Scratches? Scribbles? Scripture! Revealing the Unseen – 3D Scanning of Glagolitic Graffiti of the 10th Century at the Monastery of St. Naum

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The Monastery of Saint Naum in Macedonia is part of the UNESCO World Heritage Site "Natural and Cultural Heritage of the Ohrid region". The area is unique not only for its architecture but also its outstanding linguistic heritage. The monastery was named after Saint Naum and founded at the end of the 9th century and is visited by many tourists every day. In the transition from the narthex to the central church, the visitor immediately notices two shiny white marble columns. These columns carry unique inscriptions/graffiti, which represent some of the earliest evidence of the Glagolitic alphabet, a precursor of the Cyrillic alphabet. During the project, previously unseen inscriptions were revealed on the columns.

The huge number of tourists poses a danger to the historic surfaces of the columns, as the constant touching and rubbing of the inscriptions is causing deterioration. Therefore, there is an urgent need to image and archive the inscriptions. Using macrophotography with raking light did not work well as the columns' curvature and shiny surface caused blurring in the images, and some of the graffiti were not visible. Therefore, a structured light scanner with a 3D point resolution of 30 µm or less was used to record the columns, to both preserve and reveal these unique graffiti. The recording of the surfaces was deliberately carried out without texture information to exclude errors caused by the shiny and discoloured marble of the columns. The resulting high-resolution 3D model can be virtually illuminated from any angle, for example using raking light, allowing detailed observations and analysis. In addition to digitally preserving and archiving the inscriptions, the resulting surface models can be easily accessed by Slavistic and linguistic experts for a variety of research purposes.

Key words:
3D Scanning, Cultural Heritage, Graffiti, Surface Analysis, Revealing Lost Inscriptions.

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INTRODUCTION: THE ST. NAUM GRAFFITI DOCUMENTATION PROJECT

The documentation of the graffiti at the Monastery of St. Naum was an interdisciplinary project involving academics from Slavonic linguistics and the preservation sciences, carried out by the University of Bamberg. For the first report on the project, see also Kempgen [2019]. Initialized by Prof. Dr. Kempgen in 2015, the scanning work was carried out by the Preservation Sciences department of the University of Bamberg during one week in September and the post processing in the following months afterwards.

The project's aim was the precise 3D documentation of several Glagolitic and Cyrillic graffiti on two columns in the church at the Monastery of St. Naum in Macedonia; the resulting models should enable the linguists to study and analyse these inscriptions off site and enhance the legibility of the writings. The 3D-Documentation should work far better than 2D photos because of the potential to utilise multiple lighting scenarios, for example raking light. In

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addition the models can be easily shared with linguistic researchers, for example, over the web. The project was funded by the Bavarian State Ministry of Education and Cultural Affairs and supported by the former and current rector of the University of Bitola.

THE MONASTERY OF ST. NAUM

The Monastery of St. Naum is located on the Ohrid Lake in the south of Macedonia right next to the border with Albania (Fig. 1). It was founded at the end of the 9th century by Saint Naum. The Saint, who died in 910, was buried in an annex in the monastery's church. His burial place is visited by a huge number of tourists every day. Besides the grave of the saint, the church is decorated all over with amazing wall paintings. The monastery is nowadays part of the UNESCO World Heritage Site "Natural and Cultural Heritage of the Ohrid region". The site was inscribed to the UNESCO World Heritage List in 1979 due for its natural uniqueness and in 1980 the inscription was extended to cover the area's built and intangible heritage. This included the region's ancient Slavonic monasteries, as well as the unique spread of education, culture and writing in the old Slavonic world and other unique features in the region's preserved ancient city centers [UNESCO 1980].

Today the Monastery of St. Naum is partly reconstructed, as the monastery itself was destroyed in the 19th century and rebuilt afterwards. The church in the middle of the complex survived the destruction, but has nevertheless been renovated several times since it was built at the end of the 9th century. For more information about the building history and the monastery itself see Grozdanov [1995].

Fig. 1. The Monastery of St. Naum, Macedonia 2015.

THE OBJECTS

The main concern of the project was to document the graffiti on two columns inside the church. They are located in the nave behind a narthex, which was added to the church sometime after its construction (Fig 2). The columns are made of white marble and the surfaces have been polished. The columns are spolia, and the only existing remains of the original church.

The columns are in the shape of double columns so they are not cylindrical; the middle part is flat and the front and the back are roughly halved cylinders. As well as the flat areas, these curved parts also carry a lot of inscriptions and crosses from different times. The bases and capitals of the columns are also made of white marble and show a big cross at the front, which is not graffiti but an intended artistic feature. They also show traces of machining and the tools used. Today, the surfaces of the columns, bases and capitals are soiled by dirt, dust and candle wax and appear brownish.

As mentioned before, on the columns there are several graffiti, with varying dates of creation. Most date back to the 10th or 12th centuries, and some of them have been known since the 19th century. Antonin published some inscriptions from the Ohrid region, including some from the Monastery of St. Naum [Antonin 1886]. Some of them were drawn, photographed and documented by Antonin and by other Slavicists after him [Miljukov 1899; Ivanov 1908; Stefaniḱ1966; Grozdanov 1995]. Besides these rudimentary partial documentations, when the project started there was no satisfactory documentation of the current state of the entire columns, including all the graffiti.

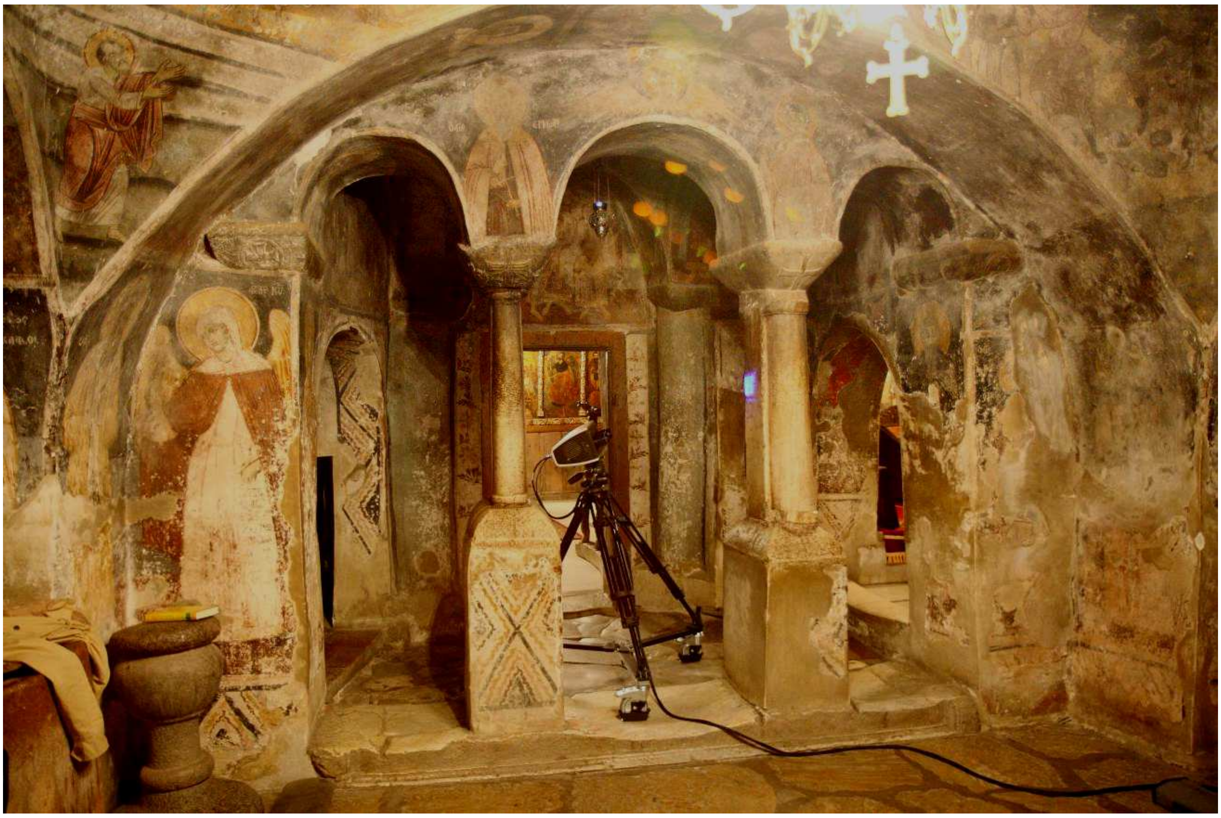

Fig. 2. The columns in the church, surrounded by wall paintings, 2015.

The graffiti vary in size and shape. Though some of them are extremely small, they can still be seen with the naked eye, because the author's intention was that they can be seen and read by other visitors to the place (Fig. 3). Although the writings can be seen, and even though some of them are scratched quite deep into the surface, they are barely legible. The crosses on the curved part of the columns have in particular been scratched quite deeply. The bigger crosses on the front of the columns are well documented in 19th century drawings [Miljukov 1899]. It is also known that the columns carry Glagolitic and Cyrillic inscriptions. Some of them represent complete phrases, others just a name or a few characters. Even small sketches like a fishnet can be seen.

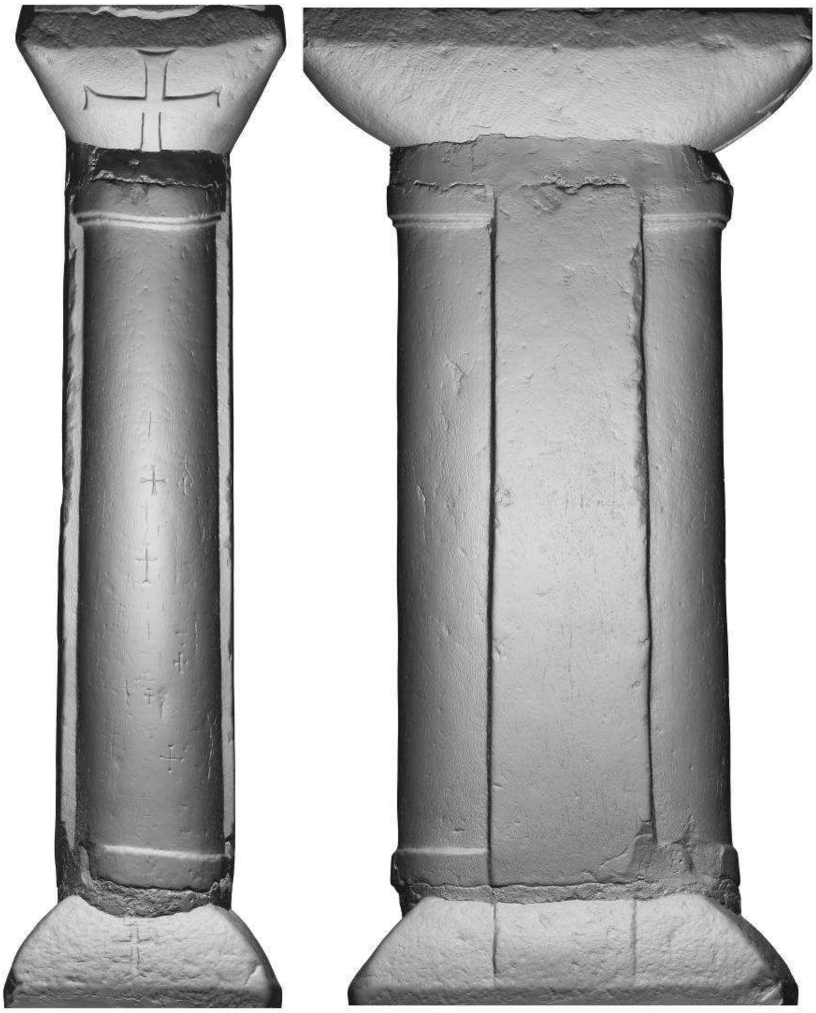

Fig 3. 3D model of the right column with crosses on the front.

The Glagolitic script is the oldest Slavic script, created by Saints Cyrill and Method in 863. The Glagolitic alphabet was the precursor of the Cyrillic alphabet, created some decades later in the capital of the Bulgarian kingdom, Preslav, using the Greek alphabet as its basis (and incorporating Glagolitic characters for sounds the Greek alphabet did not have letters for). In the Ohrid region, the Glagolitic alphabet was spread by Saints Kliment († 916) and Naum († 910), disciples of Cyrill and Method. While the Glagolitic alphabet was soon phased out in eastern Bulgaria, it lived on until the 12th century in Macedonia, where Saint Kliment had founded the "Ohrid Literary School" in 886 with Saint Naum succeeding him as head of the school. In Ohrid itself, no inscriptions or manuscripts from that time have survived; therefore, the inscriptions in the Monastery of St. Naum are among the oldest traces of the early cultural history of the Slavs.

Some characters on the columns are not scratched very deep into the surface, so the difference to the surrounding area is in the submillimetre range. In addition, the scratchings partly overlay each other and are therefore even harder to decipher. As mentioned before only the most readily noticeable inscriptions have been drawn, traced and photographed, and a complete documentation can both be used by Slavicist, and archived to preserve a permanent record for the current state was missing.

THE DOCUMENTATION WORKFLOW

Recording ancient inscriptions or other delicate cultural heritage with new digital (three-dimensional) techniques has been practiced for several years; the technologies used vary from image based approaches like photography with raking light or photogrammetry, more elaborate photographic approaches like Reflectance Transformation Imaging or Image Based Modelling, to the use of many different 3D-scanning technologies using structured light or laser technologies [Samaan et al. 2016; Historic England 2018]. For the previous use of "Structured Light Scanning" (SLS) for delicate cultural heritage see also Schäfer et al. [2012].

To meet the project's aims, a high-resolution documentation was needed. It was also vital not to put the graffiti at any further risk, for example by tracing them, so a completely contact free method for recording was required. Simply tracing the graffiti with translucent drawing paper would not have led to an acceptable result anyway, because of the very slight depth of most of the inscriptions. A further difficulty was that the work could only be carried out at night due to the many tourists and religious visitors in the church during the day. Working off the monastery's opening hours was particularly important, both to avoid disturbing the tourists, and to avoid being disturbed by them. Another challenge is presented by the fact that the marble columns have been polished, not only during manufacture, but also due to the constant touching and rubbing by the visitors. Nowadays, the surface is also dirty and appears browned at several areas. At the same time the columns are shiny due to the marble's crystalline structure. Another problem when trying to document them with photos is the curved structure; even with raking light, photography does not result in sufficiently legible inscriptions.

The decision to use a high-resolution Structured Light Scanning device was made according to the most important challenges: The construction of the columns from marble, and the surface soiled by candle wax and bounded dust. High-resolution Structured Light Scanning (SLS) of the columns was therefore carried out using a Steinbichler L3D 5M structured light scanner with changeable lenses and blue LED light source [Rahrig et al. 2018]. The camera has a 2448 x 2050 pixel sensor [Carl Zeiss/Steinbichler 2013]. The changeable lenses allow the resolution to be adjusted according to the size of the measuring field, which can improve results in especially delicate areas. The entire columns and capitals were documented with a resolution up to 100 µm, giving a precise 3D documentation of the current state, and enabling previously unseen inscriptions to be found. Certain areas with particularly delicate characters where inscriptions can be seen but not read sufficiently were documented with a resolution up to 30 µm. The higher resolution significantly enhances the legibility and helps to characterize and identify the very difficult to decipher characters.

The entire columns, as well as the details, were recorded in short time slots over three nights. Each column, including base and capital, is approximately 1.40 m high. The right column shaft itself is 0.98 m high and about 0.46 m deep.

Eight details were recorded in order to better reveal the most delicate inscriptions. In addition to the scanning of the columns a photographic documentation using raking light was done.

It was very important to document the Cyrillic and Glagolitic graffiti because the monastery is visited by many tourists each day and the inscriptions can be easily damaged by scrubbing/rubbing the surface, or even by scratching in new graffiti. If the graffiti were to be destroyed, a unique part of the intangible cultural heritage of the old Slavic scripts in Macedonia would disappear forever. SLS, used as a non-destructive technique – for example to enhance the legibility of weathered letters of greek inscriptions on stone [Papadaki 2015] or bas-reliefs [Schäfer et al. 2012] – is not a new approach. Nevertheless, the SLS scanner from Steinbichler/Carl Zeiss with a blue LED light source was considered to be the best technique to achieve the aims of this project, and has produced good results in several other case studies involving marble at the University of Bamberg [Rahrig et al. 2018]. The use of laser scanning can create an unsatisfactory result on marble because of sub-surface reflection due to the marble's crystalline structure. Regarding the columns in the church in the Monastery of St. Naum the surface of the marble is polished, which can have negative effects like extreme reflectance of the surface that is impossible to record. The problem with using lasers to record polished marble is that the laser penetrates the material, which then causes errors in the surface measurements. Godin et al. [2001] investigated both reflection and subsurface scattering in laboratory conditions and discovered already a bias in depth measurement which causes surface noise.

This phenomenon when scanning marble with lasers was also recognized by Tsakiri et al. [2003]: they stated a significant difference in noise between plaster and marble elements of sculptures. Regarding the characters of the graffiti in the Monastery of St. Naum, the noise produced by a laser scanning device would have led to unreadable results; the noise would have drowned out the shallow engravings completely. The SLS system's accuracy and resolution also made it ideal for recording some of the finest characters.

Image Based Modelling and "Reflectance Transformation Imaging" (RTI) were also considered. Using RTI for the documentation of inscriptions and nearly planar surfaces can lead to great results, as shown by several case studies like the Herculaneum Project or several others [Greco and Flouda 2017; DiBiasie Sammons 2018], but because of the curved structure of the columns and the aim to have an accurate 3D documentation of the entire column in one model, the SLS System was preferred.

POSTPROCESSING

Post-processing of the data was carried out off-site. Using the scanner's proprietary software - Cometplus 9.62 - a best-fit matching was done for each data set. After filtering redundant points and carrying out a slight noise reduction to compensate for the effects of the marble noise, the data sets were meshed. The surface models were exported as .stl files and imported into Geomagic Studio (2014) for further processing, including hole filling, and to decimate the models. Along with the raw data, the 100% .stl files were archived, as well as a 10% version which will be used to share high-resolution, but still manageable data among researchers [Rahrig 2017]. The file sizes vary from 100 MB (reduced models) to more than 1GB for the full resolution 3D models. Orthoimages were also processed to provide a quick impression of the models, and the eight high-resolution areas were aligned to the models of the entire columns.

Fig. 4. Front part of the right column: 3D model unrolled and visualized using normal map rendering in Meshlab.

The .stl format was used because it is achivable, viewable in most of the current 3D software solutions and can even be used in various (free) software solutions like Meshlab[1] (Version 2016.12).The resulting high-resolution 3D model can be virtually illuminated at any angle, for example using raking light, allowing detailed observations and analysis. It can also be unrolled and rendered as a normal map. To unroll the curved parts of the columns, CloudCompare[2] v.2.8.1 was used. In order to make edges stand out from the surrounding areas, the normal map rendering mode in Meshlab was used (Fig. 4). Using these tools helps significantly enhance the legibility of the delicate inscriptions. For sharing and to facilitate further work with the data, a web-based tool like the Digital Epigraphy Toolbox [Bozia et al. 2014] might be useful, but the size of the data sets might be problematic, and further processing may be necessary.

RESULTS

Only some examples of the project's results are shown, as the complete evaluation of the data is still a work in progress. First of all to illustrate the problem of faded out inscriptions the well investigated inscription – published by Grozdanov [1995] – is a good example of the problems and limitations of previous techniques used: Grozdanov visited the church and made several drawings from the columns. He displayed several lines of phrases (Fig. 5) on the right column and drew them alongside the many crosses. In contrast to these early drawings, today the first line in Fig. 5 can hardly be seen any more with the naked eye. Our scanning succeeded in making visible what remains of the inscription, at least to such a degree that previous readings of the inscription can be confirmed. The scanning data sets provide an interpretation-free, dimensionally stable documentation and show the location of the graffiti on the column, whereas the drawings might not show the correct position of the graffiti to each other and contain an unclear level of interpretation brought in by drawer.

Fig. 5. Details of the right column, left top: Photograph of the column showing the difficult and shiny surface; right top: Detail of the drawing by Grozdanov; left below: Detail of the model of the column in resolution up to 100µm where only parts of the graffiti is visible; right below: Part of the column in resolution up to 30µm, showing in addition the nearly faded out parts of the graffiti above the blue frame.

[1] http://www.meshlab.net/
[2] http://www.cloudcompare.org/

Another interesting challenge was the overlaying structures, where the characters are disturbed by other graffiti. The focus was on the fishnet and a writing of a name on the flat middle part of the right-hand column. The middle part is flat enough to use raking light from various angles, but the fishnet overlays the writing, making it hard to read or to determine which engraving was carried out first. With the use of the 3D surface model and suitable lighting conditions, the writing which was previously characterized as “ALEXANDER” [Mixeev 2013] could be verified.

As shown in Fig. 6, with the wrong lightning setting the inscription is invisible on the texture-less surface model. The lack of texture can, at times, obscure the required information; however, when combined with appropriate raking light illumination, the texture free surface can dramatically enhance legibility and reveal more information than one might find in a photograph.

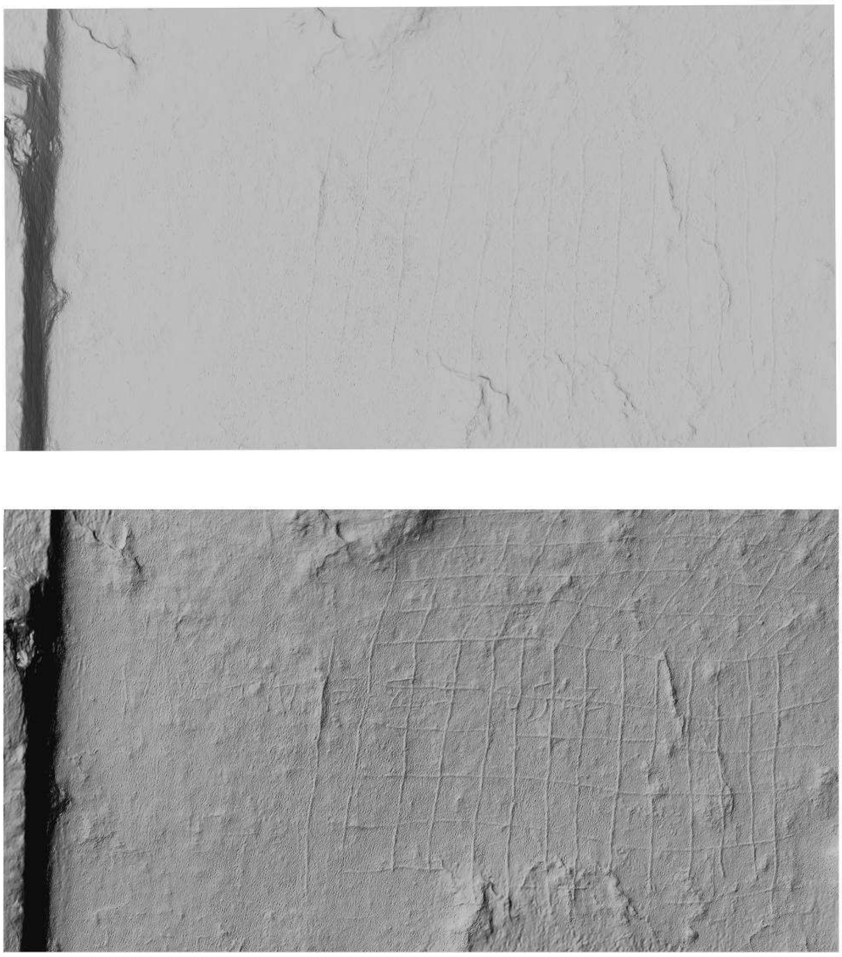

Fig. 6. 3D surface model with inadequate lighting (above) and suitable lighting conditions and legible characters (below).

As mentioned above, another challenging problem, both on-site and using photos, is that it is impossible to decide whether the fishnet or the writing was created first. Knowing which one came first can help in dating the inscriptions, as the ALEXANDER writing is Glagolitic and can therefore be dated to the 11th century [Mixeev 2013]. With the help of a normal map the authors were able to discover that the vertical lines of the fishnet must have been scratched over the existing lines of the ALEXANDER writing (Fig. 7).

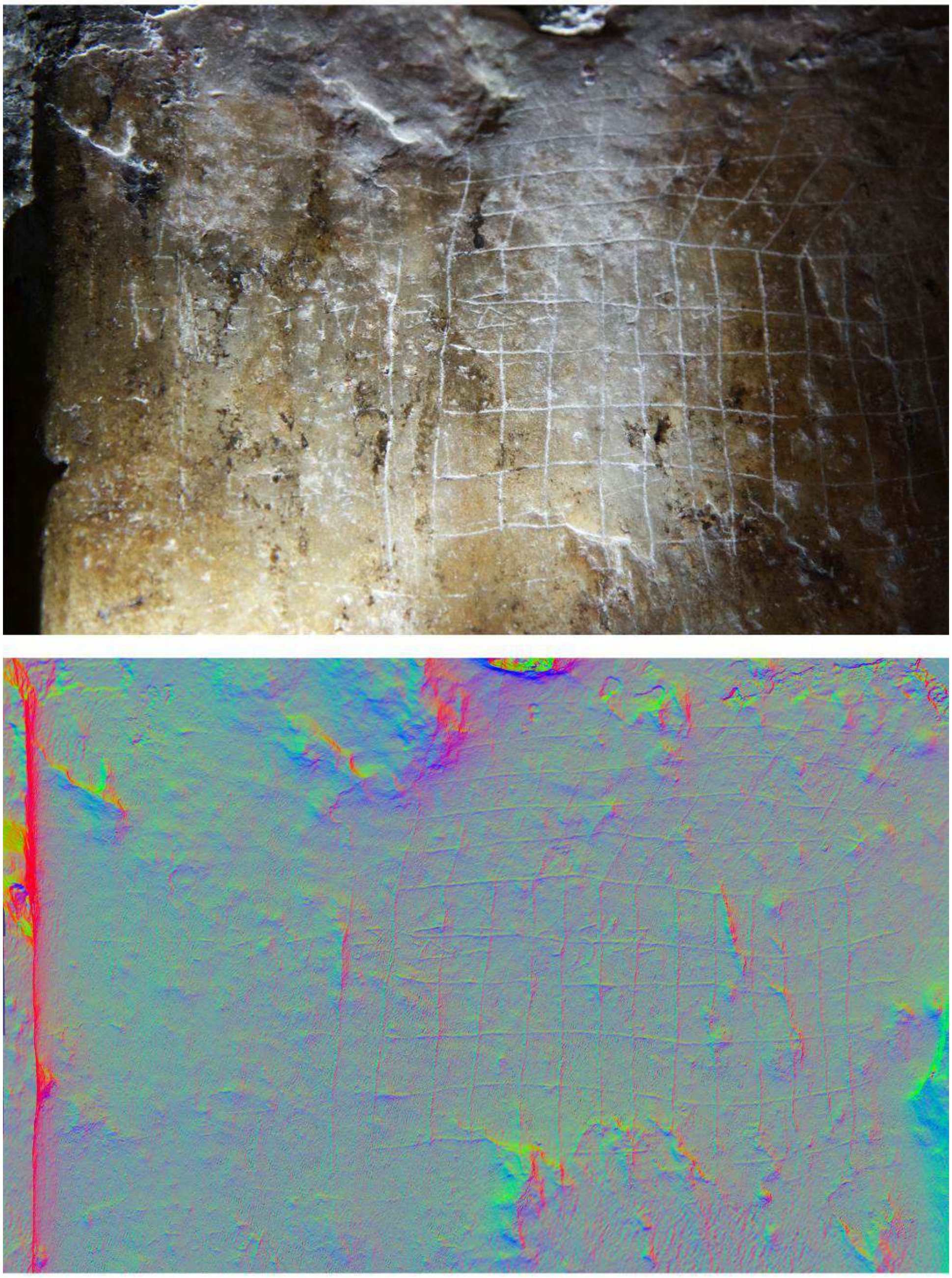

Fig. 7. Alexander-writing: photograph with raking light (above) and 3D surface model with normal map rendering (below).

The project has even made entirely new discoveries, for example, the blue light of the scanner has revealed a previously unknown inscription. It can be identified as the short form of established Cyrillic wording with the meaning “the servant of god [name] died”; a typical phrase found in graffiti. To decipher these characters and their meaning was only possible due to the 3D-Surface model. Rotating it and using the infinite lightning possibilities of the software, as well as the normal map rendering mode, dramatically enhanced the legibility (Fig. 8).

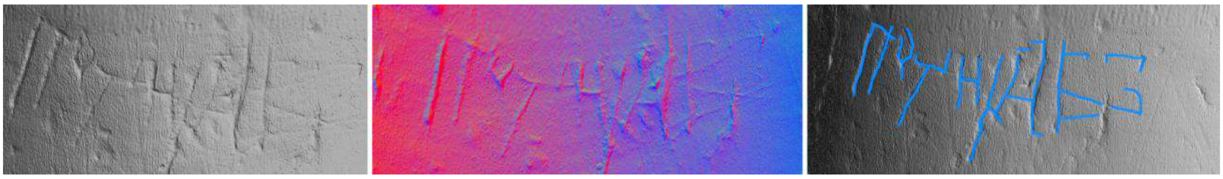

Fig. 8. 3D surface model, normal map, drawing the characters on the surface

CONCLUSION –WHAT TO DO WITH THE SCANS?

As we have demonstrated, some of the inscriptions have already been verified or deciphered, but there are also some which are a work in progress and which are much discussed among Slavicists. It is therefore important that the 3D models should remain accessible for specialists in the future, and to this end the data was shared in the .stl format, allowing them to be imported into a variety of software including free applications such as Meshlab and 3D tool. With the help of these models, which have already been shared with both Slavicists and Glagolitic specialists, it is now possible to observe and analyse the inscriptions virtually and independently off-site. The data sets will also help to preserve the intangible heritage for future generations even if the inscriptions themselves are damaged.

To archive the datasets they are exported as .stl files and stored on external hard drives, DVDs and on the server of the department of the preservation sciences at the University of Bamberg. According to a datasheet developed by the 3D-AG (consisting of the Bamberg University's "Centre for Heritage Conservation Studies and Technologies" (KDWT) and Bavarian State Office for Heritage Management) essential parameters like date and time of recording and post processing, and the persons working on the project were listed as well [Rahrig 2017]. The aim was an easy to handle standardised method of archiving the datasets in interoperable and sustainable file formats which can be easily transferred to other archives in the future. As mentioned above, using a standard file format also enables the data to be used in different free software solutions, ensuring that it will be possible to continue discovering new inscriptions and creating new research in the future.

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