Non-destructive investigation of polished stone implements found in Hungary: Methodology and case studies

Magyarországon fellelt csiszolt kőeszközök roncsolásmentes vizsgálata: Módszertan és esettanulmányok.

PhD dissertation

Thesis booklet

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Introduction

Problem description

In hard rock geology, to break, cut, pulverizing, or in one word, destroying the samples is the correct way according to the sample preparation and investigation protocols. During the investigation of pieces of cultural heritage, like paintings, jewellery and sculptures, using non-destructive or micro-invasive methods are important to save these unique and unrepeatable items, especially when they are intact, good quality objects with detailed archaeological or historical records. This is the correct approach during the investigation of remnants of stone age, especially when we are facing with unique, rare and intact items, even if their value is not as close as a Renaissance painting has. Since the beginnings of the archaeometry, it was always a large problem, how to achieve as much information as we can, without to harm or destroy these objects with incredible historical background. During the development of analysis techniques, multiple partial answers were revealed, which can support the results of each other, however, none of them able to give all necessary answers alone. In this PhD dissertation a non-destructive way of investigation has been presented, which can provide textural and mineral chemical information about polished stone implements from the Neolithic era, and usefulness and limitations of this method has been proven with a series of case studies.

Method used for the investigations

Due to the sensitive nature of the most investigated objects, main method was the SEM-EDX investigation combined with the original surface investigation method described in Chapter II; however, there were a few fractured axes where was possible to make polished thin sections. This was especially important during the demonstration of original surface investigation method, where results from polished thin sections were directly compared with results from the original surfaces of the exactly the same stone implements. An interlaboratory test was performed also during these comparisons, where the results from thin section were measured in another laboratory. Other methods were used during the investigation series:

- Two polarizers petrographic microscope for thin sections (Chapter II. only);
- PGAA for bulk rock chemistry;
- Magnetic susceptibility measurement to perform a very basic grouping on the investigated pieces;
- Stereomicroscope was used for choosing the areas to be investigated.

Main instrument during the investigations was the AMRAY 1830 SEM at the Department of Petrology and Geochemistry, Eötvös Loránd University, Budapest, Hungary. This SEM is equipped with a quite large sample chamber to have enough room for even a 30 cm long and even 5 cm thick stone implements. Detailed description of the instrument and the used method can be found in Chapter II. All measurement were standardized, the applied microanalytical standards are international standards with well-known compositions, their details can be found in the related chapters.

For SEM-EDX investigations, a special preparation and investigation method were used, their detailed presentation can be found in Chapter II. This method is the original surface investigation method, which allowed to investigate these objects without invasive sample preparation.

During this special preparation process, a layer of conductive carbon has to be applied on the surface of the objects to be measured. This layer can be easily removed immediately after the investigation.

Actual results on stone tools made of HP metaophiolites

Two articles are concentrating on a special kind of lithic raw material of certain stone tools, the high pressure-low temperature (HP-LT) metaophiolites, like eclogite and different varieties of jadeitites. Their raw material is completely missing from the Carpathian Basin, at least from the surface, as well as the presence of HP-LT metaophiolite stone implements was practically unknown until 2008. Since the discovery of their presence in old, large Hungarian collections (which were piled up from stray finds), like Miháldy collection of Laczkó Dezső Museum in city of Veszprém and

Ebenhöch collection of Hungarian National Museum in Budapest, they were found among the object assemblages of different archaeological surveys performed in XX. and XXI. centuries also.

Investigation of these stone implements have high importance because of the scarcity, inaccessibility and distance of their raw material. The distance of the nearest geological locality is over 1000 kms, however these stone implements have really large distribution in Europe thanks to their very good quality and impressively nice green colour. These implements were investigated across through Europe from Scotland to Bulgaria and from the Iberian to the Scandinavian Peninsulas.

Most pieces were found in Transdanubia area of Hungary with one exception, a piece was dug up in Gorzsa, Southeastern Hungary, close to Hódmezővásárhely. Ten of eleven pieces were found in archaeological context are belonging to Lengyel Culture, the only exception is the one from Gorzsa, which is belonging to the Tisza culture, a culture which was close relation with the Lengyel culture. 14 pieces are stray finds without archaeological context.

Raw materials of these artefacts were divided up to groups based on their bulk rock composition and mineral chemistry. Based on our results and data from the available papers on this topic, our stone tools were transported from NW Italy, so they originated from the very same sources that were supplied all Europe from Scotland to Bulgaria. Our goal was to prove that these lithic raw materials came from the well documented western European source both primary sources, like Mon Viso area or the Voltri Massif, and secondary/tertiary sources like the resedimented Oligocene conglomerates of River Po, Staffora and Curone.

Conclusion and summary

Problem & solution

Non-destructive or micro-invasive methods are crucial during the investigation of cultural heritage; however, the necessary instrumentation is hardly or not available in Hungary, especially from point of view of budgets of projects, which are running on these topics.

At first, three stone tools from Mihåldy- and Ebenhöch collections were investigated to have more detailed information. Their unique, HP-LT metaophiolite raw material was confirmed earlier with another method, PGAA, however, further details were necessary to collect more specific data about texture and mineral chemistry. Since these three items are completely intact axes carved from HP-LT metaophiolite, from a raw material group, which was unknown among Hungarian stone implements, there was no possibility to perform destructive investigations. To analyse them, a unique, non-destructive sample preparation method have been found out.

Revealing lot of useful data about these three items was the lead to extend the method to other stone tool raw material types, in fields of both metamorphic and volcanic rocks, like contact metabasite, nephrite, hornfels; basalt and foidite; however, detailed presentation of all investigated raw material types is not among the goals of this study, they can be found among the enlisted publications of the author.

Thesis 1:

Original surface investigation method requires a special sample preparation method to be a completely non-destructive investigation.

Original surface investigation method was developed for non-destructive investigation of cultural heritage artefacts, especially with geological origin, like gemstones and stone implements with well-polished surfaces. This method allows to investigate these objects without any invasive preparation process, like cutting, mounting, grinding and polishing which are the essential parts of the normal petrographic or metallographic sample preparation methods.

Steps of sample preparation process for stone implement investigations:

- Step 0: Though it is not the part of "real" sample preparation, it is a crucial one: prior to any other preparation step, it is essential to decide the final setup of the object during the investigation. For this, it is necessary to make trials on the SEMs sample holder to reveal the suitable surfaces for EDX measurements. Important criteria during this test:
    - The investigated item has to be in stable position;
    - The investigated surface has to be perpendicular to the e- beam;
    - Ideal working distance must be achieved.
- Step 1: If all the above-mentioned criteria are fulfilled, select an area on the chosen surface to investigate. It is recommended to use stereomicroscope for the best results.
- Step 2: Cover the surface of the object with aluminium foil, except the area which was chosen for investigation. Another working method is to cut out the aluminium foil at the desired location prior the carbon coating.
- Step 3: Perform a carbon coating process on the object. Proper positioning of the object is very important because carbon coating is a "line of sight" process, so area to be coated has to be positioned towards the source of carbon.
- Step 4: After the carbon coating, aluminium foil has to be left on the object to be investigated, because this will be the conductive media to make possible the investigation.

After these steps, the investigation can be performed with the setup of the object defined during the step 0. After the investigations, carbon layer can be removed easily with a soft cloth, a small amount of organic solvent, or water and a gentle rubbing of coated surfaces. For the best results, it is recommended to perform this step immediately after the investigation.

Thesis 2:

Usability of chemical and textural results of original surface investigation method have been proved by a test series performed on stone implement samples were investigated by destructive and non-destructive ways.

This method originally was developed to investigate inlaid gemstones, and later was adapted for non-destructive testing of the two identified HP metaophiolite polished stone axes from Bakony Mts, and a third one from Almásneszmély, Hungary. After the success of first trial, a question was arisen: is this method good for other raw material types also? As a kind of good luck, a group of stone implements from Diósviszló (Baranya County, Southern Hungary) were allowed to be cut for thin section showed up at the very same time. During the testing of method, this set of stone implements was extended with two other stone tools. These two stone implements already had polished thin sections from earlier investigations. One of them, from Veszprém-Kádárta, was investigated by our lab, other one is from Balatonőszöd, and it was investigated by the lab of Geological and Geochemical Institute of Hungarian Academy of Sciences made us to perform an interlaboratory comparison also. During this test series, it is turned out the original surface investigation methods is working well from POV of both imaging and mineral chemistry. BSE images are able to reveal the basic texture of rocks, zoning of individual minerals and chemical composition of most rock forming minerals, including feldspars, amphiboles, pyroxenes, epidote, muscovite, opaque minerals, like ilmenite and other accessories, e.g. zircon, monazite and apatite. Based on the results discussed in Chapter II. in most cases mineral compositions from the original surfaces are very similar to their thin section counterpart. This determination is valid in the case of interlaboratory test also. Practically it means that stone implements with raw materials built up these stable phases are determinable with this method.

Thesis 3:

Limitations of original surface investigation method were determined by the very same test series.

During the comparison tests, some limitations of this method were revealed also from both imaging and chemical measurement POV-s. On roughly polished specimens, mineral zoning may not observable (however it is measurable by mineral chemistry). Other problem can be the alteration of some minerals, like sericitization, however it can be solved with use of higher magnification during the investigation.

Phase alteration affects the original surface investigation method much deeper: while cutting of a rock sample with weathered surfaces will reveal the intact core of the specimen, a stone tool with non-stable phases on its surfaces can cause confusion during the evaluation of results and it may lead to false interpretation. Fortunately, there is not much mineral phases tends to be disappeared during the burial time, at least in stone implements. Most affected phases are foids, like analcite, nepheline and sodalite; and the volcanic glass. All of them can be altered to clay minerals during the few thousand years of burial in the soil makes the identification of raw material impossible by the original surface method.

This kind of alteration is affecting the texture of the original surface of these rocks also; disappeared phases are leaving holes, pits on the surfaces, and most of the filled up with clay minerals. Large amount of clay minerals on the surface is the only evident that the results are not suitable to step forward. In these cases, application of destructive methods is cannot be omitted if it is possible.

Another limitation of this method is a consequence of the lack of the sample preparation. Unpolished surfaces are affecting both the imaging – where the unevenness of the surface may mask of the chemical differences inside the minerals – and the chemical measurements also. During microanalysis, grain surfaces may not horizontal perfectly and their positions can change one-by-one, so results measured in this way may not suitable for sophistic geochemical calculations, like thermobarometry or age determination.

Thesis 4:

Original surface investigation method is working on inlaid gemstones also.

From the other hand, this method is able to provide data on inlaid gemstones where the most basic and traditional gemmological investigation method, refractometry fails due to the lack of direct connection between the inlaid gemstone and the refractometer. Sample preparation is very similar to the stone implements' preparation, however there are a few differences. First thing is that the investigation of inlaid gems requires a much more precise positioning, because some artefacts has inlaid gemstones on more than one surfaces (e.g. a ring or a bracelet). In these cases, objects have to be tilted, rotated and replaced during the investigation to check all the inlayed gems.

As it can be seen below, the preparation steps are very similar for the gemstones than the stone implements:

- Important criteria are the same:
  - The investigated item has to be in stable position. If one items needs to be investigated in different positions, all positions have to be planned prior the investigation;
  - All investigated surfaces have to be perpendicular to the e- beam;
  - Ideal working distance must be achieved for all positions.
- Step 1: If all the above-mentioned criteria are fulfilled, select the inlaid gemstones to be investigated. In case of small jewellery, may all inlaid stones can be investigated in one setup. If necessary, multiple positions have to be determined prior the investigation. For gem selecting it is recommended to use stereomicroscope.
- Step 2: Cover the surface of the object with aluminium foil, and cut out the foil over the gemstones to be investigated prior the carbon coating.
- Step 3: Perform a carbon coating process on the object. Proper positioning of the object is very important because carbon coating is a "line of sight" process, so area to be coated has to be positioned towards the source of carbon.

- Step 4: After the carbon coating, aluminium foil has to be removed from the item, because metal framework will be the conductive media in this case. Removing the foil is allowing the investigation of the metal part of the jewellery also, so it is the better option in this case.
- Step 5: Put conductive tape on to the gemstones to connect the carbon layer to the metal framework of the jewellery. This step is necessary for avoid the charging during the investigation.

Another important difference is the covering process: The whole item must be covered carefully to avoid the contamination of the metal framework of the inlaid gemstones, and aluminium foil must be punched through only over the gemstones to be investigated. Other difference that the covering foil better be removed after the carbon coating, as the metal framework is conductive, and maybe it has to be investigated also. Last but not least, removing the carbon layer has to be performed in the gentlest way, under stereomicroscope, with use of organic solvents like alcohol. Fortunately, very smooth, well-polished surfaces of gemstones make the removing process easier.

Gemstones have a large advantage over the polished stone implements: their surface is completely plane, and it has much better quality as most of them had been polished until their surface are shining like a mirror. That makes them better subject of investigation, since their surface is met the requirements of microanalyses. Other advantage of gemstones is the stability of these minerals: in general, hard and stable stones were chosen for gems – beyond their beautiful appearance of course.

Gemstones frequently have inclusions on their surface. This method allows the investigation of inclusion assemblages uncovered during the polishing of the gemstones, from point of view of both chemical composition and texture. These information with the chemical composition of gemstones may lead to the determination of the source area of the gemstone, and may help to reveal commercial connections between the source area and the finding area of the investigated item.

Thesis 5:

Original surface investigation method was a powerful tool to prove that stone tool carved from HP metaophiolite raw material are present in Hungary in a relatively large number.

Investigation of stone implements is a current topic all over Europe, to uncover the connection among the ancient people. High pressure metaophiolites, like jadeitites, are not widespread raw material, and this makes them a perfect tool to track down commercial connections and routes across over the prehistoric Europe.

During our work on these stone implements, an interesting difference from Western Europe attracted our attention: the low penetrations of HP stone implements towards East. Beside the few artefacts from Varna, they were practically unknown for a long time at the eastern region of Europe, including the Carpathian Basin and its environs. Altogether a few pieces were known from Croatia, in the Czech Republic and two pieces from Slovakia. These numbers were increased during this work to 25 proven HP artefacts finds from the Carpathian Basin, with a very wide range covering practically the whole Transdanubian region incorporated an area located North from Danube River in today's Slovakia; and appears also in Eastern Hungary with a single location in Hódmezővásárhely-Gorzsa.

Before 2008 HP metaophiolite raw material there were practically unknown among the stone implements found in Hungary. Friedel and colleagues (2008) mentioned this raw material type among the pieces of Ebenhöch collection without any detail, just mentioning that the group was determined based on PGAA analysis and magnetic susceptibility measurements, and other (destructive) investigations were not allowed since the tools were completely intact. The endeavour to step forward and collect more (textural and mineral-chemical) details about these items without involving destructive analytical methods was led to the development of original surface method. All the first three stone implements investigated by the original surface method was HP metaophiolite and was published by Szakmány and colleagues. During the next few years, collection of HP metaophiolite stone implements was grown from 3 pieces to 13 in the first step, and later to 25. Since the first tree pieces were all stray finds, during the next years, it turned out that some of the archaeological excavations uncovered HP metaophiolite stone implements also.

According to the actual situation, there are 14 stray finds among the Hungarian HP metaophiolite tools, and 11 pieces were found during archaeological excavations from different localities:

- Alsónyék: 5 pieces;
- Zengővárkony: 3 pieces;
- Szombathely-Olad: 2 pieces;
- Hódmezővásárhely-Gorzsa: 1 piece

The first three localities are belonging to the Lengyel culture which was widespread in Transdanubia, while Hódmezővásárhely-Gorzsa is belonging to the Tisza culture which was a contemporary culture with lot of commercial connections with the Lengyel culture.

Another interesting difference from the Western European findings that, the really large sized artefacts (up to 46 cm), which are characteristic for there, are completely missing from the above-mentioned artefact assemblages, where small and medium sized pieces can be found with a maximum length of 16-18 cm.

Thesis 6:

Based on the textural and mineral chemical results acquired by the original surface investigation method from HP metaophiolite stone implements, it has been proven that multiple HP metaophiolite types are represented among the Hungarian stone implements.

For grouping of raw materials, classification was presented in D'Amico et al. 2003 was used in this work also. Based on textural and mineral chemistry data by SEM-EDX, and bulk chemistry data by PGAA, five groups were distinguished: jadeitites, mixed jadeitites, Fe-jadeitites, omphacite/glaucophane schist and eclogite *(Table 1)*.

Table 1: Grouping of the investigated 25 HP metaophiolite stone tools identified in the Hungarian archaeological record based on their texture, mineral composition and bulk rock chemistry information.

#	Group	Short description	Inventory number of related stone tools	Localities	Context
1	**Jadeitite**	Contains much more jadeite than omphacite and/or Fe-jadeite. Na-pyroxenes are generally zoned, they have large jadeite core and thin omphacite rim. Accessory minerals are zircon, allanite, titanite and xenotim. Texture can be slightly oriented.	66/1883.147	Szentpéter (Svaty Peter, SK)	Stray
2			117/1884.130	Lekér (Hronovce? SK)	Stray
3			141/1882.44	Kövesd (Kamenica nad Hronom, SK)	Stray
4			300/1876.264	Bakonypéterd	Stray
5			55.1276	Bakony	Stray
6			M6.2010.10B.6348.1	Alsónyék	Lengyel culture, grave
7			M6.2010.10B.6380.1	Alsónyék	Lengyel culture, grave
8	**Fe-jadeitite**	Contains zoned Na-pyroxenes, they have jadeite core and Fe-jadeite rim. Omphacite and aegirine-augite are missing. Accessory minerals are zircon, rutile, titanite, allanite, ilmenite, xenotime and monazite. Texture can be slightly foliated.	39/1903	Iszkaszentgyörgy	Stray
9			3127	Lábod	Stray
10			300/1876.247	Almásneszmély	Stray
11			M6.2010.10B.792.2	Alsónyék	Lengyel culture, grave

#	Group	Short description of group	Inventory number of related stone tools	Localities	Context
12	Mixed jadeitite Iron mixed jadeitite	Contains zoned Na-pyroxenes, they have jadeite core and Fe-jadeite or omphacite or aegirine-augite rim. Accessory minerals are zircon, allanite, rutile, apatite, ilmenite and titanite. Chlorite can be found as retromorphic phase. Texture is homogeneous in general.	M6.TO.10/B.6320	Alsónyék	Lengyel culture, grave
13			N1/81-1938	Zengővárkony	Lengyel culture, grave
14			81/W2.5	Zirc	Field survey
15			N11/169-1938	Zengővárkony	Lengyel culture, grave
16			99.3.1863	Hódmezővásárhely-Gorzsa	Tisza culture, settlement
17			Olad-329	Szombathely, Olad	Lengyel culture, settlement
18	Omphacite schist Glaucophane schist	Contains zoned Na-pyroxenes with omphacite core, and jadeite rim. Accessory minerals are ilmenite, apatite, titanite. According to the texture, glaucophane was formed in the latest, retrograde stage of metamorphism. Slightly foliated/oriented texture.	106/1882.58	Mogyoród? Mogyorós?	Stray
19			N5/47-1939	Zengővárkony	Lengyel culture, grave

#	Group	Short description of group	Inventory number of related stone tools	Localities	Context
20	**Eclogite**	Contains high amount of garnets in addition to Na-pyroxenes. Omphacites seem to be homogenous, but in according to the data their core is slightly enriched in jadeite. Accessory minerals are ilmenite, zircon, apatite and rutile. Retromorphic phase (epidote) occurs rarely. Garnets are slightly zoned, but this zonation is invisible on the rough surfaces. They have foliated/oriented texture.	66/1883.41	Farnád (Farna, SK)	Stray
21			66/1883.173	Szőgyén (Svodín, SK)	Stray
22			177/1872.I/2	Unknown (Vét?)	Stray
23			M6.2010.10B.3060.3	Alsónyék	Lengyel culture, grave
24			117/1884.213	Vámosladány (Mýtne Ludany, SK)	Stray
25			Olad-321	Szombathely, Olad	Lengyel culture, settlement

Thesis 7:

Based on the previously presented data, the origin of the HP metaophiolite polished stone artefacts found in Hungary is most likely the Western Alpine HP-LT metaophiolite source.

Products of this source were widely sought-after stone tools in the Neolithic Europe with a long-distance trade network from the Western Alps to Scotland, to Scandinavian peninsula, to Iberian Peninsula and towards East, to the nowadays Bulgaria. Their origin from Monviso or Voltri Massif is a widely proven fact by the group of experts are working on this topic since a long time (JADE & JADE 2 projects). According to their results these raw materials of the Western Alps were used as very important symbolic items. This kind of HP-LT metaophiolitic rocks are characteristic rocks of the Western Alps, where they can be found from Aosta valley area at North till Monviso at South and in the Voltri Massif at the north-western end of Apennines (Monte Beigua, Liguria).

The other possible provenances are secondary and tertiary raw material sources. Secondary sources are conglomerates which are positioned at the piedmonts of the Western Alps and Voltri Massif and deposited during the Oligocene epoch. These Oligocene conglomerate deposits resedimented after the last Ice Age into tertiary raw material sources can be found in recent conglomerates of the Staffora and Curone rivers in area of NW Apennines. Sediments of upper Po River also contains this kind of HP metaophiolitic rocks, which most probably were originated from the Monviso area.

Differentiation of these Western Alpine sources is difficult, and exact source determination of the investigated stone implements exceeds the aims of this work, however, their variable materials and compositions suggest that, they are not originated from a single source; the most probable scenario is that they were transported from different areas of Western Alps and or Voltri Massif.

Conclusion

During the two years, when the investigations of these artefacts were performed, number of identified HP metaophiolite stone implements was grown from 3 to 25 pieces. In our first article about this subject we gave detailed description about three axe heads, while in this work 25 pieces of HP metaophiolite stone implements are presented divided into groups according to their rock type, and all groups are introduced with detailed description of main and accessory minerals, textural characteristics, and phases alterations if they were present. This significant increment was the result of systematic searching for greenstone artefacts in different collections (mainly in museums, however one HP metaophiolite tool was identified in a private collection also) and application of non-destructive analysis methods (PGAA and original surface method presented in this work) on artefacts which are not allowed to be a subject of destructive analysis. These methods proved their applicability to identify the raw materials of different stone artefacts, and proficiency to provide good quality data for comparison with data in the international literature. Based on the results, the origin of this raw material type is the Western Alps and/or the Voltri Massif, and/or secondary/tertiary sources sedimented from the erosion of the above-mentioned primary locations. Exact locations of these raw materials were not determined since all the above-mentioned locations are close to each other in the same direction and distance from Carpathian Basin, which means that practically they have the same significance from POV of contacts among the folks of prehistoric Europe *(Figure 1)*.

With this work, proven range of HP metaophiolite stone implements now is covering the Transdanubian region, and one piece appears at Eastern Hungary also. For the different distribution, there was a widespread explanation, that the jadeitite and the copper and gold items were in complementary distribution in Europe, however, according to the Hungarian archaeological record, they did not appear in the same archaeological periods: all the HP metaophiolites from known archaeological context are belonging to the Late Neolithic and Early Copper Age Lengyel Culture and Tisza Culture which were flourished in the second half of the Vth Millennium (approx. 4800–4500 BC); while the very early Copper Age first gold and copper artefacts can be dated to the younger Middle Copper Age.

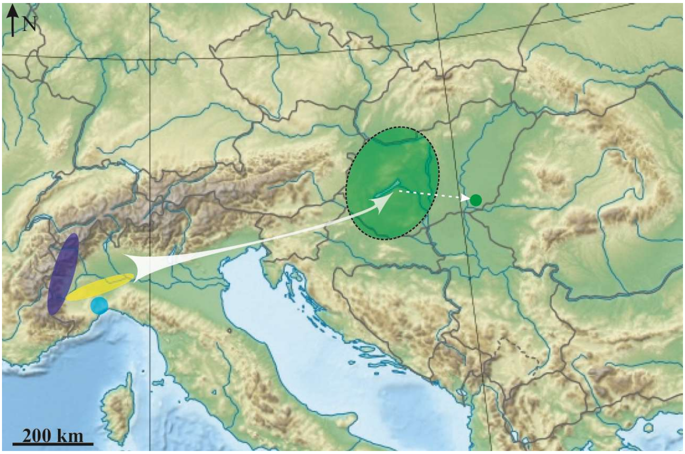


Figure 1. Map of provenance and locality range in Carpathian Basin based on this work.
Possible provenances of HP raw materials are marked with different colours: Western Alps, Voltri Massif, secondary/tertiary deposits
Most important localities of artefacts:
- Transdanubian region with Southern Slovakia (all investigated collections and archaeological localities) covered with a green area, except:
- Hódmezővásárhely-Gorzsa – the single point in Southeastern Hungary.

Articles were used to compile the dissertation

BENDŐ, ZS., OLÁH, I., PÉTERDI, B., HORVÁTH, E. (2013): Csiszolt kőeszközök és ékkövek roncsolásmentes SEM-EDX vizsgálata: lehetőségek és korlátok. Non-destructive SEM-EDX analytical method for polished stone tools and gems: opportunities and limitations. Archeometriai Műhely X/1: 51–66 (in Hungarian with English abstract and captions)

BENDŐ, ZS., SZAKMÁNY, GY., KASZTOVSZKY, ZS., MARÓTI, B., SZILÁGYI, SZ., SZILÁGYI, V., BIRÓ, K.T. (2014): Results of non-destructive SEM-EDX and PGAA analyses of jade and eclogite polished stone tools in Hungary. Archeometriai Műhely XI/4:187-206.

BENDŐ, ZS., SZAKMÁNY, GY., KASZTOVSZKY, ZS., BIRÓ, K.T., OLÁH, I., OSZTÁS, A., SZILÁGYI, V. (2018): High pressure metaophiolite polished stone implements found in Hungary. Archaeological and Anthropological Sciences 11:1643–1667

Összefoglalás

A probléma ismertetése

A geológiai minták előkészítése során teljesen megszokott a minták összetörése, elvágása, porítása, egyszóval roncsolása. Ilyen vizsgálati módszereket viszont nem alkalmazhatunk kulturális örökségünk ásvány vagy kőzet anyagú tárgyainál, például ékszerek drágakőberakásainál, szobrok, vagy festmények pigmentjeinek vizsgálata során. Ilyen esetekben a roncsolásmentes (esetleg mikroroncsolásos) módszerek alkalmazása kiemelten fontos ezeknek az egyedülálló és megismételhetetlen tárgyaknak a megőrzése szempontjából. Ez különösen igaz akkor, ha azok sértetlenek, jó minőségűek és részletes régészeti vagy történelmi dokumentációval rendelkeznek. Az archeometria kezdetei óta mindig nagy probléma volt, hogyan lehet a lehető legtöbb információt kinyerni, anélkül, hogy károsítanák vagy megsemmisítenék ezeket a hihetetlen történelmi háttérrel rendelkező tárgyakat. A kőkorszaki eszközök vizsgálatánál is célszerű roncsolásmentes vizsgálatokkal kezdeni, és csak erősen sérült, töredékes darabok esetén roncsolni a mintákat.

Az elemzési technikák fejlődése több részleges választ is adott a fenti problémára különböző elemzési módszerek formájában. Ezek a módszerek egymás eredményeit kölcsönösen alátámasztják, azonban egyik sem képes önmagában minden szükséges választ megadni. Sajnos azonban a leggyakrabban használt roncsolásmentes módszerek (XRF, Raman) egyike sem tud képi információt adni a kőzetszövetről.

Anyagvizsgálati módszerek

A minták teljesen roncsolásmentes vizsgálatának igénye és a vizuális információk szükségessége egy speciális mintakészítési módszer kidolgozásához vezetett, amely lehetővé teszi olyan minták vizsgálatát, amelyekről e módszer nélkül nem lehetett volna részletes információkat szerezni. Ezt a módszert „eredeti felszín vizsgálat”-nak neveztük el, mivel a vizsgált tárgyak eredeti (habár alaposan megtisztított) felületére összpontosít. Ennek a módszernek fő előnye a hagyományos, széles körben használt és elérhető elektronnyalábos anyagvizsgálat, amely mind szöveti, mind (ásvány)kémiai adatokat szolgáltat a mintákról. Mivel az „eredeti felületi módszer” nem igényel vágást, csiszolást vagy egyéb roncsolásos előkészítést, ez a módszer roncsolásmentesnek tekinthető (Bendő et al. 2013).

A vizsgálathoz az ELTE Kőzettan-Geokémiai Tanszékén lévő nagyméretű mintakamrával felszerelt pásztázó elektronmikroszkópot használtuk, melyben akár 30 cm hosszú mintákat is megvizsgálhatunk. A minták egy speciális mintaelőkészítési eljáráson mennek keresztül, melynek főbb lépései a tisztítás, a vizsgálandó felület kijelölése, a felület beburkolása alufóliával, legvégül pedig az előző lépések során kialakított felület vezetővé tétele vékony szénréteg rágőzölésével, mely a vizsgálat után nyomtalanul eltávolítható. Ezek után kerülnek be a leletek a pásztázó elektronmikroszkóp mintakamrájába, ahol a korábban előkészített területről készíthetünk fotókat és méréseket (Bendő et al. 2013).

A disszertációban bemutatott minták egy része töredékes volt, ami lehetővé tette, hogy roncsolásmentes vizsgálataink eredményeit a kőeszközökből készített vékonycsiszolatokon elvégzett „hagyományos" SEM-EDX vizsgálatok eredményeivel hasonlítsuk össze, ezzel tesztelve módszerünket. Eredményeink megmutatták, hogy az általunk alkalmazott teljesen roncsolásmentes módszer az archeometriai vizsgálatok során az esetek többségében jól használható, megfelelő képi és kémiai információt ad több kőzettípus esetén, azonban az is kiderült, hogy néhány kőzettípus esetén az eredeti felszín vizsgálati módszer csak részeredményeket szolgáltat. Ezekben az esetekben pontosabb eredményeket csak további – roncsolásos – vizsgálatokkal kaphatunk (Bendő et al. 2013).

Az „eredeti felszín vizsgálat"-on kívül hagyományos petrográfiai mikroszkópot, sztereomikroszkópot és mágneses szuszceptibilitás méréseket végeztünk, ill. a HP metaofiolit anyagú kőeszközök mindegyikéről teljeskőzet kémiai elemzés készült PGAA-val a KFKI-ban.

A vizsgált leletek eredete

A referenciaként (tehát eredeti felszínén és vékonycsiszolatban is megvizsgált kőeszközök) Diósviszlóról (Baranya megye), Veszprém-Kádártáról (Veszprém megye) és Balatonőszödről (Somogy megye) kerültek elő. A leletek egy része ásatásból került elő, más része szórványlelet volt (Oláh et al. 2012b, Oláh et al. 2013, Péterdi 2011).

HP-LT metaofiolit anyagú kőeszközök sokáig nem voltak ismertek Magyarország területéről, elsőként Friedel et al. 2008 és

2011 említi őket részletes vizsgálat nélkül. Következő lépésben Szakmány et al. 2013 ír 3 HP-LT metaofiolit kőeszköz részletes vizsgálatáról, melyek eredmények ezen disszertációnak is szerves részét képezik. Sajnos ezen kőeszközök többsége szórványlelet, de négy lelőhelyről 11 darabnak ismert a régészeti kontextusa. Ezek főként a Dunántúlról kerültek elő (1 tiszántúli darab kivételével), és többnyire a késő neolit Lengyel-kultúrához köthetők az egyedüli tiszántúli darab kivételével, amely a késő neolitikus Tisza-kultúrához köthető (Bendő et al. 2014, 2018).

A dolgozat eredményei

A disszertációban bemutatott eredeti felszín vizsgálati módszerről bebizonyosodott, hogy nagyon hasznos lehet a régészeti leletek és más műtárgyak vizsgálata során, különösen azokban az esetekben, ahol roncsolásos vizsgálatra nem kerülhet sor. A bemutatott esettanulmányokból kiderült, hogy a felszínről kapott képi és ásványkémiai adatok a legtöbb esetben nagyon hasonlók a vékonycsiszolatból mért adatokkal. Vizsgálataink során az is nyilvánvalóvá vált, hogy a módszer nem alkalmazható egyértelmű sikerrel minden kőzettípusnál. Ugyanakkor ezekben az esetekben is kapunk olyan információkat (szövet, az eredeti felszínen megjelenő ásványok kémiája, és a hiányzó fázisok helye, a szövetben), melyek a többi roncsolásmentes vizsgálati eljáráshoz hasonlóan jelentős többlet információt tartalmaznak (Bendő et al. 2013).

A jó minőségű, csiszolt kőeszközök készítésére alkalmas, magas nyomású-alacsony hőmérsékletű (HP-LT) metaofiolit kőzettípusok (pl. Na-piroxenit/jade, eklogit) sokáig ismeretlenek voltak a magyar leletek között, és ma is a ritkább típusok közé tartoznak.

Az első HP-LT metaofiolitból készült újkőkori kőeszközök előkerülése után a nagy kőeszközgyűjtemények részletes petrológiai vizsgálata során viszonylag nagy számban kerültek elő ezek a leletek. Jelenlegi ismereteink szerint Magyarországról 25 HP metaofiolit kőeszköz ismert. A disszertációban bemutatott leletekkel a HP-LT metaofiolit kőeszközök bizonyított elterjedési területe immár a Dunántúli régiót, valamint a mai Szlovákia déli részét is lefedi (Bendő et al. 2014, 2018).

A vizsgálatok során használt roncsolásmentes módszerek eredményei alapján a kőeszközöket 8 különböző csoportba tudtuk sorolni nyersanyaguk szerint D'Amico et al. 2003 alapján: jadeitit, kevert jadeitit, vas-kevert jadeitit, vas jadeitit, omfacitit- és glaukofánpalák, magnézium- és vas-eklogitok.

Adataink alapján a Magyarországon fellelt HP-LT metaofiolit kőeszközök valószínűleg ugyanabból a nyersanyagforrásból származnak, mint az olaszországi HP metaofiolit kőeszközök (D'Amico and Starnini 2006), vagyis a nyersanyagforrás a mai ÉNY Olaszország területén helyezkedett el. A témával foglalkozó szakirodalom szerint mind az elsődleges (Nyugati-Alpok a piemonti Monviso környékén vagy a liguriai Voltri-masszívum), mind a másodlagos előfordulások (a Po, Staffora és Curone folyók negyedidőszaki lerakódásaiban) potenciális nyersanyagforrások (Pétrequin et al. 2012a, 2012d, D'Amico and Starnini 2006, 2012). Vizsgálataink eredményei megerősítették a Pó-síkságot a Kárpát-medencével összekötő hosszú távú kereskedelmi útvonalak létezését a Kr. e. V. évezredben.

A dolgozat összeállításához felhasznált cikkek

BENDŐ, ZS., OLÁH, I., PÉTERDI, B., HORVÁTH, E. (2013): Csiszolt kőeszközök és ékkövek roncsolásmentes SEM-EDX vizsgálata: lehetőségek és korlátok. Non-destructive SEM-EDX analytical method for polished stone tools and gems: opportunities and limitations. Archeometriai Műhely X/1: 51–66 (in Hungarian with English abstract and captions)

BENDŐ, ZS., SZAKMÁNY, GY., KASZTOVSZKY, ZS., MARÓTI, B., SZILÁGYI, SZ., SZILÁGYI, V., BIRÓ, K.T. (2014): Results of non-destructive SEM-EDX and PGAA analyses of jade and eclogite polished stone tools in Hungary. Archeometriai Műhely XI/4:187-206.

BENDŐ, ZS., SZAKMÁNY, GY., KASZTOVSZKY, ZS., BIRÓ, K.T., OLÁH, I., OSZTÁS, A., SZILÁGYI, V. (2018): High pressure metaophiolite polished stone implements found in Hungary. Archaeological and Anthropological Sciences 11:1643–1667

Other publications

Based on results about HP metaophiolite stone implements, our research was extended to stone implements made of nephrite, serpentinite and hornfels raw materials. However, these researches are not finished yet, some important articles and conference papers were published already. A selection of these publications – articles only – is listed below, year-by-year, about both topics, stone implements and inlaid gemstones.

2013

HORVÁTH, E., BENDŐ, Z., MAY, Z. (2013). One hundred year later... Characteristics of materials technology and workshop affinities of the polychrome metalwork from Gáva (North-East Hungary). In: HARDT, M., HEINRICH-TAMÁSKA, O., (eds.) Macht des Goldes, Gold der Macht: Herrschafts- und Jenseitsrepräsentation zwischen Antike und Frühmittelalter im mittleren Donauraum. 251–280.

SZAKMÁNY, G., T. BIRÓ, K., KRISTÁLY, F., BENDŐ, Z., KASZTOVSZKY, Z., ZAJZON, N. (2013): Távolsági import csiszolt kőeszközök nagynyomású metamorfitokból Magyarországon (Long distance import of polished stone artefacts: HP metamorphites in Hungary.) Archeometriai Műhely X/1 pp. 83-92. 10 p.

OLÁH, I., LIGNER, J., BENDŐ, Z., SZAKMÁNY, G., SZILÁGYI, V. (2013): Különösen gazdag kőbalta és csiszolt kőeszköz leletegyüttes előzetes vizsgálati eredményei Diósviszlóról (Preliminary results on a unique collection of axes and polished stone tools from Diósviszló) Archeometriai Műhely X/1pp. 67-82. , 16 p.

2014

BENDŐ, Z., HEINRICH-TAMÁSKA, O., HORVÁTH, E. (2014): Material- und Herstellungsanalysen der goldenen und vergoldeten Metallfunde aus dem Grab A von Keszthely-Fenékpuszta, Ödenkirche-Flur. In: MÜLLER, R. (ed.) Die Gräberfelder von Keszthely-Fenékpuszta, Ödenkirche-Flur Budapest, Magyarország, Leipzig, Németország, Keszthely, Magyarország, Rahden, Németország : Verlag Marie Leidorf 377 p. pp. 311-336. , 26 p.

PÉTERDI, B., SZAKMÁNY, GY., JUDIK, K., DOBOSI, G., KASZTOVSZKY, ZS., SZILÁGYI, V., MARÓTI, B., BENDŐ, ZS., GIL, G. (2014). Petrographic and geochemical investigation of a stone adze made of nephrite from the Balatonőszöd - Temetői dűlő site (Hungary), with a review of the nephrite occurrences in Europe (especially in Switzerland and in the Bohemian Massif). Geological Quarterly 58, 1, 181–192.

PÉTERDI, B., SZAKMANY, G., BENDŐ, Z., KASZTOVSZKY, Z., T. BIRÓ K., GIL, G., HARSÁNYI, I., MILE, V., SZILÁGYI, S. (2014): Possible provenances of nephrite artefacts found on Hungarian archaeological sites (preliminary results) [Magyarországi régészeti lelőhelyeken talált nefrit eszközök és ezek lehetséges származási helye (előzetes eredmények)] Archeometriai Műhely XI/4 pp. 207-222. , 16 p.

PÉTERDI, B., SZAKMÁNY, G., BENDŐ, Z., KASZTOVSZKY, Z., T. BIRÓ, K., GIL, G., HARSÁNYI, I., MILE, V., SZILÁGYI, S. (2014) Possible provenances of nephrite artefacts found on Hungarian archaeological sites (preliminary results). Archeometriai Műhely XI/4 207-222

2015

SCHILLING, L., BENDŐ, Z., VÁCZI, T. (2015) Rangos szarmata temetkezés Szolnok-Szűcs-tanya lelőhelyről (Ein sarmatisches Adelsgrab am Szolnok-Szűcs-tanya). In: TÜRK A., BALOGH C., MAJOR B. (2015) Hadak útján XXIV. A népvándorláskor fiatal kutatóinak XXIV. konferenciája. 227-256

F., KOVÁCS P., HOPPÁL, K., MASEK, Z., HORVÁTH, E., BENDŐ, Z., VÁCZI, T. (2015): Előzetes jelentés Tiszapüspöki – Fehér-tópart gepida temető és szarmata teleprészlet feltárásáról. In: Tisicum: Jász-Nagykun-Szolnok Megyei Múzeumok Évkönyve 24 pp. 81-91. 11 p.

2016

SZAKMÁNY, G., JÓZSA, S., BENDŐ, Z., KASZTOVSZKY, Z., HORVÁTH, F. (2016): Magyarországon előkerült hornfels (mész-szilikát szaruszirt) anyagú csiszolt kőeszközök nyersanyaglelőhelyének felkutatása / Discovering the provenance of hornfels polished stone tools in Hungary. Archeometriai Műhely XIII/1 43-54

2018

HEINRICH-TAMÁSKA, O., HORVÁTH, E., BENDŐ, Z. (2018): Before or after AD 568?: Technological observations on the gold objects from Grave 2 at Keszthely-Fenéki Street. In: EILBRACHT, H., HEINRICH-TAMÁSKA, O., NIEMEYER, B., REICHE, I., VOß, H.-U. (eds.) Über den Glanz des Goldes und die Polychromie: Technische Vielfalt und kulturelle Bedeutung vor- und frühgeschichtlicher Metallarbeiten. Bonn, Germany, 313-349.

HORVÁTH, E.; ARADI, L.E.; BENDŐ, Z.; VÁCZI, T.; RACZ, Z. (2025): Byzantine polychromy at its finest: art, craft and aesthetics of the noblest Avar period jewel reconstructed. Archaeological and Anthropological Sciences 17: 163 , 19 p.

HORVÁTH, E., MOZGAI, V., BENDŐ, Z., BAJNÓCZI, B. (IN PRESS). Archaeometric investigation on polychrome jewellery from the Langobardic-period cemetery at Szólád–Kertek mögött, with special focus on niello and garnet inlays. In: VIDA, T., WINGER, D. (eds.): Szólád II. Das langobardenzeitliche Gräberfeld: Funde, Archäometrie, Biorchaeologie. Reichert Verlag, Wiesbaden, Germany. p 60.

Társszerzői nyilatkozat

Alulírott Szakmány György nyilatkozom, hogy a *Results of non-destructive SEM-EDX and PGAA analyses of jade and eclogite polished stone tools in Hungary. (Archeometriai Műhely 2014 XI/4:187-206)* és a *High pressure metaophiolite polished stone implements found in Hungary. (Archaeological and Anthropological Sciences 2018 11: 1643–1667)* publikációkban a doktorjelölt szerepe meghatározó fontosságú, nem használtam fel tudományos fokozat megszerzésekor, és ezt a jövőben sem teszem.

Kerepes, 2026 február 6.

....
(társszerző)

Társszerzői nyilatkozat

Alulírott T. Biró Katalin nyilatkozom, hogy a *Results of non-destructive SEM-EDX and PGAA analyses of jade and eclogite polished stone tools in Hungary. (Archeometriai Műhely2014 XI/4:187-206)* és a *High pressure metaophiolite polished stone implements found in Hungary. (Archaeological and Anthropological Sciences 2018 11: 1643–1667)* publikációkban a doktorjelölt szerepe meghatározó fontosságú, nem használtam fel tudományos fokozat megszerzésekor, és ezt a jövőben sem teszem.

Budapest, 2026 február 6. ....

T. Biró Katalin

Társszerzői nyilatkozat

Alulírott Kasztovszky Zsolt nyilatkozom, hogy a *Results of non-destructive SEM-EDX and PGAA analyses of jade and eclogite polished stone tools in Hungary. (Archeometriai Műhely 2014 XI/4:187-206)* és a *High pressure metaophiolite polished stone implements found in Hungary. (Archaeological and Anthropological Sciences 2018 11: 1643–1667)* publikációkban a doktorjelölt szerepe meghatározó fontosságú, nem használtam fel tudományos fokozat megszerzésekor, és ezt a jövőben sem teszem.

Budapest, 2026 február 6.

....
Kasztovszky Zsolt

Társszerzői nyilatkozat

Alulírott Oláh István nyilatkozom, hogy a *Csiszolt kőeszközök és ékkövek roncsolásmentes SEM-EDX vizsgálata: lehetőségek és korlátok. Non-destructive SEM-EDX analytical method for polished stone tools and gems: opportunities and limitations. (Archeometriai Műhely 2013 X/1: 51–66)* és a *High pressure metaophiolite polished stone implements found in Hungary. (Archaeological and Anthropological Sciences 2018 11: 1643–1667)* publikációkban a doktorjelölt szerepe meghatározó fontosságú, nem használtam fel tudományos fokozat megszerzésekor, és ezt a jövőben sem teszem.

Szada, 2026 február 6.

....
(társszerző)

Társszerzői nyilatkozat

Alulírott Szilágyi Veronika nyilatkozom, hogy a *Results of non-destructive SEM-EDX and PGAA analyses of jade and eclogite polished stone tools in Hungary. (Archeometriai Műhely 2014 XI/4:187-206)* és a *High pressure metaophiolite polished stone implements found in Hungary. (Archaeological and Anthropological Sciences 2018 11: 1643–1667)* publikációkban a doktorjelölt szerepe meghatározó fontosságú, a publikációk eredményeit nem használtam fel tudományos fokozat megszerzésekor, és ezt a jövőben sem teszem.

Budapest, 2026. február 6.

....
Szilágyi Veronika

Társszerzői nyilatkozat

Alulírott Dr. Péterdi Bálint nyilatkozom, hogy a *Csiszolt kőeszközök és ékkövek roncsolásmentes SEM-EDX vizsgálata: lehetőségek és korlátok. Non-destructive SEM-EDX analytical method for polished stone tools and gems: opportunities and limitations. (Archeometriai Műhely 2013 X/1: 51–66)* publikációban a doktorjelölt szerepe meghatározó fontosságú, nem használtam fel tudományos fokozat megszerzésekor, és ezt a jövőben sem teszem.

Budapest, 2026. február 6.

Dr. Péterdi Bálint

Társszerzői nyilatkozat

Alulírott Horváth Eszter nyilatkozom, hogy a *Csiszolt kőeszközök és ékkövek roncsolásmentes SEM-EDX vizsgálata: lehetőségek és korlátok. Non-destructive SEM-EDX analytical method for polished stone tools and gems: opportunities and limitations. (Archeometriai Műhely 2013 X/1: 51–66)* publikációban a doktorjelölt szerepe meghatározó fontosságú, nem használtam fel tudományos fokozat megszerzésekor, és ezt a jövőben sem teszem.

Budapest, 2026 február 6.

Horváth Eszter

Társszerzői nyilatkozat

Alulírott Osztás Anett nyilatkozom, hogy a *High pressure metaophiolite polished stone implements found in Hungary. (Archaeological and Anthropological Sciences 2018 11: 1643–1667)* publikációban a doktorjelölt szerepe meghatározó fontosságú, nem használtam fel tudományos fokozat megszerzésekor, és ezt a jövőben sem teszem.

Budapest, 2026 február 6.

Osztás Anett

Társszerzői nyilatkozat

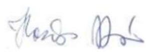
Alulírott Maróti Boglárka nyilatkozom, hogy a *Results of non-destructive SEM-EDX and PGAA analyses of jade and eclogite polished stone tools in Hungary. (Archeometriai Műhely 2014 XI/4:187-206)* publikációban a doktorjelölt szerepe meghatározó fontosságú, a publikáció eredményeit nem használtam fel tudományos fokozat megszerzésekor, és ezt a jövőben sem teszem.

Budapest, 2026. február 6.

Maróti Boglárka

Társszerzői nyilatkozat

Alulírott Harsányi Ildikó nyilatkozom, hogy a *High pressure metaophiolite polished stone implements found in Hungary. (Archaeological and Anthropological Sciences 2018 11: 1643–1667)* publikációban a doktorjelölt szerepe meghatározó fontosságú, a publikáció eredményeit nem használtam fel tudományos fokozat megszerzésekor, és ezt a jövőben sem teszem.



Budapest, 2026. február 6.

....
Harsányi Ildikó

Társszerzői nyilatkozat

Alulírott Szilágyi Szandra nyilatkozom, hogy a *Results of non-destructive SEM-EDX and PGAA analyses of jade and eclogite polished stone tools in Hungary. (Archeometriai Műhely 2014 XI/4:187-206)* publikációban a doktorjelölt szerepe meghatározó fontosságú, nem használtam fel tudományos fokozat megszerzésekor, és ezt a jövőben sem teszem.

Budapest, 2026 február 6.

....
Szilágyi Szandra