used as geomarkers in lithic analysis and have been shown to be successful for determining sources for artefacts like obsidian tools and ceramic fragments (Tykot 2002, Little *et al.* 2011, Speakman and Shackley 2013). This also proved to be successful for greenstone. Hence, our analyses indicate that pXRF is indeed suitable for non-destructive analysis of the composition of greenstone objects. We can geochemically compare measurement results from distributed artefacts without intrusive sampling. An apparent benefit is our possibility of establishing a sound frame of reference: the presumed source of origin of the greenstone (see Fig. 4 and 7). Several groups are differentiated, allowing for a wider effect of weathering based on the measured results on samples from the Bømlo area. We also identified clusters and tendencies in the employment of more than one greenstone source for Mesolithic adze production in Rogaland County (Fig. 7).

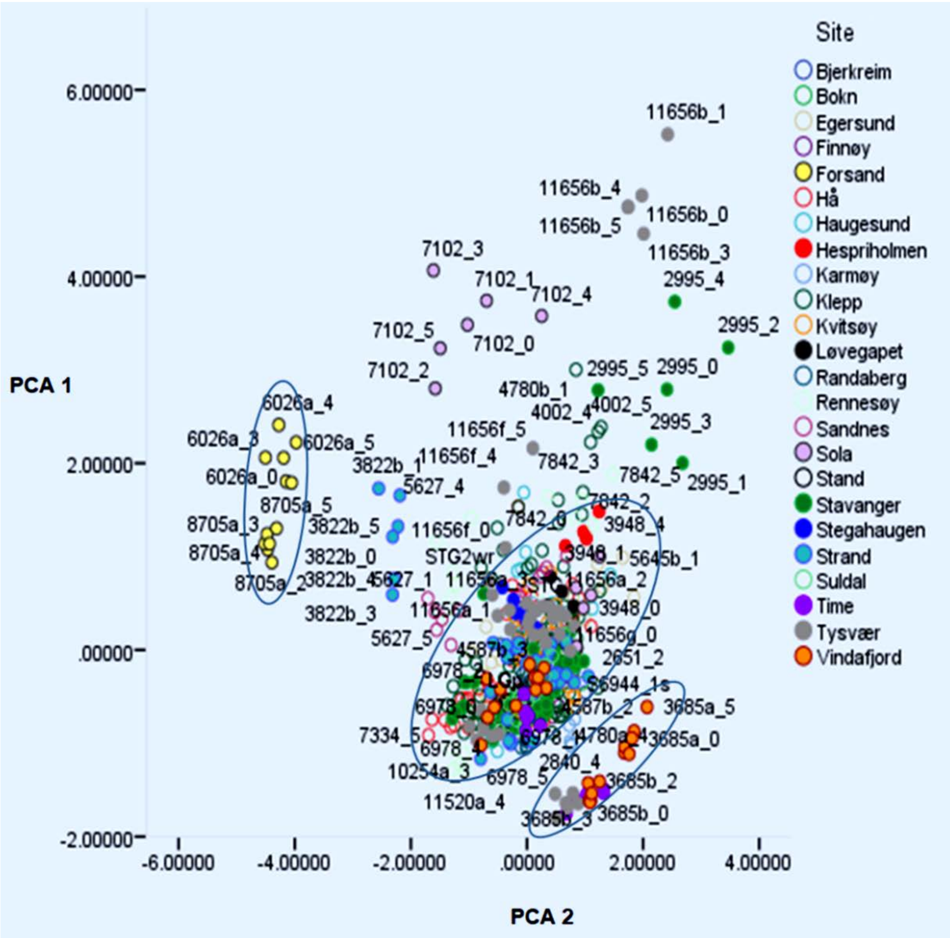

***Figure 7**: All results displayed together in diagram marking clusters of other sources. The score plot from the measurements on the adze samples and reference samples (PC1 (44.4%) and PC2 (19.8%)). Greenstone from the Bømlo area, including Hespriholmen, Stegahaugen and the workshop site Løvegapet, are found within the circle in the middle. Two groups are encircled marking other sources of greenstone exploited in Rogaland, upper left, and lower right corner. Illustration: Kidane Fanta Gebremariam.*

The PCA score plot shows some differentiation in the geochemical composition of the Bømlo area samples from a few other potential sources. The majority of the source materials used in the adzes is traced to the Bømlo area (central encircled cluster). Some samples from Time, Tysvær and Vindafjord (circle in lower right area) appear to have similar composition, yet are distinct from the Bømlo area samples. Two samples from Forsand (circle upper left area) form another distinct separation from the source from which we have reference samples. Our results thus demonstrate that among the tested adzes, greenstone from Hespriholmen was a dominant source. Overall, the visual analyses of the 1980s are more or less supported by the pXRF analyses we conducted. However, our results give rise to new questions of a more cultural-historical nature.

Discussion and implications of our finds

We could not statistically distinguish between greenstone from the Hespriholmen and Stegahaugen quarries using pXRF. However, neither the XRF analyses on ground samples from the 1980s, nor the isotope analyses of the early 2000, managed to distinguish between them either. As mentioned, the greenstone was most likely made during the same geological event. Still, archaeological investigations show a varied scale of exploitation of the two quarries, where Hespriholmen seems to have been more intensely used than Stegahaugen. Although Hespriholmen probably dominated, both were in use from the Middle Mesolithic to the Middle Neolithic (Olsen and Alsaker 1984, Alsaker 1987, Bergsvik and Olsen 2003, Nyland 2016). Hence, there seems to have been something about greenstone from the Bømlo area that caused the inhabitants of southwestern Norway to prefer rock from this place. The continuous use of Hespriholmen might have started as a predictable source for high quality raw material, yet after a millennium, and even after the transgressing sea threatened to drown the site as the sea rose, people continued to return and quarry this deposit (Nyland 2017). Even today, one may only land a boat at the islet of Hespriholmen if the weather is calm; the sea and weather around the islet are treacherous. Perhaps the latter was a reason for establishing a quarry at the safer and more accessible quarry on the main island, at Stegahaugen.

Our main result shows that the exploitation and distribution of greenstone adzes from Bømlo was indeed wide (Fig. 8). Nevertheless, even if all the greenstone adzes from Rogaland are truly from the Bømlo area, they comprise only one third of all the recorded Mesolithic adzes in Rogaland. That said, no other extensively used quarries similar to the large quarries at Hespriholmen or Stegahaugen are known in Rogaland. The results demonstrated that other sources of green rock similar to the greenstone must also have been exploited during the Middle and Late Mesolithic. Knowing the geographical location of these adzes may help us to delimit new areas of where to survey for new adze quarries, if this kind of information is pursued and expanded. Another question for future research is whether the use of greenstone that was so similar to Hespriholmen might have been an intentional strategy. Could there have been restrictions on access to greenstone from the Bømlo area? If so, could a green adze represent the same as Bømlo greenstone in a socio-cultural setting?

The confirmed distribution of Mesolithic adzes indicates that the quarry, or indeed the Bømlo area, probably did function as a node in a social territory. Throughout the Mesolithic, the Hespriholmen quarry also physically developed a monumental character. In an area where there were no other enduring human-made structures, these persisting scars made by previous generations could, over time, have come to materialize a mythical past and ancestors (Nyland 2016, 2017). Hence, in addition to confirming the theory presented in the 1980s, our pXRF study also indicates that we should explore the fact that there can be more to rock than meets the eye.

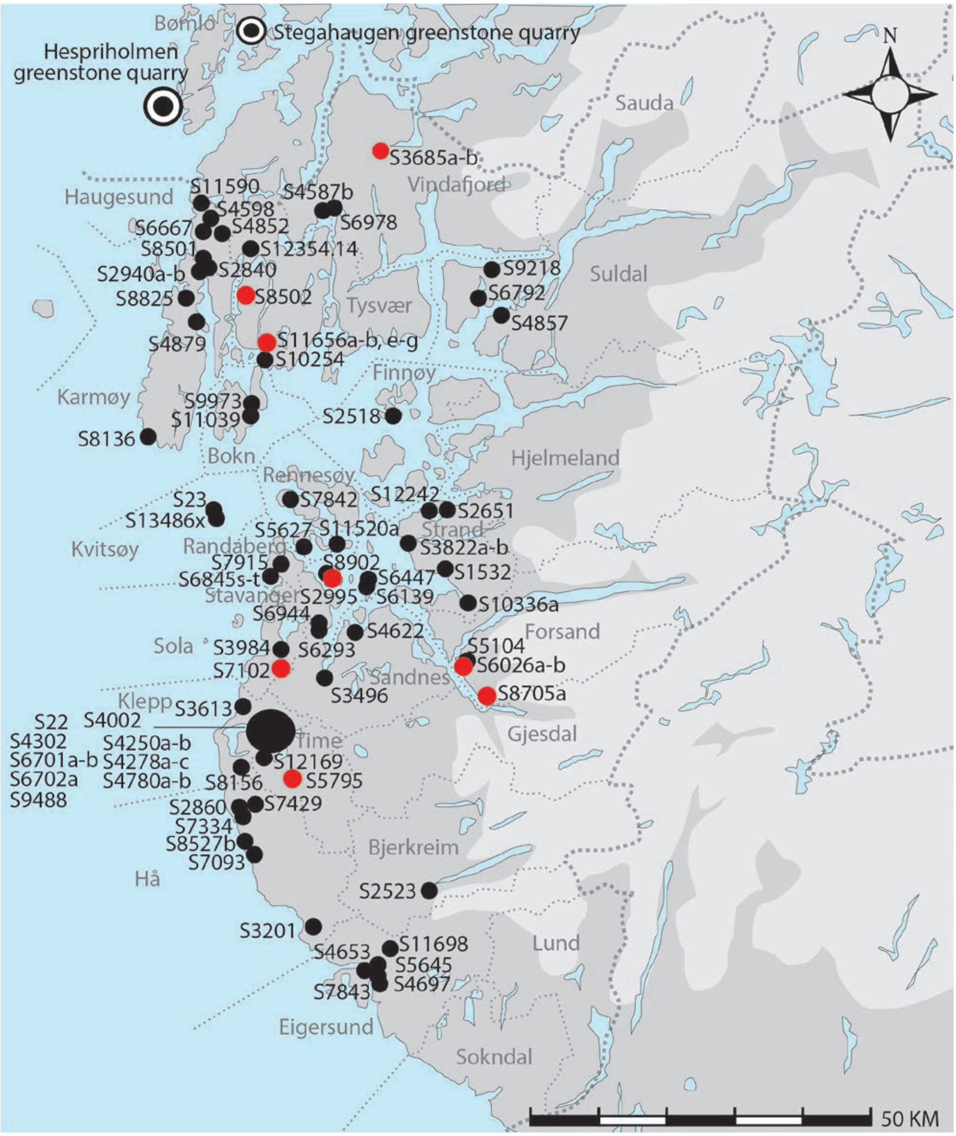

***Figure 8**: Distribution map of the measured adzes. The ones that are most likely not made of Bømlo greenstone are marked with red. Illustration: Astrid J. Nyland.*

Final remarks

There has been a growing trend in the last decade to use methods and approaches from the natural, 'hard' sciences to analyse archaeological material. This interest in applying scientific methods can be seen, for example, by the number of pages in the annual volume of the Journal of Archaeological Science, which has increased five times over the last two decades: from 600 pages in 1990, to around 1200 in the year 2000, to around 3400 in 2015. Advances in technology provide archaeology with an expanding empirical base for interpreting and gaining insight into past human lives and societies. New techniques enable more aspects of the archaeological record to become part of archaeological considerations. The new advances in technology have made it possible for archaeologists to demonstrate and establish relations between sources and sites with more certainty than before. Since the results are used to validate sometimes lofty theories, our trust in the validity, or refutation, of identified relations and empirical data is thus of outmost importance. This trust is often founded on our confidence in the applied methods, but it requires that we acknowledge the challenges and problematic aspects associated with these new methods and techniques, too. In this article, we hope that the technique we used and the methodical generation of our results are transparent. As pertains to our point of departure, pXRF did prove to us to be a powerful tool, offering suitable data to challenge old truths and theories. With reference to future research, we are in the process of comparing and contrasting the results from the portable instruments with a more sensitive and accurate analytical method: Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), which can be used for comparisons with the XRF results from reference samples of the known sources. However, that will be the topic of another paper. Furthermore, and perhaps even more important, the patterns revealed will be put to use to write more histories of the past (Nyland 2021).

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In this volume, 10 papers from the Stone Age Conference in Bergen 2017 are presented. They range thematically from the earliest pioneer phase in the Mesolithic to the Neolithic and Bronze Age in the high mountains. The papers discuss new research and methodological developments showing a diverse and dynamic Stone Age research community in Norway.

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