This book is dedicated to my late friend and colleague Dr. Amnon Rosenfeld who first sparked my interest in the field of geoarchaeology.

Contents

Chapter 1

Introduction

Many interesting and important geoarchaeological discoveries have been made over the last several years in Israel. Geoarchaeology, simply put, refers to those disciplines of archaeology relating to issues and methods of the geosciences (Neuendorf et al. 2005). It utilizes a multidisciplinary approach to solving archaeological problems, including areas in geology such as, but not limited to, sedimentology, carbon dating, stratigraphy, and field methods.

I have worked with my late coauthor Dr. Amnon Rosenfeld for many years on various geoarchaeological projects. Amnon was responsible for stimulating my interest in the field of geoarchaeology, and for that, I am extremely grateful. We both specialized in paleontology, Amnon in the study of ostracodes and myself in the taxonomy and paleoecology of brachiopods. I present some more details of our relationship in Chapter 2.

Chapters 3, 4, and 5 represent perhaps our most significant contribution to the field of geoarchaeology. In these three chapters, we describe the Jehoash Inscription tablet that bears an ancient Hebrew inscription composed mainly of quartz and feldspar minerals on a fine-grained arkosic sandstone known from the Cambrian rocks found south of the Dead Sea, in the Timna area, and in southern Sinai (e.g., Serabit el-Khadem inscriptions). The inscription describes renovations to the First Temple and is the only written record indicating the existence of the First Temple. The tablet was declared a forgery by the Israel Archaeological Authority, and the owner of the tablet, Oded Golan, was arrested and put on trial for forgery. We wrote a paper entitled "Archaeometric analysis of the Jehoash Inscription tablet" that was provided as evidence in the trial. After a lengthy trial, Mr. Golan was acquitted and the tablet was returned to him.

The significance of environmental dust is discussed in Chapter 6. Dust from the environment can be trapped and preserved within the patina of an artifact, preserving its geological signature. Modern-day dusts in urban and agricultural regions within Israel differ in composition from their historical counterparts. Ambient dust from other geographical regions contains characteristic components that can be used to reveal the area of origin. Archaeological materials as well as blatant forgeries are all exposed to the local environment, be it that of a tel (an Arabic term for a mound or hill composed of refuse from past inhabitants), a cave, soils, or the ambient air of a laboratory. The dust in the patina of an ancient artifact and that of a forgery may be significantly different, especially if the forgery was carried out in a geographical region different from the one that it purports to represent. Therefore, it is proposed that when the validity of potentially important artifacts is called into question, the dust preserved in the accrued surface patina should be studied along with the other ancillary methods in the process of archaeological authentication.

Chapters 7 and 8 describe a remarkable stone oil lamp that was carved during the Second Temple period in Jerusalem and represents a Jewish tradition related to religious purity laws. The upper part of the oil lamp contains the following traditional Jewish decorations: a seven-branched menorah, a date palm tree, a grape leaf and grapes, olive branches, a wheat ear, a barley ear, a basket with figs, and pomegranates. The multilayered silicified patina with slow growing microcolonial fungi (MCF) structures attached to the surface of the lamp is indicative of natural long-term development in a burial environment. The MCF structures found within the patina represent fungal colonies that grow at a very slow rate. Soot found within the multilayered patina is another indication of the lamp's authenticity. In general, it can be concluded that this stone oil lamp with its carvings was produced many centuries ago.

Chapters 9, 10, and 11 describe how the James Ossuary was archaeometrically studied, resulting in the belief that the ossuary and its inscription are authentic. The patina covering the ossuary was carefully examined. Patination consists mainly of the weathering product of the source rock (Early Senonian, Mount Scopus Group) and the *in situ* accreted variable environmental and anthropogenic components. The ossuary stone is enriched in phosphorous due to leaching from the original bones it contained. The composition of the patina is mainly calcite and contains the following elements: Si, Al, Fe, P, and Mg. It contains no modern elements and adheres firmly to the stone. The beige-to-gray patina and its morphology can be observed on the surface of the ossuary, gradationally continuing into the engraved inscription, even though the ossuary was cleaned unprofessionally with a sharp implement and with unidentified cleansers. The engraving clearly does not cut the patina. Ultraviolet illumination does not indicate any new engraving marks. Thin striations, over which the patina has accreted, about 0.5 millimeters wide and several centimeters in length, are found on the outer sides of the walls. Some vertical/diagonal patinated striations that continuously transect the letters appear to be from the friction of falling roof rocks induced by earthquake, floods and landslides during its long burial in the cave. Many dissolution pits are superimposed on several of the letters. In addition to calcite and quartz, the patina contains the following minerals: apatite (calcium phosphate), whewellite (hydrated calcium oxide), and weddelite (calcium oxalate). These minerals result from the biogenic activity of microorganisms such as MCF, yeasts, lichens, and bacteria that require a period of at least 50–100 years (if not longer) to form the biopatina.

The research article on the unprovenanced artifact known as the "Miriam Ossuary" is discussed in Chapter 12. The ossuary was acquired and commissioned by the Israel Antiquities Authority, and it represents an important step in the continuing quest for the identification of forged versus real artifacts, especially in Israel (Zissu and Goren 2011). In a country where most of the artifacts were and are being looted (mainly from Judea and Shomron) no artifacts should be discarded; on the contrary, they should all be studied by scholars. Zissu and Goren (2011) identified the soil attached to the "Miriam Ossuary" as a terra rossa (dark color) soil. However, according to the Israel soil map, the "Ella Valley soil contains redzina (light color) and alluvium type of soils." This kind of soil is well developed on chalks that are found in the surrounding mountains (dating back to the Eocene Epoch between 53 and 34 million years ago) of the Ella Valley. Thus, the first location determined by Zissu and Goren (2011) as the original cave in which the "Miriam Ossuary" was found, namely, the Ella Valley, appears to be incorrect. The terra rossa soil type found on the "Miriam Ossuary" could have been developed in Israel not only in the Jerusalem mountain region but also in the Galilee, but also definitely not in the Ella Valley.

Chapter 13 deals with determining the authenticity of artifacts by the oxygen isotope analysis technique. This technique is used to determine the authenticity of artifacts by comparing the oxygen isotopic composition of speleothems to the carbonate included within the patina of unprovenanced artifacts, yet it is of questionable value. The unprovenanced Jehoash Inscription Tablet and the James Ossuary are of potentially immense historical and cultural importance. Nevertheless, they were both rejected by workers based on the oxygen isotope technique, which provided the major foundational evidence of forgery in the longest running archaeological trial in Israel. As a result, both artifacts were not determined to be forgeries. The initial incongruence between the oxygen isotopes of the speleothems of the Soreq Cave (Israel) purported to represent the unique composition of Jerusalem rainfall, and the patina on the artifacts, can be readily explained by the accretion of materials and geo-biochemical processes expected in normal patina formation in the Jerusalem region. The patina formation involves sporadic events in disequilibrium kinetic processes that are opposed to the equilibrium formation of speleothems in a sealed cave. Moreover, twenty-three of fifty-six patina samples on well-documented ancient artifacts from Israel yielded oxygen isotope values greater or lower than the expected speleothem values of $-4\ \delta^{18}O$ ‰ [PDB] to $-6\ \delta^{18}O$ ‰ [PDB]. Thus, the speleothem–patina correlation is invalid, and the applied oxygen isotope technique for determining the authenticity of patinas on artifacts is not a useful tool in the authentication of artifacts.

Some West African brass figurines of the Jenne–Dogon culture are presented in Chapter 14. Although these artifacts are not from Israel, I believe that they are interesting enough to include in this volume on geoarchaeology. The eleven West African brass figurines ranging from 10.5 cm to 34.1 cm in height are described and illustrated for the first time. They possess a unique elongation of the limbs, heads, and torsos, and some have scarification marks and serpent like ornamentation. The figurines exhibit artistic features characteristic of both the Jenne and Dogon cultures. Their brass composition with 28% zinc on average, together with a high content of the trace elements like arsenic (As) (0.9%), iron (Fe) (0.7%), and nickel (Ni) (0.4%), may point to their alloy production between the fifteenth and eighteenth centuries CE.

Various abstracts presented at annual and section meetings of the Geological Society of America that deal with the topics mentioned above, as well as some other research projects that have not yet been published as manuscripts, make up the basis for Chapter 15.

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Finally, thanks to my wife Susan, who enthusiastically supported my research over the years.

Chapter 2

Amnon Rosenfeld—In Memoriam (1944–2014)

It was with shock and great sadness that I heard from my colleagues about Amnon and his wife Tami's terrible accident and his passing. We are hoping for Tami's speedy recovery and our prayers are with her.

Amnon and I worked together for many years on different aspects of geoarchaeology. He had a wonderful, quick, and sarcastic sense of humor and was always ready for a good laugh. When Amnon came to the United States, we developed a serious routine of working together. We ate breakfast first (Amnon always loved this part of our work together) and then we worked at my computer writing about everything from ostracodes to artifacts.

Amnon was an expert on ostracodes, a class of the Crustacea phylum that is usually 1 mm in size. They are bivalved, live in both marine and non-marine environments, and range from the lower Cambrian period to the Holocene period (570 million years ago until the present). He wrote extensively on these fossils and was considered to be an expert in this area. One of his papers, co-authored by Oertli, Honigstein, and Gerry in 1987, described Jurassic-age ostracodes from the Majdal Shams area at the foot of Mount Hermon in the Golan Heights, Israel. In a more recent publication, Amnon wrote about Holocene ostracodes from the continental shelf and slope of the Eastern Mediterranean. His expertise was wide-ranging indeed.

Amnon was always interested in geoarchaeology and became even more well known for his paper on the Jehoash Inscription Tablet (JI) that was entered into evidence at the trial of Oded Golan. Based partially on this paper, Golan was acquitted of forging the tablet. Recently, Hershel Shanks noted, “While it can never be proved with absolute certainty that the JI is authentic, the case is certainly highly likely. We should treasure the JI as very probably an authentic inscription of an Israelite (or rather Judahite) king.” Ironically, Amnon’s last article was published at bibleinterp.com right before he died. This project was his passion for many years and it showcased his point of view and persistence in getting to the heart of the matter. The article is titled “The Antiquities Game - Behind the Trial of the Century.” Some years ago, Amnon joined me and my students in the field looking at Ordovician, Silurian, and Devonian rock formations in New York’s Hudson Valley. He was right at home even though his expertise was in studying younger Mesozoic rocks and fossils. The students gained much from Amnon’s interpretation of the history of Earth as recorded in the formations that we observed, as well as from his stories detailing his experiences in Israel.

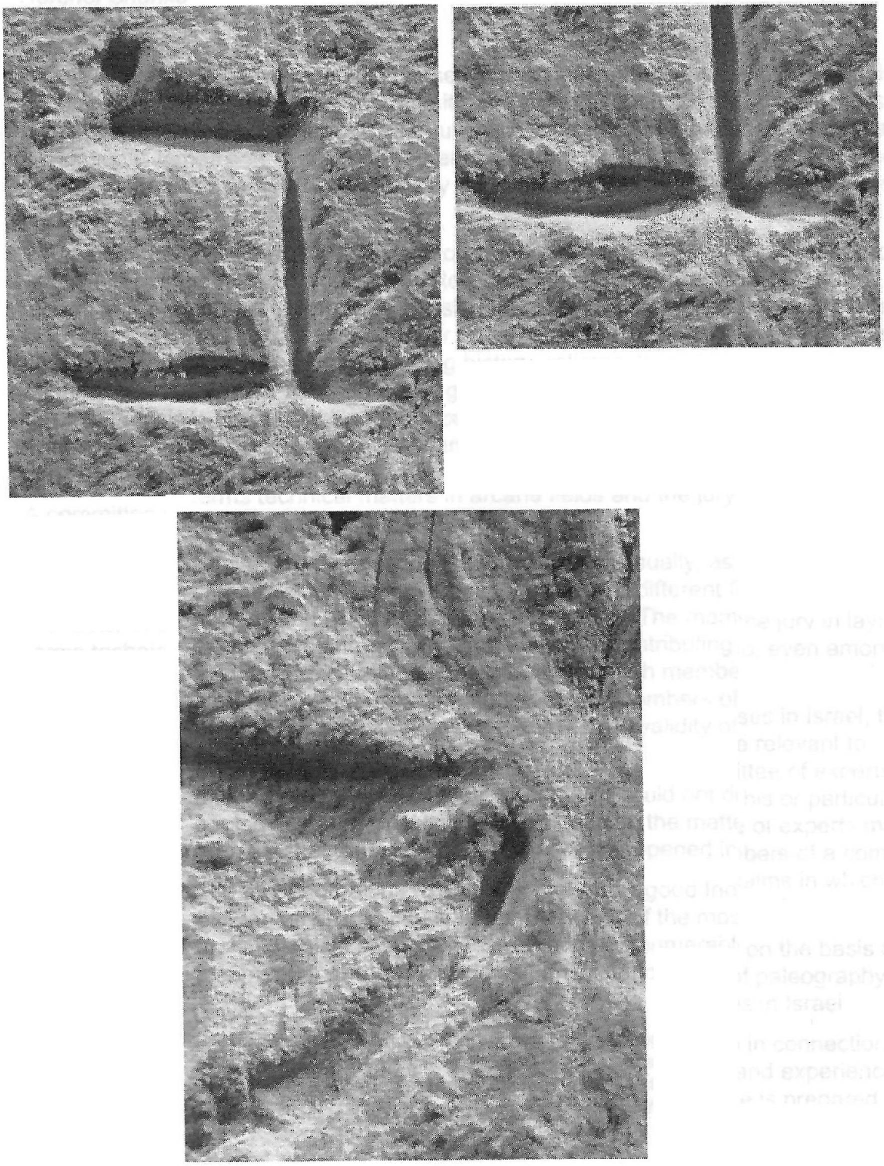
Amnon will be sorely missed, not only by his wife Tami and his children and grandchildren and many good friends, but by the geological and archaeological community of scholars. We have lost a beloved individual in our field. May he rest in peace.

Chapter 3

Archaeometric Analysis of the Jehoash Inscription Tablet

Abstract

A gray, fine-grained arkosic sandstone tablet bearing an inscription in ancient Hebrew from the First Temple Period contains a rich assemblage of particles accumulated in the covering patina that includes calcite, dolomite, quartz and feldspar grains, iron oxides, carbon ash particles, microorganisms, and gold globules (1–4 mm in diameter). There are two types of patina present: thin layers of a black-to-orange-brown, iron oxide-rich patina, a product of micro-biogenetical activity, as well as a light beige patina mainly composed of carbonates, as well as quartz and feldspar grains. The patina covers the rock surfaces and inscription grooves post-dating the incised inscription as well as a fissure that runs across the stone and several of the engraved letters. Accelerator Mass Spectrometry (AMS) analyses of the carbon particles in the patina yields a calibrated radiocarbon age of 2340–2150 Cal BP and a conventional radiocarbon age of 2250 ± 40 years BP. The presence of microcolonial fungi and associated pitting indicates slow growth over many years. The occurrence of pure gold globules is evidence of melting (above 1,000°C) and indicates a thermal event. This study supports the antiquity of the patina, which in turn strengthens the contention that the inscription is authentic.



Introduction

A rectangular, dark stone tablet 31 x 25 x 9 cm in size was subjected to archaeometric examination by the authors. The stone tablet is engraved with an inscription in ancient Hebrew (Figs. 1A–B) known as the Jehoash

Inscription (JI). The inscription commemorates the renovation of the First Temple carried out by King Jehoash, who reigned at the end of the ninth century BCE. (ca. 2,800 years BP). A similar account of the Temple repairs is found in the Bible (Kings II:12). This tablet represents the only Judahite royal inscription found to date. According to Cohen (2005), the translation of the sixteen lines of the ancient Hebrew is as follows:

"[I am Yeho'ash, son of A]hazyahu, k[ing over Ju]dah, and I executed there[pai]rs. When men's hearts became replete with generosity in the (densely populated) land and in the (sparsely populated) steppe, and in all the cities of Judah, to donate money for the sacred contributions abundantly, in order to purchase quarry stone and juniper wood and Edomite copper/ copper from (the city of) 'Adam, (and) in order to perform the work faithfully (one-quarter without corruption),—(then) I renovated the breach(es) of the Temple and of the surrounding walls, and the storied structure, and the mesh-work, and the winding stairs, and the recesses, and the doors. May (this inscribed stone) become this day a witness that the work has succeeded (and) may God (thus) ordain His people with a blessing."

The JI tablet is said to have been found near the southeastern corner of the wall of the Temple Mount complex, where it was used as a secondary building stone in a tomb. It was found in the Jerusalem antiquities market and it is now under the custody of the Israel Antiquities Authority (IAA). The authenticity of the JI has been a fiercely debated topic over the past few years. Epigraphic and philologic analyses of the tablet are inconclusive as to its authenticity. Cohen (2007) contended that if it is a forgery, it is a brilliant one, near genius. Freedman (2004) advised not to rush to judgment; the JI may be authentic. Sasson (2004) noted that the text of this inscription is not a forgery. If it is a forgery, then a combination of some incredible factors must have operated in producing it. Cross (2003), however, maintained that the inscription is a poor forgery. This dispute should not come as a surprise, since no Hebrew royal inscription from the First Temple period was ever found that could serve for typological comparison. Ilani et al. (2002) and Rosenfeld et al. (2005) concluded that it may be authentic based on chemical and petrographic analyses. Following their report on the patina to the IAA, Goren et al. (2004) claimed that the inscription on the JI tablet was a forgery. New evidence based on microcolonial fungi (MCF) as producers of a black and orange-brown patina strengthens the view that the inscription was not recently engraved.

Methods

The mineralogic composition of the tablet rock was determined by using a petrographic microscope and a Philips X-ray diffractometer. Samples were removed from the rock-tablet by using a diamond-tipped hand drill and from the patina by peeling with a sharp steel blade. A scanning electron microscope (SEM, JEOL-840), equipped with an energy dispersive spectrometer (EDS, Oxford-Link-Isis) was employed for detailed inspection of the physical properties and structural features of the tablet and its patina, as well as for chemical analysis. A Hitachi S-3200N SEM with low vacuum was used for further analyses of microorganism content within the patina layers. Additional geochemical analyses were carried out using inductively coupled plasma atomic emission spectroscopy (ICP-AES) in the geochemistry laboratories of the Geological Survey of Israel. A stereoscopic binocular and a light transmitting ore mineral microscope were also used to study the morphology, structural features and thin sections of the rock (see Fig. 1C for sample locations).

Results

Rock-Tablet

The general color of the fine-grained JI rock-tablet is medium gray. The gray color was observed in fresh breakage of the rock and in the samples of the drilling material. A fissure, less than 0.5 mm in width, runs across the central part of the tablet parallel to the broken upper edge, crossing ten letters in four lines (Fig. 1B). The fissure begins in the eighth line and descends at an angle of 18° toward the left margin of the eleventh line (Figs. 1A and B). The tablet broke into two separate pieces along this fissure.

Petrographic analysis reveals that the rock from which the tablet was produced is an arkosic sandstone (Fig. 2) composed mainly of unsorted sub-angular quartz grains 50–500 mm in size, and angular to sub-rounded unsorted feldspar grains, up to 100 mm in size. Thin section analyses of the rock material indicate that it is composed of: quartz (35%), feldspars (albite and orthoclase; 55%), epidote (3%), chlorite (1%), rutile and sphene (up to 1%), and iron oxides and opaques (2–5%). A similar composition was obtained by XRD examination (Fig. 3). However, the results are slightly different (e.g., here we note the presence of calcite and illite) because the XRD samples may have included material from the patina.

Many of the incised letters on the tablet exhibit defects in shape at the edges. These defects are due to the detachment of quartz and feldspar grains during subsequent weathering of the sandstone. Illuminating the tablet with ultraviolet light (Newman, 1990) did not exhibit the characteristic glow that would indicate fresh engraving scars.

According to the chemical analysis by ICP-AES, the oxide composition of the rock (samples Z-10 to Z-12; Fig. 1B) from which the tablet was engraved is (% oxides; normalized to 100%): SiO_2–60; CaO–13; Fe_2O_3–5.5; Al_2O_3–11.5; Na_2O–3.0; MgO–2.5; K_2O–1.8; P_2O_5–0.3; MnO–0.1; TiO_2–0.7; SO_3–<0.1.

Patina

There are two areas on the tablet, one just above and to the left of the crack, and the other just below and to the right of the crack, that lack a patina and so were almost certainly cleaned since the tablet's discovery. The patinated areas can be differentiated by their pale orange-brown color. The left lower part retains black to orange-brown as well as light beige patina layers up to 2 mm thick that cover the tablet and the inscription (Fig. 4). The first layer attached to the rock is a thin, 1-mm thick, metallic black-orange-brown iron oxide layer that covers the surfaces of the tablet and the engraved letters. In places the black and orange- brown layers alternate, occurring one next to the other. As the rock-tablet contains about 5% iron oxides, we suggest that the formation of both black and brown layers may be related to natural geo-biological weathering processes. The overlying and uppermost layer, orange-brown to light beige in color and up to 1 mm thick, is found mostly within the letters but also on the surfaces that were partly cleaned. The black orange-brown patina forms a continuous cover on the surface of the tablet as well as within the grooves of the letters (Fig. 5). Some natural bleaching and incipient light patina formation (light-gray zone just below the surface of the tablet) due to exposure to the air near its inscribed surface is also evident. Results of the SEM–EDS analysis of samples from the patina are presented in Table 1. We analyzed nine samples (Fig. 1C; Table 1) using the SEM–EDS backscattered method for detecting heavy elements. We did not detect the presence of any element, such as Cr and V, which would have indicated the use of modern tools in the engraving process.

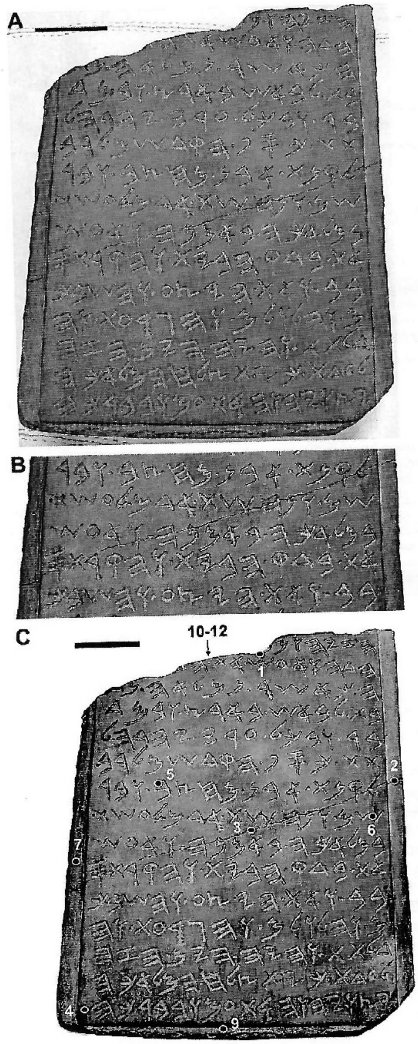


Figure 1A. The Jehoash Inscription tablet composed of arkosic sandstone with ancient First Temple period Hebrew inscription (scale bar ¼ 5 cm).
B. Detail of panel A showing the prominent central fissure transecting the engraved letters.
C. The sites of the rock and patina samples from the tablet. Samples Z-1 to Z-7 and Z-9 are from the patina on the inscription face of the tablet; Z-8 (not shown) was collected from the quartz vein on the back side of the tablet; and Z-10 to Z-12 (not shown) were taken from the tablet's side and include only the arkosic sandstone (scale bar ¼ 5 cm).

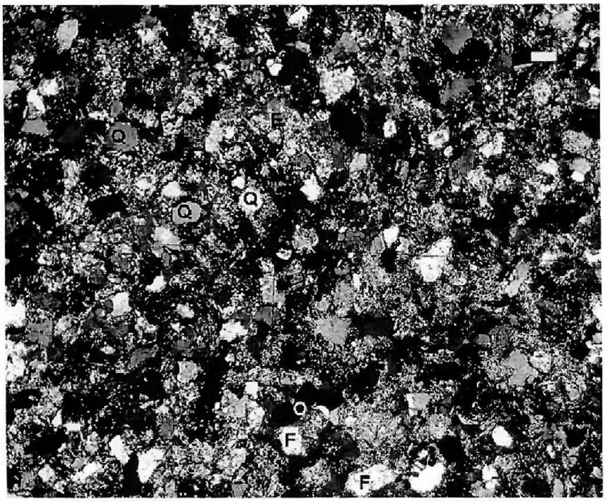


Figure 2. Thin section of the arkosic sandstone from the tablet. Q, quartz; F, feldspar; E, epidote; O, iron oxide minerals (scale bar ¼ 100 mm).

The patina is composed of Si, O, Ca, Al, Mg, K and Fe. Many rectangular and spherical carbon ash particles 20–100 mm (Fig. 6) were found inside, as well as a trace amount of pure gold globules 1–4 mm in diameter (Fig. 7). Some gold globules were alloyed with about 2.5% copper and 3.2% iron. Sub-angular iron particles, 3–10 mm in size, were also found in the patina and these particles contain oxygen which clearly implies oxidation. The particles are devoid of any other element usually found in modern tools, and may have belonged to the scriber's tools used in the engraving. Some platy idiomorphic feldspar crystals of about 100 mm and some sub-angular quartz grains were observed in the patina. The light patina is composed mostly of quartz, feldspar, carbonate and iron oxide with a small amount (less than 1%) of clay cations Na, Al, Mg and K. The average contents of the oxides in the patina measured and calculated by SEM–EDS are (% oxides; normalized to 100%): SiO_2–53%; CaO–16%; Fe_2O_3–18%; Al_2O_3–5.5%; Na_2O–2.5%; MgO–2%; K_2O–1%. Compared to the rock-tablet the patina is enriched with Fe_2O_3 by about 12% and CaO by 3%.

The iron concentration in the patina is about three times more than in the rock itself. The mineralogic composition of the patina, investigated by XRD analysis (Fig. 8), includes quartz, calcite, dolomite and feldspar in a texture (confirmed by the SEM–EDS) of interlocking grains within a matrix of calcite.