Scientific paper

Study of the Provenance and Technology of Asian Kris Daggers by Application of X-ray Analytical Techniques and Hardness Testing

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Abstract

Museum objects, such as the daggers presented in this study, contain a wealth of information regarding their role in certain historic periods, their potential users, the art of manufacture, the type of material used etc. Utilization of various modern instrumental techniques facilitates compositional information about the unknown artifact under investigation. In this study, a set of traditional Asian daggers called kris or keris, with scarce information about their entry into museum collections, their origin, the type of material used, the date of production, etc., were analysed by Energy Dispersive X-ray Fluorescence spectrometry (EDXRF), Proton Induced X-ray Emission (PIXE) and hardness measurements. In this way, the traditional procedure of historian inspection was supplemented by the scientific approach to obtain information about the artifacts.

Keywords: Kris, analysis, XRF, PIXE, provenance

1. Introduction

In its broadest sense, »archaeometry« (or »archaeological science«)[1] represents the interface between archaeology and the natural and physical sciences. This interdisciplinary field requires close collaboration between archaeologists, art historians, museum curators and scientists who apply modern instrumental techniques to extract structural and compositional information from ancient materials. The results of analysis by modern analytical techniques should reveal answers to the frequently asked questions about the artifacts, namely, the material used and its origin, their construction details, their authenticity, and the possibility of more exact dating.

The kris is an easily recognizable dagger with a highly decorative blade and pistol-grip handle. It is the ethnic weapon of Indonesia, and of Malaya as well. Its history can be traced back at least to the 14th century. In Indonesian culture the kris is far more than merely a utilitarian weapon. It represents a symbol of social status and a spiritual object of great importance, often associated with magic powers, revered in folk tales and legends. The supernatural capabilities of the kris – or more specifically, its long, slender, usually wavy blade – were believed to derive at least partly from the complex method of manufacture. The kris was traditionally pattern-welded and allegedly, the best blades were forged out of such rare materials as meteoritic iron.[2–4]

The surfaces of a kris blade show patterns closely resembling pattern-welded Damascus swords and oriental gun barrels. For this reason, it has been suggested that their technique of hammer forging may have been imported from Persia or India.[5] Pamor, the pattern-welded steel traditionally used in the blades of Southeast Asian krisses, appears to have been originally a smelted Fe-Ni alloy. Once finished, the blades were etched in an acidic solution of citrus juice and As. The etching produced a rough surface and brought out the contrast between the heterogeneous layers of pattern-welded steel. Apart from slag inclusions and weld lines associated with the forging process, it was the addition of etch-resistant Ni that produced the characteristic patterns and silvery spots in the pamor.[4]

Many modern kris enthusiasts believe that krisses were formerly made of meteoritic iron. This view was particularly advocated by the great Dutch researcher Isaäc Groneman, who believed that true pamor could be forged only from meteoritic iron. It is true that in 1797 a meteorite fell near the ancient temple site of Prambanan in central Java. Fragments of the Prambanan meteorite were indeed used to forge kris blades. However, it was clearly a very exotic material available only in limited quantities. Modern research suggests that only a small number of krisses for the Sultan of Surakarta were actually forged of meteoritic iron, pamor prambanan.[6]

The addition of Ni was of great importance to the Indonesian smiths. Their main source of iron was Luwu in Central Sulawesi, where the iron ore already has a natural Ni content of about 0.4%. However, meteoritic iron is far richer in Ni, containing as much as 4–5% and this produces a much finer pamor. Therefore, the use of meteoritic iron could bring obvious benefits. But regardless of the scarcity of meteoritic iron, the craft of the Indonesian bladesmith was already in decline by the end of the 19th century. With rapid modernization and the constraints of Dutch colonial rule demand was rapidly decreasing. Around 1900, the few remaining bladesmiths began experimenting with imported modern alloys such as bicycle frames. Attempts were even made by Groneman himself to stimulate the production of pamor with imported sheets of pure Ni. Yet such efforts could not prove successful in the long run and the intricate skill of making pamor faced its inevitable demise.[4,5]

Although the kris has been quite popular among Western collectors for at least a century, it is interesting to note that its origins and background remain a matter of much speculation. Many attempts have been made to research the complex history of the kris and establish a solid typology. Still, for all these efforts a truly satisfactory general study has yet to be published.[4]

Usually, effective investigation of such blade samples was carried out by extensive destructive metallographic analysis. Such study requires that the blades be cut into sections for microscopic examination, and small quantities must be sacrificed for destructive chemical analysis.[7–9]

Since the museum objects studied in the present work were considered too valuable and too well preserved, only nondestructive analytical tools which enable non-invasive inspection of the blade with no possible damage could be used. For this purpose, EDXRF, PIXE, Neutron Activation Analysis (NAA) and Wavelength Dispersive X-ray Fluorescence spectroscopy (WDXRF) were available.[10–12] Besides these non-invasive hardness measurements provided valuable additional feedback.

In this study, a combination of EDXRF, PIXE and ultrasound hardness tests were chosen as the methodology of choice. EDXRF offers fast and nondestructive multielement determination of the blade composition, and PIXE with an external beam spot of 1 mm^2 enables inspection of the inclusions within the bright spots characteristic of the blades described. The Ultrasonic Contact Impedance (UCI) surface hardness measurements are especially suitable for inspection of non-flat objects like dagger blades and provide a quick, non-invasive indication of the heat treatment and composition of the blades.

In this work, the above mentioned methodology was tested on a set of kris blades of unknown origin stored in the National Museum of Slovenia. The analyses were primarily aimed at investigating the structure and composition of the kris blades, in particular the type of material used and the technique of their manufacture. Apart from providing greater insight into the work of the traditional bladesmiths, the results could provide a more reliable assessment of the daggers' overall quality, their actual age and provenance.

2. Experimental

2. 1. Samples and Methods

The collections of the National Museum of Slovenia (*Narodni muzej Slovenije*) in Ljubljana contain a number of arms from non-European cultures. Among them an interesting group of three kris daggers complete with their sheaths were available. Their exact origin is unknown. Even their accession date is now impossible to determine due to the lack of records. The photographs of above mentioned daggers with corresponding archive numbers are shown in Fig 1 (N 32590), Fig 2 (N 32591) and Fig 3 (N 32592). It is evident that all three daggers are well made with pattern-welded blades of considerable age, dated probably from the mid- to late-19th century. They are undoubtedly genuine antiques of considerable value, far surpassing the now common souvenir-grade kris daggers made for the tourist market in the post-WWII period.

In the first place, visual inspection of the artifacts under investigation revealed that all three daggers share a

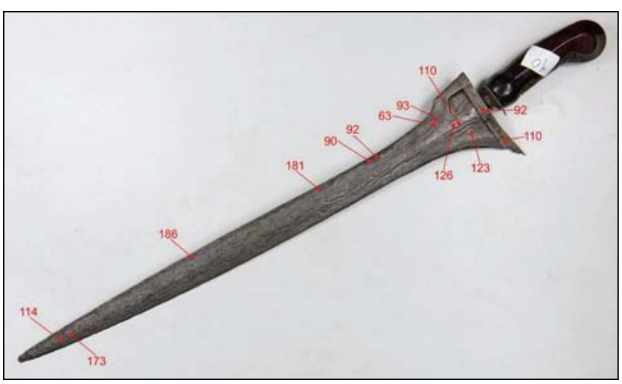

Figure 1: Photograph of kris N 32590, with locations and corresponding results of hardness measurements.

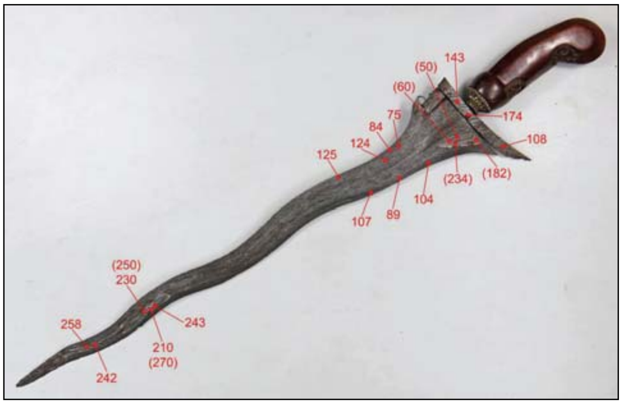

Figure 2: Photograph of kris N 32591, with locations and corresponding results of hardness measurements.

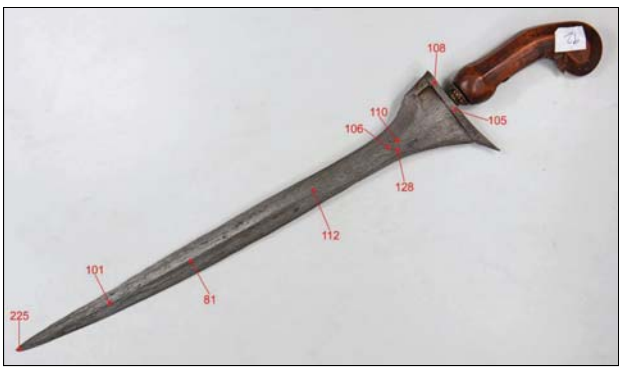

Figure 3: Photograph of kris N 32592, with locations and corresponding results of hardness measurements.

similar hilt construction. All have pattern-welded blades but their shape and the quality of pamor differ considerably. The most impressive of the group is the kris N 32591 (Fig 2). It measures 44.1 cm in length overall while the maximum blade width at the base of the shoulder is 8 cm. The highly decorative, aggressively etched blade has seven waves, suggesting that it was made for a nobleman or courtier of high rank. The longitudinal "hair" pamor is not particularly interesting. However, the blade was clearly forged of heterogeneous steel. Even with the naked eye it is possible to identify a number of relatively large bright spots measuring several square mm. It was initially suspected that these inclusions were areas of particularly high Ni content.

The other two daggers have straight blades. Their surface has not been roughened by etching so much. A closer visual inspection reveals quite heterogeneous pamor with numerous weld lines. Particularly in the case of N 32590 there is significant visible contrast between the welded layers, implying that the blade was forged of softer and harder steel bars with markedly different composition.

In order to obtain statistically more relevant results and comparative data three further krisses were temporarily loaned from the Slovene Ethnographic Museum (*Slovenski etnografski muzej*). These daggers were all of relatively recent acquisitions and of modern manufacture, tentatively dated no earlier than the mid-20th century. Photographs of two of them are reproduced in Fig 4 (MG 662) and Fig 5 (MG 666), originating from the collection of Aleš Bebler, the former Yugoslav ambassador in Indonesia in 1961–1963. Visual inspection shows that Bebler's daggers are highly decorative and made with attention to detail. However, their blades seem to be of modern workmanship. The pamor is very plain. Only MG 662 shows small characteristic streaks of contrasting bright metal. The third kris, Fig 6 (22/85–B), was donated by a private collector. It is also of more recent date and the blade is

Figure 4: Photograph of kris MG 662, with locations and corresponding results of hardness measurements.

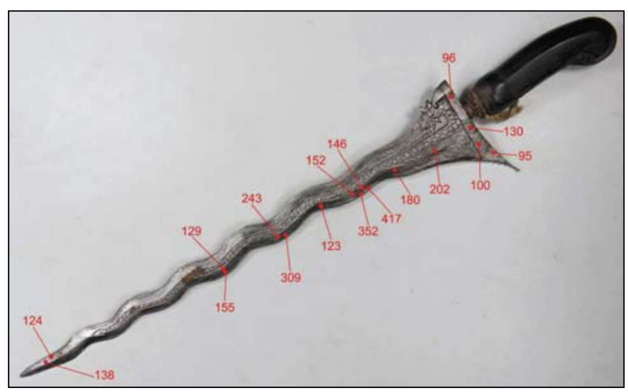

Figure. 5: Photograph of kris MG 666, with locations and corresponding results of hardness measurements.

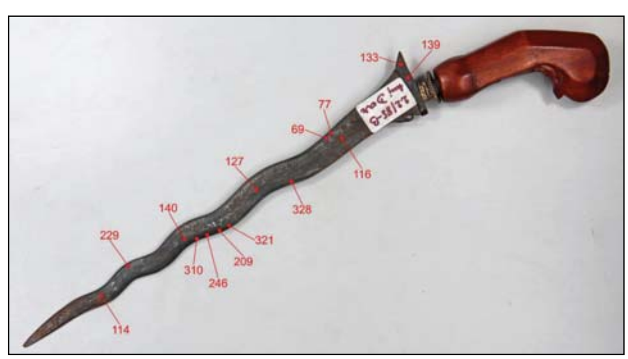

Figure 6: Photograph of kris 22/85–B, with locations and corresponding results of hardness measurements.

quite simple, typical of the modern souvenir kris. It was evidently forged of modern homogenous steel. The workmanship is downright crude, with marks left by machine grinding along the entire length of the blade.

2. 1. 1. Edxrf

The blades were first analysed nondestructively by EDXRF. The Cd-109 disc radioisotope excitation source (10 mCi) from Isotope Products Laboratories, U.S.A. was mounted in a holder which was placed on a vertical Si(Li) detector. The artifacts were placed onto the holder and the area analysed was 0.6 cm^2. The emitted fluorescence radiation was measured by an energy dispersive X-ray spectrometer composed of a Si(Li) detector (Ortec EG&G), a spectroscopy amplifier (Canberra M2025), ADC (Canberra M8075) and PC based MCA (S-100, Canberra). The energy resolution of the spectrometer was 175 eV at 5.9 keV. A typical fluorescence spectrum of a kris is presented in Fig.7.

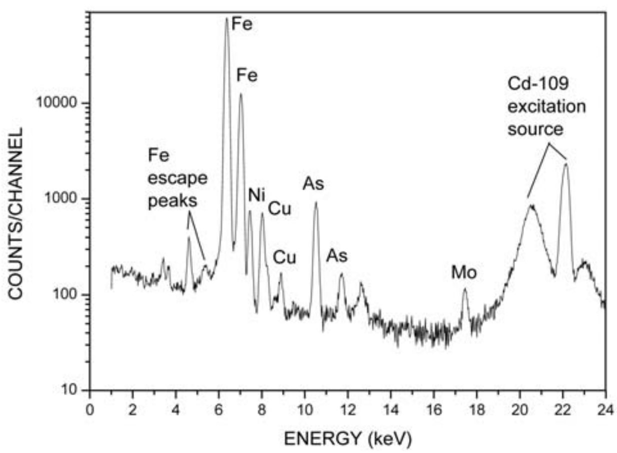

Figure 7. Fluorescence spectrum of a kris (N32591)

The analysis of the complex X-ray spectra was performed by the AXIL[13] spectral analysis program. The program yields the intensities of fluorescent as well as of scattered lines. The evaluated uncertainty of this procedure included the statistical uncertainty of the measured intensities and the uncertainty of the mathematical fitting procedure. This part of the uncertainty contributes to the overall uncertainty of the analytical results not more than 1 %.

The total uncertainty of the analytical result combines the uncertainties of the measured statistics, analysis of spectra by the AXIL program and the uncertainty due to the iteration procedures applied in the quantification program QAES.[14] The last contribution strongly depends on the total matrix of the sample and assumes that the sample is homogeneous, which is usually not true. Usually is the accuracy of the analytical result much better than the estimated combined uncertainty, which is in our case between 5% and 10%.

2. 1. 2. Pixe

The in-air proton beam of the Tandetron accelerator of the Jožef Stefan Institute was used for excitation of fluorescent radiation emanating from the excited area. The nominal proton energy was 2.5 MeV; after passing an 8 μm aluminum exit foil and about a 1 cm air gap, the energy at the sample was 2.14 MeV. The beam profile was Gaussian with 0.8 mm full width at half maximum. The excited X-rays were detected by a Si(Li) detector with a resolution of 160 eV at 5.89 keV. The proton current was set to about 1 nA, and the detector was equipped with an absorber of 0.1 mm aluminum foil, which suppressed the intense iron X-rays by a factor of 13. The duration of measurement at a particular point was several minutes. Different parts of the blade were analysed, notably the bright spots that were expected to contain more Ni than the nearby dark surface. The recorded spectra were fitted by the AXIL program, and the respective concentrations were evaluated by a program developed in the lab, which is based on the method of independent physical parameters and takes secondary excitation of X-rays into account.[15] The metal concentrations were normalized to 100%, therefore measurement of the proton dose was not necessary. The normalization procedure also suppressed errors due to variation of the air-gap travelled by protons, which varied by a few millimeters from one measuring point to the other. The uncertainties in the concentrations deduced were estimated to be ±5%.

2. 1. 3. Hardness Tests

The hardness of blades was measured non-destructively using an Instron Wolpert DynaTestor 10 with the load of the indenter of 20 N. The DynaTestor 10 provides a direct reading in Vickers HV with an accuracy of ±1%. This highly-accurate UCI (Ultrasonic Contact Impedance) device is suitable for measurements on thin or very large structures. The UCI hardness measuring method is based on measurement of the frequency shift of a resonating rod during penetration of the indenter into the measured specimen. A frequency shift is caused by the essentially elastic nature of the finite area of contact between the indenter and the test piece. As indenter a Vickers diamond pyramid with a 136-degree angle between facets is used. During this kind of hardness measurement the diagonals of the indentation are not optically measured as in traditional Vickers tests. For this reason there is no need for optical evaluation of the indentation with a microscope. The indentation area is electronically detected by measuring the frequency shift which is proportional to the size of the indentation. On penetration of the pyramid into the tested sample (blade) under permanent load, a change in the indenter resonating frequency is observed (frequency shift), determined by the hardness of the tested blade.

The first three krisses were analysed by EDXRF and PIXE, the other three of known origin by EDXRF and all six were also subjected to extensive non-invasive surface hardness tests. The results, measured on the Vickers hardness scale (VPH), are represented graphically in Figs. 1–6. Due to the very uneven surface of the etched blades obtaining consistent measurements was in some cases quite challenging. Where the measured values could not be determined with absolute certainty, they are shown in parentheses.

3. Results and Discussion

Table 1 presents the results of elemental analysis by EDXRF. Comparison of the elemental contents reveals that the first three krisses from the National Museum of Slovenia (N 32590–2) show better but varying quality of pamor, containing Ni and/or traces of Mo. Somewhat unexpectedly, there is also a considerable amount of Cu, up to 1,6%.

Measurements were performed at different locations on the blades and the results obtained show fluctuations in the measured concentrations of elements across the surface of the blade. This means that the quality of pamor, the production procedure and materials used were more complex, which is certainly no surprise. This confirms the results of visual inspection mentioned above. Pattern-welding is a technologically relatively simple but very labour-intensive method. It has been used historically to create quality blades by forge-welding steel bars of varying composition. This would ensure the end result being more uniform, even though the raw materials used initially had very different C and alloy contents. It could also allow an experienced smith to deliberately make a cutting implement with a hard edge and a tough, softer core. However, a pattern-welded blade is by its nature much more heterogeneous and contains more impurities than one made of homogeneous modern steel.[16–19]

The second group of krisses (MG 662, MG 666, 22/85–B) is clearly quite different. None of the blades contains Ni. They are made of plain, unalloyed steel and the trace element Mo is absent. Also, the composition of the blades is significantly more uniform. All in all, this indicates more recent production in the mid-20th century.

Note must be made of As, which was found on five out of six krisses. Its presence can be explained easily. Traditionally, krisses were ceremonially cleaned in a complex procedure over the course of several days. The blade was first cleaned in an acidic solution, then soaked in liquid Arsenical compound (warangan). Kris 22/85–B, a modern product aimed primarily at the tourist market, may never have been submitted to such ritual cleaning.

The comparison of results obtained by both techniques is particularly interesting in the case of the kris N 32591. The pamor of its blade is dark grey colour with a strongly etched pattern and small bright spots. The external PIXE excitation beam was focused on one of these inclusions. The results in Table 2 show that Ni was indeed concentrated in the measured region.

This leads us to another important issue, namely the Ni content of the analysed blades. Interestingly enough, Ni has been detected in only two krisses. The relatively small figure of 0.2% in the case of N 32590 is typical for Sulawesi iron ore as mentioned above. But the Ni content of N 32591 is far higher and in fact exceeds 2%. This blade may have been forged at least partly from Ni-rich meteoritic iron, which is all the more logical considering the high overall quality of the dagger in question.

Comparison of the EDXRF and PIXE data shows that the material of the krisses is very inhomogeneous. The Ni content can be negligible or as low as 0.2 %, which is a value typical of Sulawesi iron ore. However, the Ni content in the most elaborate kris N 32591 can be as high as 25%, which may point to an intentional addition of pure Ni or a Ni-rich Fe alloy. Concerning a possible meteoritic origin, such Fe-Ni combination can be obtained from a taenite-containing meteorite.

In the absence of detailed metallographic analyses, which could not be carried out due to their destructive na-

Table 1. Results of measurement of elemental content of kris blades by XRF:

			C (wt %)			
El.	**N 32590**	**N 32591**	**N 32592**	**MG 662**	**MG 666**	**22/85–B**
Fe	98.9 ± 2.4	95.2 ± 2.2	97.3 ± 2.2	98.8 ± 2.4	99.7 ± 2.4	99.1 ± 2.4
Ni	0.2 ± 0.04	2.1 ± 0.1				
Cu	0.6 ± 0.05	1.6 ± 0.1	1.1 ± 0.1	0.1 ± 0.02		0.1 ± 0.01
Zn						0.1 ± 0.01
As	0.2 ± 0.02	0.7 ± 0.07	0.2 ± 0.02	0.09 ± 0.01	0.1 ± 0.01	
Mo		0.01 ± 0.001	0.002 ± 0.0002			

Concentration in weight %, g/100 g
Each inividual EDXRF measurement covered an analysed area of 0.6 cm^2. However, all the krisses were also analysed at various locations on the blade by PIXE with a 1-mm^2 beam area. The results were more or less comparable to EDXRF, except for Mo which was beyond the detection limit for PIXE.

Table 2. Results of PIXE measurements on kris blades from the National Museum. Of the four spots on N 23591, the first two were measured on the dark iron part, and the second two on bright spots.

	C (wt %)					
	N325990	**N32591**				**N32592**
Fe	99.2 ± 0.2	94.4 ± 0.6	98.5 ± 0.2	90.8 ± 1.0	74.3 ± 2.2	98.6 ± 0.2
Ni	–	2.40 ± 0.2	0.17 ± 0.02	8.08 ± 0.50	25.0 ± 1.2	–
Cu	0.63 ± 0.06	1.33 ± 0.07	0.46 ± 0.05	0.53 ± 0.05	0.42 ± 0.04	1.08 ± 0.06
Zn	–	0.28 ± 0.03	–	–	–	–
As	0.15 ± 0.02	1.63 ± 0.08	0.86 ± 0.05	0.53 ± 0.05	0.29 ± 0.03	0.31 ± 0.03

ture, the measurements of surface hardness provide useful additional complementary data on the metallurgy of the daggers related to the their C content and type of production. As expected, there is considerable variation in the measured values, not only between the krisses analysed but even among particular sections of individual blades. Such inconsistencies are normal for hand-forged artifacts, especially blades of pattern-welded steel. A traditional coal forge allows little control over the temperature and atmosphere. Without the support of precision instruments, the forging process is left entirely to the experience and instinct of the smith.[16–19]

The hardness tests of the antique krisses from the National Museum of Slovenia (Fig 1–3) reveal that the final half of the blade toward the point is generally the hardest, reaching up to approximately 250 VPH. The base of the blade is softer however, in the range of 100 VPH. For proper cutting efficiency the edge ought to be harder than the core but that is not always the case. It seems that such technical considerations were beyond the control of most Indonesian smiths.

For the three daggers from the Slovene Ethnographic Museum (Fig 4–6), the results are even less uniform. In some cases their blades are notably harder, reaching values over 400 VPH. This may be attributed to the use of modern steels with a considerably higher C content. However, the distribution of hard and soft areas seems much more erratic. There is no longer any perceptible tendency to create a blade with a hard point and soft base as may have been common in earlier times with true pamor. Quite the contrary – the hardest portions may be observed on the central portion of the blade.

At any rate, the results confirm the already established fact that kris blades were not generally heat-treated to improve their mechanical properties or edge-holding ability. The hardness of kris blades was apparently not the result of a deliberate quenching and tempering process. Instead, it was predominantly achieved mechanically by forging itself.[16–19]

4. Conclusion

The nondestructive analytical methodology employed using EDXRF, PIXE and hardness measurement was confirmed as quite simple, efficient and fast in studying the provenance, the origin, the type of production and materials used in Asian daggers. The curator's traditional approach of visual inspection and typological study was succesfully upgraded and confirmed by means of modern instrumental investigation of the artifact. The results obtained, although necessarily limited in scope, provide many clues useful to museum curators and collectors elsewhere, broadening our understanding of Indonesian metallurgy and the kris blade as its most iconic product.

5. References

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Povzetek

Kovinski predmeti iz muzejskih zbirk – denimo bodala, ki jih obravnava pričujoča raziskava – v sebi skrivajo bogate podatke o njihovi vlogi v določenem zgodovinskem obdobju, njihovih potencialnih uporabnikih, kovaški umetnosti, vrstih uporabljenih surovin itd. Z uporabo različnih sodobnih analitskih tehnik tako lahko razkrijemo pomembne informacije o predmetih neznanega izvora. V tej študiji smo se osredotočili na skupino azijskih bodal, imenovanih kris ali keris. Ker njihove prvotne provenience in načina pridobitve ne poznamo, smo jih skušali podrobneje opredeliti ter določiti surovine, iz katerih so izdelani, njihovo starost ipd. Pri tem smo uporabili metodo energijsko disperzivne rentgenske fluorescenčne spektrometrije (EDXRF), protonsko vzbujeno rentgensko emisijo (PIXE) in meritve trdote. Na ta način smo tradicionalni muzealski analitski pristop nadgradili z naravoslovnimi metodami, da bi pridobili nove podatke o analiziranih predmetih.