

Article

Reading Tool Marks on Egyptian Stone Sculpture

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For millennia the ancient Egyptians filled their tombs and temples with stone sculpture. Egyptian stone workers were extremely prolific, quarrying vast quantities of stone from along the Nile Valley and the deserts beyond, and turning it into sculpture ranging from miniature to monumental. Particularly impressive is their exploitation of hard stones, such as granite, granodiorite, graywacke, anorthositic gneiss, or basalt. Although secondary sources including tomb paintings and excavated tools provide insight into hard stone working methods, there is significant disagreement among scholars about the forms and materials of the tools themselves, how they were used by ancient stoneworkers, and how these factors relate to the broad range of surface textures we observe. This paper seeks to demonstrate the utility in addressing these questions through the systematic characterization of tool marks using Reflectance Transformation Imaging (RTI), augmented by the examination of ancient tools, experimental archaeology, and consultation with contemporary stone carvers. This approach is demonstrated through a series of case studies which illustrate useful comparisons between tool marks on Egyptian stone sculpture in the collection of The Metropolitan Museum of Art. Topics addressed include: differences in hard stone and soft stone carving; variations in finishing work on statuary elements; variations in the carving of hieroglyphs; and possible evidence of a changing tool kit.

فك التشفير على النحت الحجري المصري

ملخص

لآلاف السنين، ملأ المصريون القدماء مقابرهم ومعابدهم بالمنحوتات الحجرية. كان إنتاج النحاتون المصريون كبيراً جداً، حيث كانوا ينحوتون آلاف القطع الحجرية على طول وادي النيل والصحاري المجاورة، وتحويلها إلى منحوتات مختلفة الأحجام من صغيرة إلى ضخمة جداً. يثير للإعجاب بشكل خاص استخدامهم للأحجار الصلبة، مثل الجرانيت أو الجرانوديوريت أو حجر الجرواق أو حجر الأنورثوسايت (صخور فانيرتيك بركانية نارية) أو البازلت. بالرغم من أن المصادر الثانوية، بما في ذلك لوحات القبور وأدوات الحفر التي توفر معلومات جيدة عن أساليب نحت الحجارة الصلبة، إلا أن هناك خلافاً كبيراً بين الباحثين حول أشكال ومواد الأدوات نفسها، وكيف استُخدمت من قبل النحاتين القدامى. نحاول من خلال هذا المقال تقديم الجهاز الذي يساعد في معالجة هذه الأمور للرد على تلك الاستفسارات، من خلال الوصف المنهجي لخصائص القطع باستخدام تصوير التحوّل الانعكاسي (RTI)،- تتمثل التقنية في النقاط صور متعددة عن طريق تغيير ميل الضوء واتجاهه للكشف عن خصائص السطوح المصوّرة، ومقارنتها مع عينات حجرية حديثة- تعتمد هذه المقالة على مجموعة دراسات توضح اختلاف علامات الأدوات الواضحة على سطح المنحوتات الحجرية المصرية ضمن مجموعة قطع محفوظة في متحف المتروبوليتان للفنون. الموضوعات التي تمت تناولها هي: الاختلافات بين الحجر الصلب والنحت على الحجر، الاختلافات في طرق إنهاء العمل عند نحت التماثيل، الاختلافات في حفر الرموز الهيروغليفية، والأدلة المحتملة في حالة تغيير مجموعة أدوات النحت.

1. Introduction

An object worked in stone is a document that, correctly understood, describes its own manufacture. This is especially true of unfinished works, of which there are many, but it is also true of finished works. A piece of worked stone has a language inscribed on its surface that can be read by those who have learned the signs.

Peter Rockwell, *The Art of Stoneworking*, 1993

For millennia ancient Egyptians quarried vast quantities of stone from the Nile Valley and the deserts beyond, and turned it into sculpture ranging from miniature to monumental. Particularly impressive is their exploitation of hard stones, such as granite, granodiorite, graywacke, anorthositic gneiss or basalt. While tomb paintings can provide some insight into hard stone working methods, there is significant disagreement among scholars about the forms and materials of the tools themselves, how they were used by ancient stoneworkers, and how these factors relate to the broad range of surface textures we observe. This paper addresses these questions through a systematic characterization of the tool marks remaining on the objects' surfaces.

The need for an in-depth study of tool marks on stone sculpture, particularly for the benefit of authenticity studies, has already been noted,¹ and the case studies presented in this paper come out of a multidisciplinary research project addressing this gap in scholarship. Open questions about the forms and materials of the tools themselves and the processes used by ancient stoneworkers to produce a wide range of surface textures were explored through the following methods: documentation of tool marks with Reflectance Transformation Imaging (RTI); examination of ancient tools; experimental archaeology; and consultation with stone carvers.² This paper will largely focus on the evaluation of imaging results, presenting case studies that illustrate useful comparisons between tool marks observed and recorded on Egyptian stone sculpture in the collection of The Metropolitan Museum of Art. The specific objects explored in this paper are relatively small-scale sculptures, and although the

means of their production undoubtedly has overlap with large-scale sculpture, lapidary work, architecture, and stone vessel production, I have attempted to limit the number of variables explored. Most of the objects included in this study were excavated by The Met in the early 20th century.

My observations are grounded in a comprehensive review of previous scholarly work,³ and are especially indebted to the work of Peter Rockwell and Deryn Stocks. Stocks' in-depth exploration of Egyptian stoneworking technology takes into consideration environmental factors, natural resources, evaluation of unfinished artifacts and existing tools, as well as other archaeological and pictorial evidence, and combines this research with experimental work.⁴ Rockwell, a traditionally trained sculptor and expert on the history of the craft, published important works on stone carving technology⁵ and taught this subject extensively. I had the privilege of learning from him first-hand through an independent study and then as a Fellow at the American Academy in Rome. My assessment of tool marks builds on Rockwell's comprehensive tool mark analysis, some of which has been recorded in *The Art of Making in Antiquity: Stoneworking in the Roman World* (<https://artofmaking.ac.uk/>), a web feature on which he collaborated. Although little of Rockwell's published work deals directly with stone carving in ancient Egypt, the methodology he employed is broadly applicable. Indeed, in their essay on stoneworking tools and tool marks for the website *The Art of Making in Antiquity*, Wootton, Russell and Rockwell observed that "practitioners are often the best guides for interpreting toolmarks on ancient carvings and how these were made because they are used to working in a wide variety of stones and are aware of the ranges of tools in existence."⁶

I collaborated with Rockwell on a series of experiments in soft and hard stone carving, most of which were based on the previous experiments of Zuber⁷ and Stocks. In fact, many assumptions about stone carving tools and methods are based at least in part on replication experiments and the observation of contemporary workshop practice. Replication experiments can be invaluable in informing our understanding of ancient technology. Craft production is simultaneously a visual, audio and tactile experience, and while we might be able to understand the

main steps in the *chaîne opératoire* from more conventional investigations, there are many micro-decisions in the craft process that can only be guessed at.⁸ Well-researched replication might help us understand some of those unknowns – the sound the tool makes, the changing nature of the tools as they are damaged through use, etc – and should be driven by the objects themselves, based on a systematic cataloguing of toolmarks. While it is important to recognize the impossibility of replicating all variables in the system, and that ancient craftspeople lived in a completely different environment and developed collective skills over millennia,⁹ it is clear that an intimate knowledge of craft practice must inform all scholarship on stone carving in the ancient world.

2. An Overview of Egyptian Stone Carving Materials, Tools and Methods

When looking at tool marks it is important to understand the physical properties of the substrate. Hardness and homogeneity are critical factors that inform how and with what a stone can be carved.¹⁰ In this paper, as in most literature on the subject, the term “soft stone” is used to describe stones such as limestone, sandstone and steatite which have an equivalent scratch hardness of 3 or below on the Mohs Scale.¹¹ Stones such as indurated limestone, graywacke, granite, granodiorite and silicified sandstone, which have an equivalent scratch hardness that is greater than 3 on the Mohs Scale, are classified as “hard stones”. However, these categories are not rigid and can vary based on the geological origin of the stone. For example, as will be discussed later, serpentinite is classified by Aston, Harrell and Shaw as a hard stone, but, according to Klemm and Klemm, Egyptian serpentinite has a hardness equivalent to that of calcite, which is Mohs 3. Of equal importance is the recognition that the Mohs scale was developed for assessing mineral hardness; the equivalent Mohs hardness of a rock reflects that rock’s cohesiveness, and may have little to do with the hardness of the minerals that compose it.¹² Scratch hardness is a useful determination when discussing the ease with which a stone is carved, but I am not aware of any systematic study of the scratch hardness of Egyptian stone types. Where Mohs numbers are presented in this paper, it should be noted that they come from literature references where the meth-



Fig. 1: Nina de Garis Davies (1881–1965). *Sculptors at Work*, Tomb of Rekhmire, Dynasty 18, ca. 1479–1425 BCE. Original from Egypt, Upper Egypt, Thebes, Sheikh Abd el-Qurna, Tomb of Rekhmire (TT 100). Tempera on paper, facsimile: h. 54 cm (21 1/4 in); w. 38.5 cm (15 3/16 in) scale 1:1. The Metropolitan Museum of Art, Rogers Fund, 1930 (30.4.90).

od used to calculate the Mohs number is not reported. This paper focuses predominantly on the implications of tool marks on our understanding of tool kits and carving methodology. Much has been written on quarrying methods,¹³ the extent to which statues were carved at the quarry site,¹⁴ what can be learned about sculpture production through the study of the few urban workshops that are known to us,¹⁵ and stone-working debris at building sites.¹⁶ However, Stocks notes the difficulty in assessing the chronological development of ancient Egyptian technology, especially because we don’t know if there are any tools missing from the archaeological record.¹⁷ Painted depictions of sculptors at work, such as that represented in Fig. 1, provide insight about tool form and use, but it has been generally acknowledged that these images are not always reliable sources for technological information – Egyptians tend to show statues in their finished state, even when they are at an early stage in the sculptural process.¹⁸

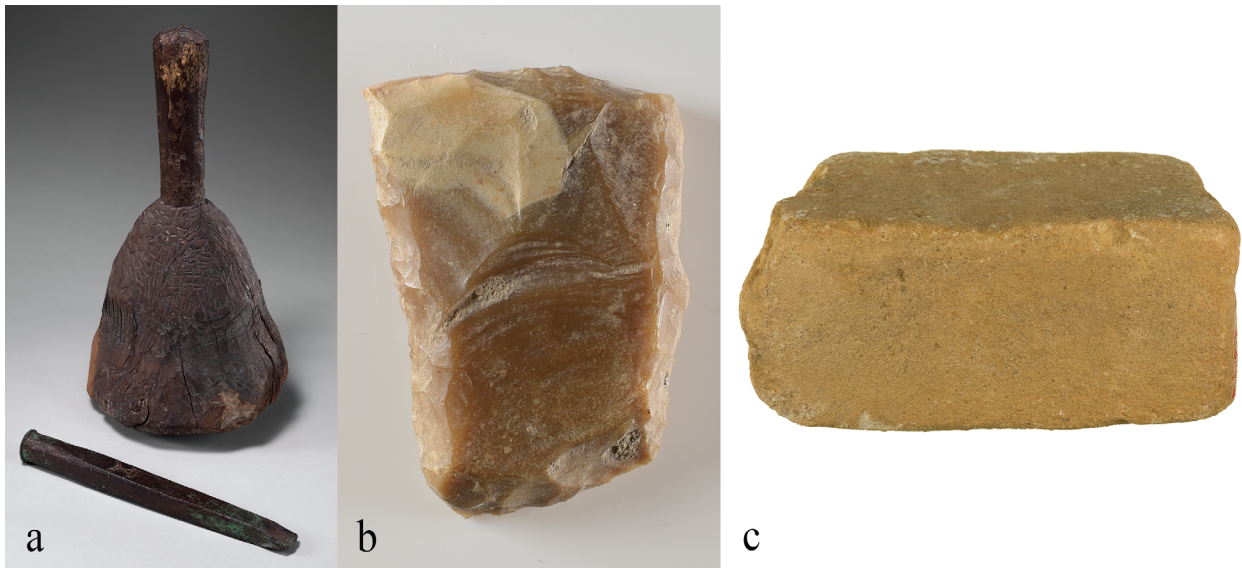


Fig. 2: a) Stone mason's chisel and mallet; chisel: Middle Kingdom, Dynasty 11, reign of Mentuhotep II, ca. 2051–2000 BCE. Egypt, Thebes, Deir el-Bahri, Tomb MMA 101, in front of chamber 3 west, MMA excavations, 1926–27. Hammered bronze or copper alloy, L. 19.5 cm, W. 2.2 cm. The Metropolitan Museum of Art, Rogers Fund, 1927 (27.3.12); mallet: Middle Kingdom, Dynasty 12, reign of Senwosret I, ca. 1961–1917 BCE. Egypt, Memphite Region, Lisht South, Pyramid Temple of Senwosret I, MMA excavations. Wood, H. 28 cm, W. 15 cm. The Metropolitan Museum of Art, Rogers Fund and Edward S. Harkness Gift, 1924 (24.1.76).
 b) Scraper, probably New Kingdom, Ramesside – Third Intermediate Period, ca. 1184–664 BCE. Egypt, Memphite Region, Lisht North, MMA excavations. Flint, L. 4.5, W. 3.2cm. The Metropolitan Museum of Art, Rogers Fund, 1948 (48.105.38n).
 c) Grinding stone, New Kingdom, Ramesside, Dynasty 19–20, ca. 1295–1070 BCE. From Egypt, Memphite Region, Lisht North, Late New Kingdom Settlement, MMA excavations, 1906–08. Silicified sandstone (?), L. 9 cm. The Metropolitan Museum of Art, Rogers Fund, 1915 (15.3.1717).

What is known about stone carving tools and methods can be summarized as follows. The ancient Egyptians, and indeed most cultures across time and geography, worked stone with a combination of percussion and abrasion. Percussive tools take a variety of forms: they can be simply held and struck against a stone surface, they can be mounted to a handle and wielded, or they can be held and struck with a mallet. They include pounders, axes, mauls, adzes and chisels¹⁹ and they either cut or fracture the stone, depending on the form of the tool and the nature of the stone. Abrasive tools include grinders, rubbers, scrapers and loose abrasive particles or abrasive slurries used on their own or with saws and drills.

In the Predynastic Period, craftspeople employed stone tools, including axes, adzes and grinders; these tools were predominantly used in the prolific stone vessel industry. Skills honed in this era were integral to early experimentation with hard stone carving in the Early Dynastic Period²⁰ and the proliferation of statuary production in the Old Kingdom. Cast copper tools first appear from Nagada II,²¹ and Petrie

suggested that certain stone tools were imitated in copper.²² However, copper and bronze tools, such as adzes and chisels,²³ were almost certainly used exclusively for the working of soft stones like limestone. My experimental work,²⁴ and that of Zuber and Stocks, demonstrates that percussive tools made from copper or bronze are ineffective on hard stone, suggesting instead the use of stone percussive tools. Mauls, hammers and pounders made from dense hard stones would have been used for rough shaping and creating flat surfaces. Interestingly, Arnold notes that Incan stone workers in 15th-century South America dressed their granite, porphyry and andesite with practically the same tools.²⁵ These tools varied in shape and size and were used for almost the entire carving process. The marks left by this category of tools generally appear as shallow pits or depressions, formed as the stone is shattered or fractured from impact. The worked surface always has contiguous depressions, most often with no discernible direction.²⁶ Fine carving, on the other hand, was likely done with chisels made from flint.²⁷ Although flint tools defin-

itively identified as implements for stone working have yet to be identified, a few flint tools knapped to the appropriate shape have been noted,²⁸ and flint flakes have been found among builders' debris, although the relative absence of deposits of flint debris is noteworthy.²⁹ This might be explained by the presence of finished flint tools at quarry sites,³⁰ suggesting that tools were knapped at the flint quarries rather than in sculpture workshops, but this point requires further investigation. More critical evidence for the use of flint can be found in the examination of tool marks,³¹ a point which will be reinforced later in this paper. Flint chisels driven by wood or stone mallets could have been effectively used on both hard and soft stones throughout Egyptian history. Stocks also convincingly proposes the use of flint tools as gravers and scrapers to create fine lines and sharp outlines, respectively.³²

While it is likely that the use of flint tools extended well in to the first millennium, the place of iron tools in this narrative is still debated. Arnold notes that by the 26th Dynasty iron was as common a material as bronze, and he believes that tool marks indicative of iron can be seen on hard stone at this time³³ while Devaux writes that iron tools capable of working hard stones come into use in the 27th Dynasty.³⁴ Stocks, on the other hand, argues that Late Period iron chisels could not have been used to cut hard stone, and that flint tools were still used for this task.³⁵ Despite disagreement about the exact timing of this technological shift, there is evidence that the process for making quenched and tempered steel was known in the Mediterranean region by the 7th century BCE, and this would have had significant impact on the utility of metal tools on hard stones. Regardless of the type of percussive tool used, it is clear that abrasive methods were especially crucial for the working of hard stones, not just to impart the desired surface but also for rough shaping. Copper drills and saws first appear in the Old Kingdom, and these were used in combination with an abrasive slurry for cutting hard stones.³⁶ In fact, it is highly likely, from an efficiency perspective, that a significant amount of stone removal and rough shaping were accomplished with abrasive technology. Finishing was likely carried out with a combination of rubbing or grinding stones³⁷ and abrasive slur-

ries. Rubbing or grinding stones were often made from silicified sandstone³⁸ and other stones with a high quartz content. The composition of the abrasive materials used has been extensively debated:³⁹ were hard stones shaped and polished using solely quartz-based abrasives, or did the Egyptians have access to harder materials? It has been demonstrated through archaeological evidence and experimental data⁴⁰ that corundum, a mineral with a hardness of Mohs 9, and emery, a stone containing corundum minerals, were employed by craftsmen in the ancient Mediterranean and Near East, but were these materials part of the Egyptian tool kit? Although some scholars have posited the use of emery abrasive powder,⁴¹ this was countered by others citing the lack of direct evidence for the use of this material in Egypt, as well as the lack of known sources of emery in Egypt and the presence of quartz sand embedded in ancient drill holes.⁴² However, abundant corundum particles were found in the base of a drill hole in a small fragment of indurated limestone (57.180.142), excavated at the Great Temple of the Aten at Amarna.⁴³ These particles were mixed with powdered limestone, and corroded fragments of a bronze drilling tool. This discovery suggests that corundum could have been introduced as an abrasive material by 1350 BCE, but in order to draw any inferences about the implications of this on sculpture production more data points are necessary.

In terms of methodology, unfinished statuary demonstrates that the basic sculptural process was to rough out a cube of stone, execute preliminary drawings on all sides, and then to work inwards from each side.⁴⁴ Thinking specifically about hard stone statuary, Rockwell cites the unfinished seated statues of Mycerinus in the MFA Boston, the carving of which is also discussed in detail by Devaux.⁴⁵ They are carved in "a hard-stone technique, whereby the stone is removed by vertical pounding so that it is shattered into small bits as the carver moves over the surface. The surface is pitted, and the pitting becomes finer and finer as the carving nears completion."⁴⁶ Rockwell compares these third millennium statues with unfinished works from the second and first millennia.⁴⁷ All of the statues demonstrate a method in which the form evolves using a sequence of progressively more complex geometric solids. The

difference lies in which geometry was used as the basis for the finished form: for example, the second millennium carver has a more sophisticated sense of geometric solids than the third millennium carver, and the first millennium carver uses a series of sequential planes rather than squared or curved solids of the earlier works.⁴⁸ Regardless of manufacture date, the subtractive nature of stone carving usually ensures that completed works will bear little or no evidence of the vast majority of the carving process; often the only marks preserved will be from finishing, such as the percussive carving of fine details or abrasive processes.

An equally important methodological point relates to tool usage. Rockwell notes that granite is often worked by holding a tool vertical to the stone and smashing it. Therefore, tools are thicker and blunter than those for softer stones and must be sharpened or re-forged more often.⁴⁹ Rockwell was referring to granite carving after pharaonic Egypt – should we assume that flint chisels were used in the same manner? The mechanism by which a tool is used to remove stone has direct bearing on the tool marks left behind, as does the material from which a tool is made, its shape, and the methodological approach that the carver takes to realize the finished work. This is the salient point when assessing a stone sculpture from a technical perspective, whether one's interest is in the relative effort that went into an object's production, workshop practice, or authenticity. What can tool marks tell us? Does an iron chisel bruise the stone differently than flint? What is the difference between abrasive marks from quartz and harder minerals like corundum? What is the relationship between tool marks on a surface and how can we use this relationship to make observations about tool usage and methodology? As Rockwell writes, "[i]n a technology where the written documentation is scarce and often confusing, or written by those who were not familiar with it, usually the only accurate evidence is the object itself."⁵⁰

3. Documenting Tool Marks

Most investigations of tool marks on stone present them either using conventional photography or SEM images of silicone rubber impressions. The merits and drawbacks of these methods have been previ-

ously discussed,⁵¹ and on this basis, RTI was used here as the primary method for visual analysis and documentation.⁵² With RTI, a series of high-resolution images, each with distinct information about highlights and shadows, are synthesized to create interactive image files. RTI reveals texture and detail that are often difficult to see with the naked eye or challenging to record due to an object's optical properties. Color and shape information are encoded in each pixel, allowing the user to re-light the object from an infinite number of angles and facilitating the mathematical enhancement of surface features.⁵³ All images presented in this paper are exported from RTI files that were generated using the Highlight-based RTI Capture and Processing methods published by Cultural Heritage Imaging (CHI).⁵⁴ RTI data sets were captured using a Canon 5D Mark II DSLR with a Canon 100mm f/2.8L Macro lens. The light source was a Canon speedlight that was triggered with a remote transmitter mounted on the lens and a handheld remote. Enhancement modes applied in RTI-Viewer are noted in the caption of each image. The two enhancement modes found to be most useful for visualizing the surfaces of the objects presented in this paper are specular enhancement⁵⁵ and coefficient unsharp masking.⁵⁶

The visualizations generated through this relatively inexpensive, readily available technique are qualitative and their limitations must be recognized,⁵⁷ but if executed according to CHI Guidelines RTI can reduce some of the subjectivity of standard photography and can be highly accurate and reproduceable.⁵⁸

4. Reading Ancient Sculpture: Case Studies

In the process of recording tool marks on a wide range of stone objects, several interesting threads of inquiry emerged: differences in hard stone and soft stone carving; variations in finishing work on statuary elements; variations in the carving of hieroglyphs; and possible evidence of a changing tool kit. I explore these topics below through a series of case studies which lay out a methodology for the exploration of stone carving tools and technology. The objects presented here come from a range of time periods and vary in place of origin and function. The majority are from the collection of The Metropoli-

tan Museum of Art, most of which were excavated by The Metropolitan Museum and acquired through the division of finds.

It should also be noted that the stone identifications presented in this paper have most often been carried out by visual examination rather than scientific analysis. In general, the misidentification of stone types in museum labels and publications is common. The stone identifications in this paper are most often based on visual characteristics and comparison with scientifically identified samples and relevant literature, in consultation with geologists. Detailed petrographic classification would require the preparation and analysis of thin sections.

4.1 Soft Stone vs. Hard Stone

When investigating tool marks as evidence of technique, establishing the observable differences between hard and soft stone carving is the first step. As has been previously noted, approaches to soft and hard stone carving must have differed vastly. Indeed, in Egypt, as in other ancient cultures, the carving of hard stone was likely a particular specialization

with dedicated craftspeople.⁵⁹ On a visit to the Nicoli workshop in Carrara, I was introduced first to the team of sculptors who worked with marble and then to the team of sculptors who worked with granite. Although extrapolating ancient methods from contemporary practice should be done with caution, this split between practitioners in this 150-year-old workshop is worth noting.

This difference is readily visible in examining two small sculptures, both excavated by The Metropoli-



Fig. 3: Upper part of the statue of a man, Middle Kingdom, Dynasty 12–13, ca. 1981–1640 BCE. Egypt, Memphite Region, Lisht North, MMA excavations, 1906–07. Serpentine, H.6.7 cm, W.6.5 cm. The Metropolitan Museum of Art, Rogers Fund, 1915 (15.3.579).



Fig. 4: Seated statue of Kay, Middle Kingdom, Dynasty 12–13, ca. 1950–1640 BCE. Egypt, Memphite Region, Lisht South, tomb of Senwosretankh, debris, MMA excavations, 1932–33. Granodiorite, H. 24.5 cm. The Metropolitan Museum of Art, Rogers Fund, 1933 (33.1.3).

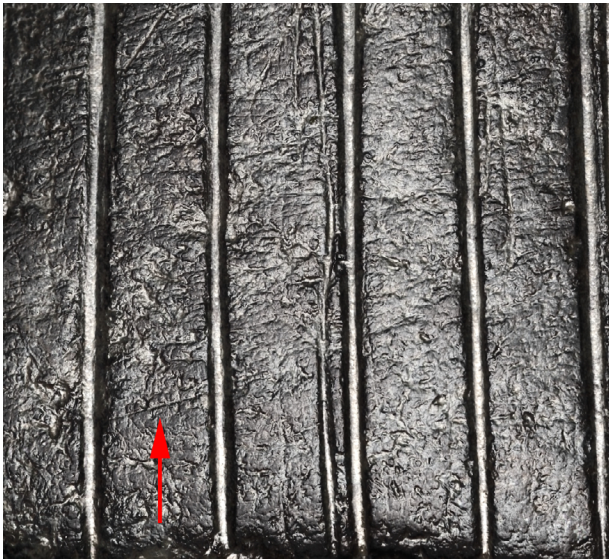


Fig. 5: Image captured from RTI of detail of wig from 15.3.579 (serpentinite) with specular enhancement. The red arrow indicates traces of rough polishing. Image captured by the author.
[Go to RTI web viewer.](#)



Fig. 6: Image captured from RTI of detail of wig from 33.1.3 (granodiorite) with specular enhancement. The red arrow indicates tool slip. Image captured by the author.
[Go to RTI web viewer.](#)

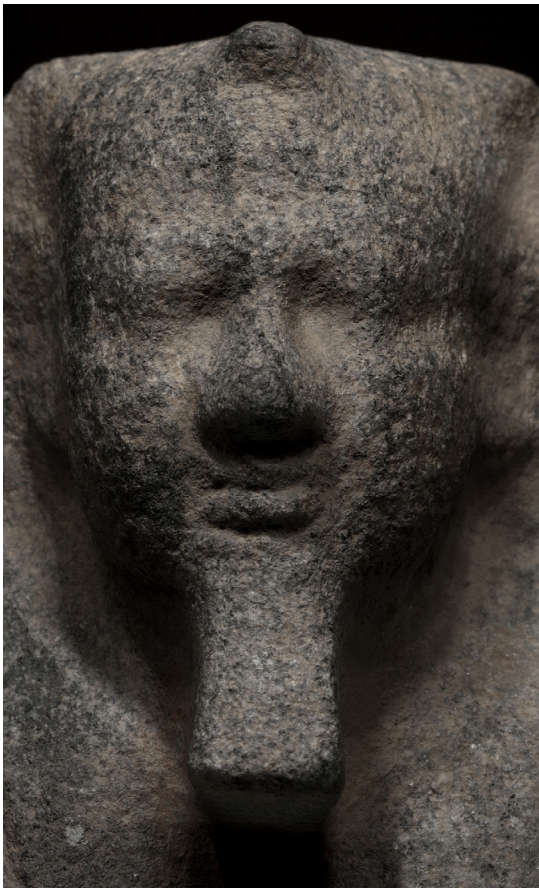


Fig. 7: Images from RTI of MFA 11.732 with specular enhancement (left) and coefficient unsharp masking (right).
[Left: go to RTI viewer.](#)

Anorthositic gneiss, 36 x 16 x 23.2 cm, Old Kingdom, Dynasty 4, reign of Menkaura 2490–2472 BCE, Menkaura Valley Temple, Harvard University – Boston Museum of Fine Arts Expedition. Images captured by the author.
[Right: go to RTI web viewer.](#)

tan Museum of Art at Lisht. The first, the upper part of the statue of a man (Fig. 3, 15.3.579), is from the 1906-7 Lisht North excavations and dates to the Middle Kingdom. It is carved from serpentinite, a metamorphic rock containing different minerals, mostly from the serpentine group (hydrated magnesium silicate), which is widely distributed in Egypt's Eastern Desert.⁶⁰ As a rule, serpentinites vary in hardness, but according to Klemm and Klemm Egyptian serpentinite can be considered a soft stone with an equivalent hardness to calcite (Mohs 3).⁶¹ The second, a seated statue of a man named Kay (Fig. 4, 33.1.3), is from the 1932-33 excavations at Lisht South and also dates to the Middle Kingdom. It is carved from granodiorite, often referred to colloquially as "grey or black granite". Like granite, granodiorite is composed mainly of quartz and feldspars, and is distinguished based on its ratio of alkali to plagioclase feldspars; granodiorite has more of the latter than the former.⁶² Granodiorite is quarried at Aswan and the equivalent hardness of this heterogeneous stone is situated between 6 and 8 on the Mohs scale.⁶³ Examining details from the wigs of both statues (Figs. 5, 6), which are at roughly the same scale, one can see several distinct differences. First, the raised, flat surface of the serpentinite statue still bears rough scraping or abrasion that was likely one of the final steps in sculpting the wig. This was followed up by polishing with finer abrasives, but in this case the deeper cuts from the rough finishing step were not fully polished away and are still preserved. The hard stone, on the other hand, was probably shaped by pounding until it was very close to its final form. Stocks noted the characteristic pitted appearance of ancient hard stone artifacts;⁶⁴ a remnant of this process can be seen on the unfinished statuette of king Mycerinus from the Museum of Fine Arts, Boston (Fig. 7, MFA 11.732). In contrast, the seated statue of Kay (Figs. 4 and 6, 33.1.3) appears to have been worked to completion, likely with progressively finer abrasives. The surface preserves very few signs of the abrasive process used to create the finished form because the hardness of the stone precludes deep scratches, and most of the shallow scratches are polished away. On both of these objects, and indeed on most Egyptian statuary I have examined, fine lines and other details were carved

only after the finished forms were fully realized through rough and fine polishing. On the serpentinite object, a fine-tipped tool has been used to cut or scrape through the stone. The troughs of these lines are roughly v-shaped, but the v isn't quite as sharp as it would be if created with a modern steel chisel. The width and depth of the line changes slightly, but not enough to indicate that the tip of the tool was constantly damaged by the carving process. Although tiny striations in the deeper lines indicate that they were likely done in more than one pass, the relatively deep "slip-ups" alongside two of the lines indicate that the stone can be deeply scraped with a single pass. On the other hand, the lines in the granodiorite, even though they are very finely done, clearly represent significantly more effort. These lines would have likely been done with a flint chisel, held at a very steep angle to the surface and utilizing percussive fractures at grain boundaries to remove stone. The width and depth of the lines vary quite a bit and there are fractures along the edges of the line troughs where grains dislodged during the percussive process. Slip-ups can often be observed on hard stone – for example, the slip along the second line from the left; but this too has an inconsistent depth and edge fractures. The sculptor of the granodiorite also seems to have had a more difficult time keeping the lines parallel.

Even if both statues were carved with flint tools, those tools would have been used very differently. And in the case of the serpentinite statue, bronze tools cannot be ruled out. These two images highlight not only varying tool kits and tool functions, but also differences in finishing technique.

Interestingly, an indurated limestone unfinished seated statue of King Menkaure (Fig. 8, 37.6.1) exhibits traces of both hard and soft stone carving techniques. In a detail of the face one can see both the pitted appearance of an unfinished hard stone surface and the deeper scratch marks of the scraping action that was used to shape softer stones. This statue is carved from indurated limestone, which is harder than other limestones owing to more coarsely crystalline calcite or the presence of secondary dolomite or secondary quartz.⁶⁵ Also worth noting is the link between tool form and use in the Old and Middle Kingdoms; although both unfinished statues of Men-



Fig. 8: Image from RTI of 37.6.1 with coefficient unsharp masking. Seated statue of King Menkaure, Old Kingdom, Dynasty 4, reign of Menkaure, ca. 2490–2472 BCE. Egypt, Memphite Region, Giza, Pyramid Complex of Menkaure, Valley Temple: Sculptor's workshop, Harvard-Boston MFA excavations, 1911. Indurated limestone, H. 20 cm. The Metropolitan Museum of Art, Rogers Fund, 1937 (37.6.1). Image captured by the author.
[Go to RTI web viewer.](#)

kaure are significantly older than the serpentinite and granodiorite statues, similarities in tool marks suggest a continuity of tools and their functions.

4.2 Variations in Hard Stone Technique: Finishing Work

It is clear that hard stone carving required specialized tools and methods, but even among hard stones there is significant variation in the carving process and its product. And as with the distinction between hard and soft stone methodology this difference is driven by the make-up of the stone itself. Consider the divergent finishing work evident in the examination of a group of sculpture fragments excavated at Amarna (Fig. 9).

The crown with disks (Fig. 9a, 21.9.533) and body fragment with garment pleats (Fig. 9b, 21.9.536) are both carved from a dark hard stone which is identified as diorite.⁶⁶ The torso of a king with the hand of a queen offering behind (Fig. 9c, 21.9.436) and the mouth of Akhenaten or Nefertiti (Fig. 9d, 21.9.18) are carved from stone commonly referred to in English as pink or red quartzite, but geologically it is

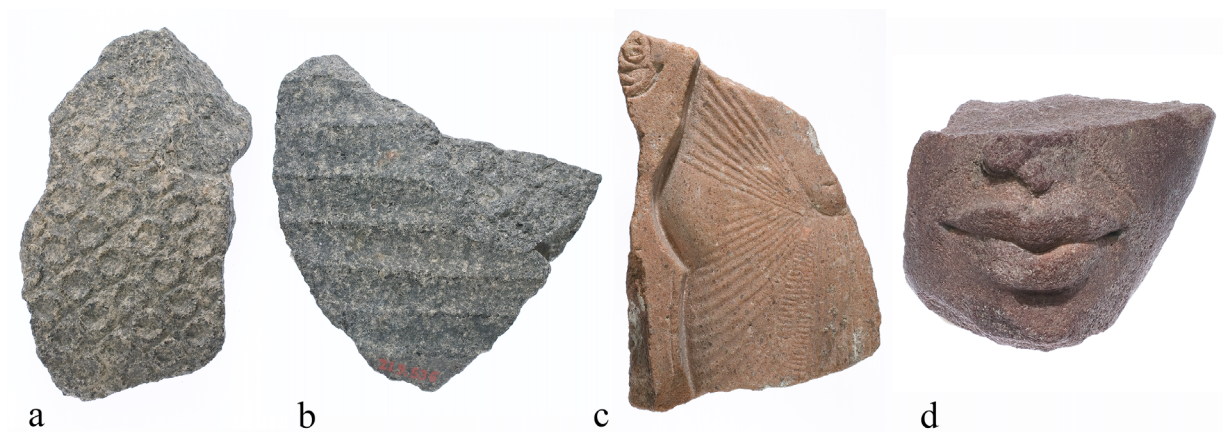


Fig. 9: a) Crown with disks, New Kingdom, Amarna Period, Dynasty 18, ca. 1353–1336 BCE. Egypt, Middle Egypt, Amarna (Akhetaten), Petrie/Carter excavations, 1891–92. Diorite, H. 11 cm. The Metropolitan Museum of Art, Gift of Edward S. Harkness, 1921 (21.9.5333).
 b) Body fragment with garment pleats, New Kingdom, Amarna Period, Dynasty 18, reign of Akhenaten, ca. 1353–1336 BCE. Egypt, Middle Egypt, Amarna (Akhetaten), Petrie/Carter excavations, 1891–92. Diorite, H. 10.5 cm. The Metropolitan Museum of Art, Gift of Edward S. Harkness, 1921 (21.9.536).
 c) Torso of king with hand of queen offering behind, New Kingdom, Amarna Period, Dynasty 18, ca. 1352–1336 BCE. Egypt, Middle Egypt, Amarna (Akhetaten), Petrie/Carter excavations, 1891–92. Silicified sandstone, H. 22 cm. The Metropolitan Museum of Art, Gift of Edward S. Harkness, 1921 (21.9.436).
 d) Mouth of Akhenaten or Nefertiti, New Kingdom, Amarna Period, Dynasty 18, reign of Akhenaten, ca. 1353–1336 BCE. Egypt, Middle Egypt, Amarna (Akhetaten), Petrie/Carter excavations, 1891–92. Silicified sandstone, H. 5.5 cm, W. 8 cm, D. 7 cm. The Metropolitan Museum of Art, Gift of Edward S. Harkness, 1921 (21.9.18).



Fig. 10: Detail from RTI of 21.9.533 (diorite) with specular enhancement. Image captured by the author.
[Go to RTI web viewer.](#)

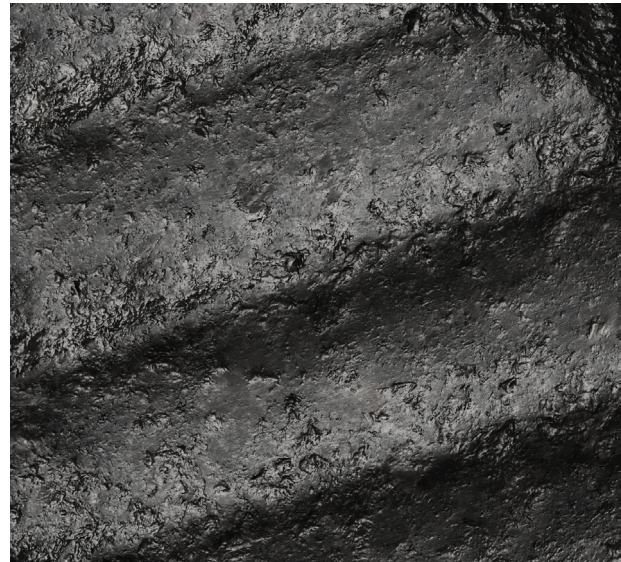


Fig. 11: Detail from RTI of 21.9.536 (diorite) with specular enhancement. Image captured by the author.
[Go to RTI web viewer.](#)

silicified sandstone, a hard sedimentary rock found predominantly in the Eastern and Western Deserts in which grains of quartz sand are tightly cemented by silica.⁶⁷ While the working of both stones would have presented significant challenges, the carvers of the diorite had the advantage of abundant softer minerals dispersed among the hard quartz and feldspar grains. A blow from a flint chisel held at a steep angle would fracture the softer minerals, dislodging the harder quartz and feldspar grains; replication experiments by Zuber, Stocks and myself demonstrate that this can be done with relative ease. As Stocks points out, and as I also experienced, it is advantageous for the carver to constantly vary the position of the chisel to account for the different orientations of quartz crystals within the stone.⁶⁸

Variation in the chisel position is evident in the crown fragment (Fig. 10). Individual blows are evident in the lines around the circular elements, and the centers of the circles appear to have been carved with a few blows from varying angles. Though the sculptor seems to have used a system of squares to keep the circular elements relatively regular, overall the carving appears to have been executed with the aim of speed, rather than striving for perfect uniformity, and there is no evidence of the use of abrasives after the percussive work. The fragment of the garment, on the other hand, has little remaining evidence of percussive work (Fig. 11). Some pitting visible in the image may be traces of chisel blows,

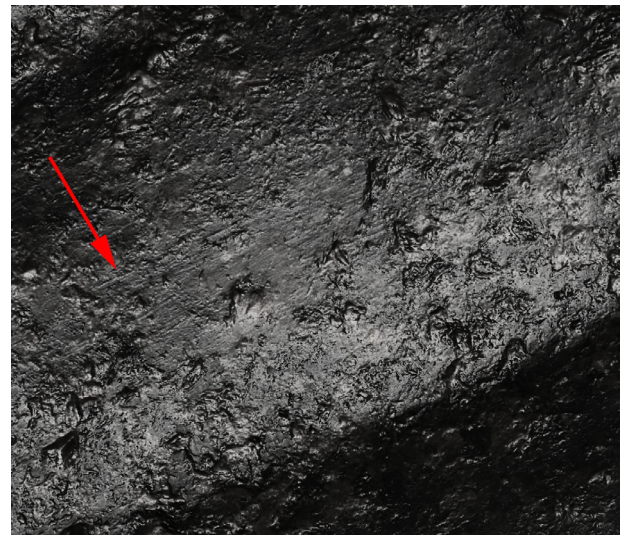


Fig. 12: Detail from RTI of 21.9.536 (diorite) with specular enhancement, showing traces of abrasive marks (indicated with red arrow). Image captured by the author.
[Go to RTI web viewer.](#)

but such pitting also results from natural weathering. More importantly, this surface has been worked extensively with abrasives, minor traces of which can be seen running parallel to the ridges (Fig. 12). In both cases, it might be speculated that the sculptor was exploiting the textural differences that result from these divergent finishing methods. Another possibility is that the sculptor was unable to satisfactorily smooth the surface of the crown without losing definition, while smoothing the surface of the garment was a significantly simpler process. The silicified sandstone fragments exhibit several important differences in technique. As Aston *et al.*



Fig. 13: Detail from RTI of 21.9.436 (silicified sandstone) with specular enhancement. Image captured by the author.
[Go to RTI web viewer.](#)



Fig. 14: Detail from RTI of 21.9.18 (silicified sandstone) with specular enhancement. Image captured by the author.
[Go to RTI web viewer.](#)



Fig. 15: Upper right arm with Aten cartouches, New Kingdom, Amarna Period, reign of Akhenaten, ca. 1353–1336 BCE. Egypt, Middle Egypt, Amarna (Akhetaten), Petrie/Carter excavations, 1891–92. Diorite, H. 11.9cm. The Metropolitan Museum of Art, Gift of Edward S. Harkness, 1921 (21.9.450).



Fig. 16: Upper right chest of a queen wearing a pleated garment and an elaborate broad collar, with cartouches of the Aten, New Kingdom, Amarna Period, Dynasty 18, reign of Akhenaten, ca. 1353–1336 BCE. Egypt, Middle Egypt, Amarna (Akhetaten), Great Temple of the Aten, pit outside southern wall, Petrie/Carter excavations, 1891–92. Silicified sandstone, H. 9.4 cm. The Metropolitan Museum of Art, Harris Brisbane Dick Fund, 1957 (57.180.52).

note, the quartz sand grains within the stone are so tightly cemented that tools had to break *through* the grains rather than around them.⁶⁹ This would likely have required significantly harder blows and more precision, possibly with the chisel held almost com-

pletely vertical. Examining the details from the RTI (Figs. 13 and 14), one sees very little spalling along the edges of lines.

However, this less fluid approach does not necessarily imply greater precision. The carved pleats in the

detail from the torso of a king (Fig. 13), for example, meander somewhat and vary in depth. Does this suggest a carver of intermediate skill, an aesthetic choice (such as intentional irregularity to mimic the folds of an actual garment), or a craftsperson working to overcome an obstacle – larger grains embedded in the stone, a tool that was slightly too dull for the task, significant time pressure, or just the sheer number of lines to carve (and maybe this outcome was simply “good enough”)? On the other hand, the mouth of Akhenaten or Nefertiti (Fig. 14) exhibits a high degree of precision, particularly in the fine line running from the nose to the corner of the mouth. This line has consistent depth, except where the carver chose specifically to taper it, and there is very little spalling along its edges. Both fragments were undoubtedly worked with abrasives after percussive carving, although almost no traces of this process exist. This is likely because of the lack of softer minerals that can be easily scratched with quartz abrasives. Quartz can slowly abrade quartz, but this action is unlikely to leave defined scratch marks. The characteristic appearance of details in “quartzite” sculpture⁷⁰ is almost certainly linked to the specialized method required to produce it. But while methodology is highly dependent on the properties of the stone

and the available tools, it is also dependent on the skills and micro-decisions of the operator and other factors which could include financial resources, time constraints and aesthetic goals. Indeed, the rendering of fine details in hard stone varies rather significantly.

4.3 Variations in Hard Stone Technique: Inscriptions

This technical variation across stone types is also apparent when one examines the inscriptions added to sculpture. Take, for examples two 18th Dynasty sculpture fragments in The Met’s collection. One is a statue fragment, possibly of an upper right arm, with Aten cartouches (Fig. 15, 21.9.450) is carved from a dark hard stone previously catalogued as diorite. The other is the upper right chest of a queen wearing a pleated garment (Fig. 16, 57.180.52), which is carved from silicified sandstone.

The inscription on the diorite fragment (Fig. 17) exhibits evidence for chisel angle variation discussed in the previous section, including micro-spalling along the edges of the lines and forms, and irregular pock-marks within the troughs, which indicate points of impact where the chisel was struck.

In the inscription on the silicified sandstone fragment shown in Fig. 18, on the other hand, it is clear



Fig. 17: Images from RTI of 21.9.450 (diorite) with specular enhancement. Image captured by the author.
[Go to RTI web viewer.](#)



Fig. 18: Images from RTI of 57.180.52 (silicified sandstone) with specular enhancement. Image captured by the author.
[Go to RTI web viewer.](#)

that the frames of the cartouches were created by executing a series of very controlled blows in two relatively even rows. There is almost no micro-spalling visible and the impact marks seem to have been created with a tool held nearly vertical to the surface. The hieroglyphs within the cartouche appear to have been carved in a similar manner, with a single row of blows. Interestingly, there is little evidence that the size and shape of the tool's striking point or edge is changing very much as the carving progresses. Would a flint tool employed in this type of carving require a specialized form? Was the tool made from another material altogether? Perhaps this is one of the tools Stocks suggests is missing from the archaeological record, or perhaps the way the flint was knapped made the tool more resistant to damage with each blow. Regardless, it is clear that the Egyptians who carved silicified sandstone had a special methodology which is still not entirely known.

As with the finishing work previously described, the variations in inscription carving extend beyond differences in the working properties of a particular stone. The carving of hieroglyphs in granites, granodiorites and similar stones can range from rough lines and forms that appear more rapidly executed (Fig. 19a, 15.3.227, and Fig. 19c, 35.9.1) to highly precise renderings (Fig. 19b, 35.9.1, and Fig. 19d, 22.1.200). Interestingly, Figs. 19b and 19c are two details from the same object, illustrating that the handling of tools can vary over the surface of a single sculpture.⁷¹ Fig. 19d also exhibits another variation –

lines which appear to have been scraped or polished after percussive carving. The economic impact of this added step on some sculpture is worth considering. This group of images demonstrates that the close examination of individual tool marks can help help us better understand the manner of a sculpture's production, and its implications.

It is also important to note where our current understanding of tools and methods cannot explain the marks visible on a surface. Still mysterious are the incredible fine, relatively deep details carved into hard stone sculpture such as a statuette of Khentykhetty from the Museo Barracco in Rome (Fig. 20).⁷² This small, exquisitely carved statue from the Middle Kingdom has hieroglyphs and other fine details that are incredibly small and highly precise. Clearly they were executed with a percussive tool, but that tool would require an extremely hard and extremely fine point. Can flint knapped to such a fine point hold its shape beyond a single blow? What other materials could have been used to make these marks?

This section and the previous one have focused predominantly on small details, but it is equally critical to pull back and understand the relationship between marks across a surface, and note trends in the directionality of tool marks and the degree to which the object is “finished”. Regarding the latter point, Kozloff *et al.* note that “the contribution of the polished surface to the completed statue is, for those in hard stone, an index of the monument's status—and generally of its aesthetic merit.”⁷³ Mapping these obser-



Fig. 19: Images from RTIs of the following objects, with specular enhancement.

a) Block statue of Minhotep, Middle Kingdom, late Dynasty 12 – early Dynasty 13, ca. 1850–1640 BCE. Egypt, Memphite Region, Lisht North, cemetery south of pyramid below House A2:2, Pit 495, MMA excavations, 1913–14. Diorite, H: 17.5 cm. The Metropolitan Museum of Art, Rogers Fund, 1915 (15.3.227).

[Go to RTI web viewer.](#)

b) and c) Block statue of the scribe of divine offerings, Tjaenwaset, son of Harsiese, Late Period, Kushite-Saite, Dynasty 25–26, ca. 690–610 BCE. Upper Egypt, Thebes, Karnak, Temple of Amun, Cachette. Diorite, H: 25 cm. The Metropolitan Museum of Art, Gift of Edward S. Harkness, 1935 (35.9.1).

[Go to RTI web viewer.](#)

d) The Chief of Police, Mentuhotep, Middle Kingdom, Dynasty 12, reign of Amenemhat I – Senwosret I, ca. 1981–1917 BCE. Egypt, Memphite Region, Lisht North, cemetery south of pyramid south of House A1:4, Pit 898, MMA excavations, 1920–21. Granodiorite, H: 45.9 cm. The Metropolitan Museum of Art, Rogers Fund and Edward S. Harkness Gift, 1922 (22.1.200). Images captured by the author.

[Go to RTI web viewer.](#)



Fig. 20: Statuette of Khenti-Kheti, Middle Kingdom, ca. 1987–1640. Upper Egypt, Abydos. Granodiorite, 29.7 cm. Museo Barracco, INV.MB11. Images captured by the author.

[Go to RTI web viewer.](#)

Note that individual hieroglyphs visible in image on the right are approximately 1–2 cm in height and lines are only about a millimeter wide, at most.

[Go to RTI web viewer.](#)



Fig. 21: Block statue of the scribe of divine offerings, Tjaenwaset, son of Harsiese, Late Period, Kushite-Saite, Dynasty 25–26, ca. 690–610 BCE. Egypt, Upper Egypt, Thebes, Karnak, Temple of Amun, Cachette. Dolerite, H. 25 cm. The Metropolitan Museum of Art, Gift of Edward S. Harkness, 1935 (35.9.1).



Fig. 22: Statue of the priest Harnefer, son of Nesmin and of Nehemesrattawy, Ptolemaic Period, late 4th century BCE. Egypt, Upper Egypt, Thebes, Karnak, Temple of Amun, Cachette. Diorite, H. 59.2 cm. The Metropolitan Museum of Art, Mr. and Mrs. Isaac D. Fletcher Collection, Bequest of Isaac D. Fletcher, 1917 (MMA 17.120.145).

variations over the entirety of an object's surface could be facilitated by 3D imaging technology, a topic which will be touched upon in the conclusion of this paper. In general, the similarities and differences between the tool marks on the sculptures presented here, and on others examined in the course of this study, may be attributable to numerous factors: degree of finish, skill of the craftsman (or craftsmen), workshop traditions, desired aesthetic effect, time-investment, the dimensions of the sculpture, the context for which it was made, and so forth. We must also recognize that methodology and desired aesthetic shifted over time, and that our understanding of the marks on a sculpture's surface must be informed by its state of preservation and any subsequent modifications. Determining the relative significance of these similarities and differences relies on broad visual comparison.

4.4 Evidence of a Changing Tool Kit

Wootton, Russell and Rockwell note that stone carving is generally a conservative craft,⁷⁴ and while this is certainly true for Egypt, over the approximately 4000 years of history that spanned the Predynastic through the Greco-Roman Periods there were some important changes in tool kit and methodology that were driven both by technological advances and by changing requirements for tools. One such shift, already mentioned, is the adoption of iron tools for stone carving. Sheila Adam argued convincingly that Greek stone carvers used iron tools on marble,⁷⁵ but at what point does the shift away from flint tools for hard stone carving occur? Can we see evidence for this shift, and how different are the marks made by these tools?

A useful comparison can be found in examining the tools marks remaining on two statues from the 4th century BCE and comparing these with the marks on



Fig. 23: Images from RTIs of 35.9.1 (dolerite) with specular enhancement. Images captured by the author.
[Go to RTI web viewer.](#)

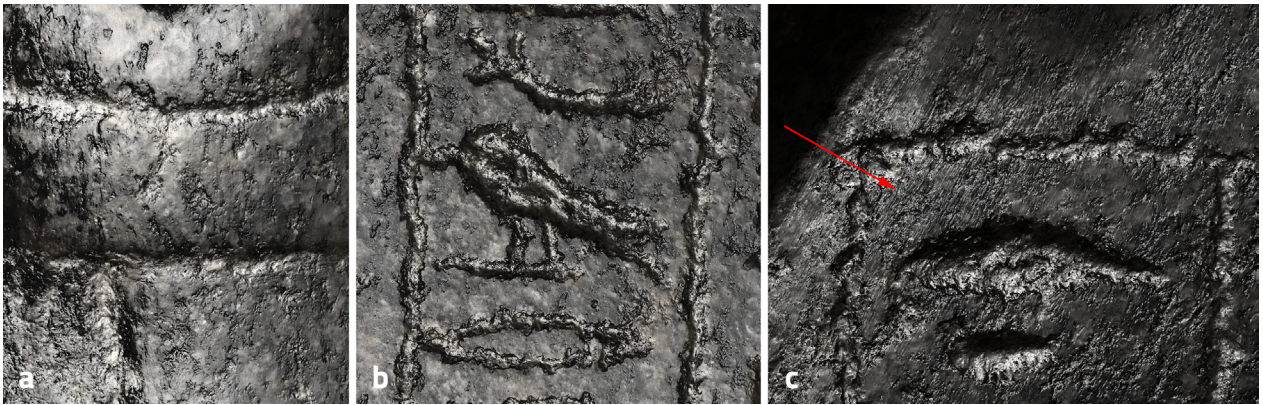


Fig. 24: Images from RTIs of 17.120.145 (diorite) with specular enhancement. Images captured by the author.
[Go to RTI web viewer.](#)
 The red arrow in (c) indicates diagonally running abrasive marks.
[Go to RTI web viewer.](#)

a statue from the Dynasty 25-26. The latter (Fig. 21, 35.9.1) is a block statue of a scribe of divine offerings, Tjaenwaset, son of Harsiese, which is carved from a dense, dark gray stone identified as dolerite.⁷⁶ The statue bears traces of the pitting that is characteristic of the percussive processes used to create the overall forms and relatively flat surfaces necessary for the carving of hieroglyphs and other fine details. The carving seen in Fig. 23 shows visible chisel marks that are consistent with earlier carving methods. An iron tool cannot be entirely ruled out, but these marks are certainly consistent with marks produced by flint chisels. In the image of the kneeling figure one can almost see each individual blow required to complete the form – it is evident that each blow re-

moved only a relatively small amount of stone.

Some subtle but critical differences are evident a statue of the priest Harnefer (Fig. 22, 17.120.145) which dates to the late 4th century BCE. Deep chisel marks appear to have been made relatively rapidly in the carving of the lines of the kilt (Fig. 24a) as well as of the hieroglyphs (Figs. 24b and 24c). The sides of some of the troughs appear very steep, almost perpendicular to the sculpture's surface. Similar marks can be seen in the hieroglyphs carved on another 4th century hard stone sculpture, a head from a statue with magical texts (Fig. 25, 1989.281.102). Although such steep trough angles are found in earlier sculpture, they seem to have required repeated percussion or abrasion to achieve. Therefore, the seemingly



Fig. 25: Images from RTIs of 1989.281.102 (basalt) with coefficient unsharp masking.

[Go to RTI web viewer.](#)

The red arrow in (b) indicates vertical abrasive marks along break edge. Images captured by the author.

[Go to RTI web viewer.](#)

rapid execution of these marks may suggest the use of iron tools rather than stone.⁷⁷

Also interesting to note are the abrasive marks running diagonally across the hieroglyphs in [Fig. 24c](#) and vertically along the break edge in [Fig. 25c](#). These marks are different in character from earlier abrasive marks – they are relatively deep, highly parallel and very long. Perhaps this is evidence for the use of an iron scraper or a similar tool employed by Roman stone workers.⁷⁸

Returning to the question of chisel material, it is notable that experiments I conducted with a modern steel chisel on Aswan granite produced similar marks ([Figs. 26, 27c](#)) to those seen on the 4th century BCE statues. As previously discussed, replication experiments cannot stand alone as evidence for (or against) the use specific tools or techniques, especially when the work is carried out by a practitioner who is not a trained and practicing sculptor. But imperfect as my experiments are, the distinct differences in the marks made by flint and steel ([Figs. 27b, 27c](#) respectively) do suggest that such tools would produce different results. And although the steel chisel I used is decidedly different from its ancient iron predecessor, this experimental evidence suggests that the subtle differences noted in this section could well be linked to changes in the tool kit.

Did the Egyptians replace their flint chisels with iron chisels, and if so, when? Iron was used in Greece by



Fig. 26: Images from RTIs of 1989.281.102 (basalt) with coefficient unsharp masking.

The red arrow in (b) indicates vertical abrasive marks along break edge. Images captured by the author.

[Go to RTI web viewer.](#)

1000 BCE and tempering – which would produce iron tools that were tough without being brittle – was known by the 8th century BCE.⁷⁹ Given what is known about the movement of materials and craft-speople around the Mediterranean and Near East in the first millennium BCE, it is theoretically possible

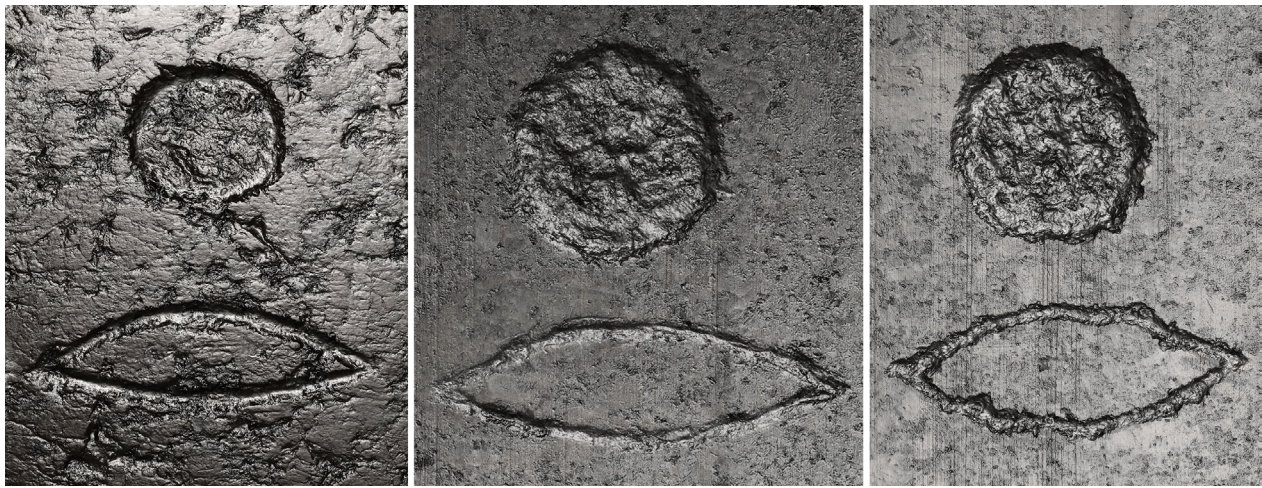


Fig. 27: Images of RTIs of (a) hieroglyphs on the sarcophagus of Mindjedef (54.80).

[Go to RTI web viewer.](#)

b) Hieroglyphs copied by the author using an experimentally produced flint chisel and c) a steel chisel. All substrates are Aswan granite. All images have specular enhancement applied.

[Go to RTI web viewer.](#)

that iron chisels made their way to Egypt prior to the production of the statue of the priest Harnefer and the head from a statue with magical texts, mentioned above. The differences between the tool marks observed on these two objects from the 4th century BCE and the 7th century BCE block statue of the scribe of divine offerings, Tjaenwaset, son of Harsiese seem to imply that the introduction of iron tools was gradual, perhaps slowly replacing their flint predecessors over several centuries.⁸⁰ Certainly iron was the tool material of choice by the Roman period; there are second-century AD ostraka from the Mons Claudianus granodiorite quarries in the Eastern Desert attesting to large numbers of blacksmiths.⁸¹ But even so, tool marks seemingly made with flint tools found on Roman period sculpture do not necessarily imply an earlier date. Indeed, sculptors in Roman Egypt may have sometimes chosen flint, the tool material which they had relied on for millennia.

5. Conclusion

As this article has demonstrated, documentation with RTI allows for a more detailed comparison of tool marks on a wide variety of stone types and a more accurate recording of complex surfaces. RTI documentation brings to light a wide variety of tool marks, many of which can reasonably be assigned to tools in the ancient stoneworker's tool kit. However, this systematic recording of tool marks also generates a number of new questions, and there are still

some tool marks that cannot yet be explained by existing scholarship. For example, could flint chisels really be used to produce the incredibly fine and relatively deep hieroglyphs on the seated Middle Kingdom statue from Museo Barracco? Are there, as Stocks suggests, tools that are completely missing from the archaeological record? Perhaps there are flint nodules that are especially tough and which could be knapped in a particular fashion so that they held a very fine point. Or perhaps chisels with incredibly fine points could be fashioned from dolerite or a similarly dense stone. Maybe points made from hard minerals like corundum, microcrystalline varieties of quartz or other gemstones could be embedded in another material like copper or wood and used as a graver. All of these hypotheses require further investigation, including the consideration of contemporary gemstone carving technologies around the region.⁸²

Given the challenges to interpretation already mentioned, the images and observations presented in this article should serve not as definitive examples of a particular tool or technique, but rather as a starting point for useful comparison. Despite the seemingly programmatic approach to sculpture production, Egyptian stone statuary exhibits tremendous technical variation at the micro level. This makes sense – the ancient world had craftspeople with skill levels that were miraculous, mediocre, and everything in between. Tools must also have varied in quality

and certainly their efficacy changed with use. And despite the seeming consistency in tools and techniques throughout the Pharaonic era, no doubt there were many minor shifts in practice that resulted in variation which may now seem puzzling to us.

A better understanding of all of this variation would be greatly aided by further exploration of the relationship between tool marks over the entire surface of an object. This is, of course, part of standard visual examination, but *really* understanding the relationship between toolmarks across a sculpture's surface may benefit from technology beyond RTI. The creation of high-resolution 3-D models could facilitate the recording and scholarly exploration of tool marks across a surface while also providing actual geometric data, such as the specific angle and depth of a mark. This technology is rapidly advancing, and I plan to explore its possibilities in future work.

Another useful avenue to explore would involve looking beyond the borders of Egypt. What can we learn by exploring other ancient stone carving traditions? Sculptors of hard stone in the ancient Near East, South America, Asia and elsewhere faced similar challenges to their Egyptian counterparts. Cross-cultural comparison of tool marks might shed some additional light on questions such as the dis-

tinction between abrasive marks made by quartz and harder minerals, or the distinction between marks made from stone and iron chisels.

And lastly, in the realm of authenticity studies, it will be necessary to thoroughly understand the carving technology employed in the creation of forgeries. Documenting tool marks on known forgeries would provide another critical point of comparison.

This study leaves many questions unanswered and raises many new questions that are equally challenging to address. However, it is clear that learning to read the marks inscribed in a surface helps us to tell the production story of an object. Even if there are gaps in the story, the actions illuminated by the study and documentation of tool marks may give significant insight into the context of a sculpture's production. Tool marks can help us better understand aesthetics and style, and they can also hint at energy expenditure and the resources required for sculpture production. Lastly, tool marks have an immediacy. They can give us access to the individuals who created an object, including their handling of tools, micro-mistakes and decision-making – sometimes this is the closest we can get to these often extraordinarily skilled individuals who were rarely memorialized.

Notes

¹ Craddock, *Scientific Investigation of Copies, Fakes and Forgeries*, 2009, p. 245.

² This interdisciplinary research project was summarized in a poster presented at the Science of Ancient Egyptian Materials and Technologies International Conference November 4–6, 2017, Cairo, Egypt.

³ Previous publications that provide the background for this research include: Petrie, *Tools and Weapons*, 1917; Zuber, *Techniques et civilisations* 29/5 (1956), pp. 161–215; Lucas' chapter on "Building Materials" in his *Ancient Egyptian Materials and Industries*, 1962; Arnold's comprehensive text on Pharaonic stone masonry in Arnold (ed.), *The Royal Women of Amarna*, 1991, pp. 41–84; Aston, Harrell and Shaw's chapter on stone in Nicholson and Shaw (eds.), *Ancient Egyptian Materials and Technology*, 2000; Devaux's articles in *RdE* 50 (1999), pp. 275–277 and *RdE* 51 (2000), pp. 39–53, Connor in Miniaci et al. (eds.), *The Arts of Making*, 2018; and Connor, *Être et paraître*, 2020. Papers by Gorelick and Gwinnett and Sax and Meeks focus specifically on stone drilling and other stoneworking techniques in Egypt and the Near East, using silicone rubber impressions and scanning electron microscopy (SEM).

⁴ Stocks, *Experiments in Egyptian Archaeology*, 2003, p. 2.

⁵ Rockwell's publications include *The Art of Stoneworking*, 1993, *The Compleat Marble Sleuth*, 2004, and *The Unfinished: The Stone Carvers at Work in the Indian Subcontinent*, 2016, a collaboration with Vidya Dehejia.

⁶ Wootton et al., "[Stoneworking Tools and Toolmarks](#)", 2013.

⁷ Zuber, *Techniques et civilisations* 29/5, 1956.

⁸ Russell and Wootton discuss the complexities and critiques of the chaîne opératoire paradigm, and pose critical questions about embodied knowledge, the realities of craft production, and the myriad factors that influence the act of making; Russell and Wootton, in Lichtenberger and Raja (eds.), *The Diversity of Classical Archaeology*, 2017.

⁹ Stocks, *Experiments in Egyptian Archaeology*, 2003, p. 7.

¹⁰ Stocks demonstrates, for example, that calcite and gypsum (Mohs 3.5 and Mohs 2, respectively) require completely different tools and methods for cutting, incising and drilling (Stocks, *Experiments in Egyptian Archaeology*, 2003, p. 15).

¹¹ The Mohs hardness scale measures the hardness of single minerals; hardness of rocks is usually an average of the lithotype. For assemblages of minerals the hardness varies based on composition, texture,

- compaction, etc., and one might find different values for the same rock (Federico Carò, personal communication, 2021).
- ¹² James Harrell, personal communication (2022).
- ¹³ Arnold, *Building in Egypt*, 1991, pp. 27–41; Aston et al., in Nicholson and Shaw (eds.), *Ancient Egyptian Materials and Technology*, 2000, pp. 5–7.
- ¹⁴ For example, Aston et al. (op. cit., p. 15) cite the existence of nearly complete colossal statues and obelisks in several hard stone quarries as evidence for some in situ carving (p. 15); see also Kozloff et al., *Egypt's Dazzling Sun*, 1992, p. 138, and Connor, in Miniaci et al., (eds.), *The Arts of Making*, 2018.
- ¹⁵ For discussions about the sculptors' workshops excavated at Amarna, see Arnold, *The Royal Women of Amarna*, 1996, and Phillips, in Bourriau et al., (eds.), *Invention and Innovation*, 2012.
- ¹⁶ See Arnold, *Building in Egypt*, 1991, p. 285.
- ¹⁷ Stocks, *Experiments in Egyptian Archaeology*, 2003, p. 2.
- ¹⁸ Aston et al. in Nicholson and Shaw (eds.), *Ancient Egyptian Materials and Technology*, 2000, p. 65.
- ¹⁹ Stocks refers to the use of both punches and chisels for the carving of fine details in hard stone. A punch is a variation on the point chisel with a slightly wider cutting edge. See Wootton, W., Russell, B., and Rockwell, P. (2013) and Sheila Adam (1966), Chapter 1. Rockwell writes that the term "punch" is used extensively in archaeological literature, but is not universal terminology and seems mainly to be used in Great Britain (p. 2). Given that the term does not directly translate to stone tools, the term "chisel" will be used as a general term to describe a category of tools that vary somewhat in the shape of their cutting edge.
- ²⁰ Roehrig and Serotta, in Patch (ed.), *Dawn of Egyptian Art*, 2012, pp. 210–11.
- ²¹ Stocks, *Experiments in Egyptian Archaeology*, 2003, p. 12.
- ²² Petrie, *Tools and Weapons*, 1917, p. 1.
- ²³ Stocks, *Experiments in Egyptian Archaeology*, 2003, p. 27.
- ²⁴ Unpublished experimental work, some of which was summarized in a poster presented at the Science of Ancient Egyptian Materials and Technologies International Conference, November 4–6, 2017, Cairo, Egypt.
- ²⁵ Arnold, *Building in Egypt*, 1991, p. 50.
- ²⁶ Devaux, *RdE* 51 (2000), p. 40.
- ²⁷ Stocks, *Popular Archaeology* (July 1986); Stocks, *Antiquity* 73/282 (1999), pp. 25–29; Stocks, *Antiquity* 75/287 (2001), pp. 918–22; Devaux, *RdE* 51 (2000), p. 41. Devaux suggests that chisels could also have been made from silicified sandstone or dolerite.
- ²⁸ Arnold (*Building in Egypt*, 1991, p. 285) notes that some of the flint specimens published by Petrie (*Kahun*, 1890, p. 16; *Illahun, Kahun and Gurob*, 1891, pl. 7) and one example from Giza (Nour et al., *Cheops Boats*, Part I, 1960, pl. 15A) could have been used for stone. Stocks (*Experiments in Egyptian Archaeology*, 2003, p. 79) also references several flint tools from Kahun that he hypothesizes could have been "driven with a hammer or mallet for punching into hard or soft stone".
- ²⁹ Arnold, *Building in Egypt*, 1991, pp. 264, 285.
- ³⁰ Köhler et al., *PLOS ONE* 12/2 (2017).
- ³¹ Stocks, *Experiments in Egyptian Archaeology*, 2003, pp. 81, 84–85, 88.
- ³² Stocks, *Experiments in Egyptian Archaeology*, 2003, pp. 77, 94.
- ³³ Arnold, *Building in Egypt*, 1991, p. 257.
- ³⁴ Devaux, *RdE* 50 (1999), p. 275.
- ³⁵ Stocks, *Experiments in Egyptian Archaeology*, 2003, p. 77; Stocks notes that Engelbach's experiments also led to the same conclusion.
- ³⁶ Stocks, *Experiments in Egyptian Archaeology*, 2003, pp. 12–13.
- ³⁷ Arnold (*Building in Egypt*, 1991, p. 264) states that sandstone and quartzite were the most commonly used.
- ³⁸ Heldal et al., *Marmora* 1 (2005), pp. 11–35.
- ³⁹ Summaries of this debate can be found in Lucas and Harris, *Ancient Egyptian Materials and Industries*, 1962, pp. 72–74; Gorelick and Gwinnett, *Expedition* 25 (1983), pp. 40–47; Stocks, *Experiments in Egyptian Archaeology*, 2003, pp. 105–11.
- ⁴⁰ Heimpel et al., *Journal of Cuneiform Studies* 40/2 (1988), pp. 195–210; Gorelick and Gwinnett, *Iraq* 54 (1992), pp. 57–64; Lazzarini, *Atti dei convegni Lincei, I cento anni dello scavo di Festòs*, 2001, pp. 575–96.
- ⁴¹ Petrie, *The Arts and Crafts of Ancient Egypt*, 1909, pp. 74, 79. Lucas and Harris also list other scholars who previously proposed the use of emery, including Borchardt, Hölscher, Junker, and Reisner. Aston et al. (in Nicholson and Shaw [eds.], *Ancient Egyptian Materials and Technology*, 2000, p. 65) also mention emery used as an abrasive.
- ⁴² Lucas and Harris, *Ancient Egyptian Materials and Industries*, 1962, pp. 73–74; Stocks, *Experiments in Egyptian Archaeology*, 2003, pp. 110–11.
- ⁴³ Carò and Serotta, *Horizon* 14 (Spring 2014). The mineral assemblage identified on the Amarna fragment differentiates this material from emery. Possible sources for this material could be byproducts from the mining of gem-sized crystals which could have potentially provided corundum-rich loose material with a technical and economic value of its own. In Egypt, the only known corundum deposit of this type is located in the southern part of the Eastern Desert, at Hafafit.
- ⁴⁴ Aston et al., in Nicholson and Shaw (eds.), *Ancient Egyptian Materials and Technology*, 2000, p. 66.
- ⁴⁵ Devaux, *RdE* 51 (2000), pp. 45–48.
- ⁴⁶ Rockwell, *The Art of Stoneworking*, 1993, p. 74.
- ⁴⁷ Unfinished statues of Akhenaton and Daughter, Egyptian Museum, Cairo. JE 44866; Unfinished Osiris from the Louvre, E 27140.
- ⁴⁸ Rockwell, *The Art of Stoneworking*, 1993, pp. 74–77.
- ⁴⁹ Rockwell, *The Art of Stoneworking*, 1993, p. 23.
- ⁵⁰ Rockwell, *The Art of Stoneworking*, 1993, p. 5.
- ⁵¹ Serotta, *Metropolitan Museum Studies in Art, Science, and Technology* 2 (2014), pp. 197–201.
- ⁵² The interactive RTI images are linked to in the digital versions of this article – web and PDF.
- ⁵³ RTIViewer, currently the most commonly used

- software for visualizing RTI files, “can apply mathematical transformations to the surface normals as well as the RGB color information, resulting in reflectance enhancements of various kinds. These enhancement tools (or rendering modes) use information from surface shape and color in combination or surface shape or color by themselves. By using the shape data in RTI images, the enhancement functions in RTIViewer can disclose far more information about the subject than filters that use only RGB color data at each pixel.” [Cultural Heritage Imaging Guide to RTIViewer](#).
- ⁵⁴ [Cultural Heritage Imaging Guide to Highlight Image Capture](#), [Cultural Heritage Imaging Guide to Highlight Image Processing](#).
- ⁵⁵ According to [Cultural Heritage Imaging](#), “Specular enhancement is an image enhancement technique that yields improved perception of surface shape by photographically acquiring the reflectance functions of a surface, extracting per-pixel surface normals from these reflectance functions, and then rendering the resultant surface with added specular highlights computed from the surface normals using a Phong lighting model.”
- ⁵⁶ According to [Cultural Heritage Imaging](#), “Sharpening applies an unsharp mask to the image data in order to enhance the high frequency details and increase the edge contrast of the image. Sharpening algorithms look for discontinuities in the data that typically indicate edges in the photographed object. In an RTI, the mask can be applied to the normal data, finding and emphasizing sharp changes in depth as well as color... Coefficient unsharp masking emphasizes discontinuities in reflectivity, by applying the gain factor to each coefficient of the reflectance function.”
- ⁵⁷ The RTIs used in this study were captured periodically over approximately 8 years, during which time my understanding of and approach to this imaging technique evolved. For example, in retrospect I would have included a scale in each image, so that all still shots could be more directly comparable. Logistical considerations necessitated other variation in capture conditions. For example, sometimes capture was carried out in a photo studio, while some objects were captured in galleries or storerooms. Also, it should be noted that the processing software was updated several times over the course of this study. As a result, some of the RTIs were processed using the original PTM Fitter algorithm, while some RTIs were processed using the HSH Fitter algorithm; some were processed using both, and some older data sets were re-processed prior to publication. Additionally, it is important to recognize that digital artifacts can be created in processing, which is why one always has to go back and forth between the RTI file and the actual object.
- ⁵⁸ Mudge et al., *VAST*, 2005; Earl et al., *JAS* 37/8 (2010), pp. 2040–50.
- ⁵⁹ Connor, *Middle Kingdom Studies* 10 (2020), p. 244.
- ⁶⁰ Aston et al. in Nicholson and Shaw (eds.), *Ancient Egyptian Materials and Technology*, 2000, p. 56.
- ⁶¹ Klemm and Klemm, *Stones and Quarries in Ancient Egypt*, 2008, p. 12.
- ⁶² Aston et al. in Nicholson and Shaw (eds.), *Ancient Egyptian Materials and Technology*, 2000, p. 35; personal communication with Federico Carò.
- ⁶³ Arnold, *Building in Egypt*, 1991, p. 28.
- ⁶⁴ Stocks, *Experiments in Egyptian Archaeology*, 2003, p. 88.
- ⁶⁵ James Harrell, “Building Stones”, p. 7.
- ⁶⁶ Diorite is an igneous rock found in the Eastern Desert that is composed of plagioclase feldspar, greenish black hornblende amphibole or augite pyroxene, and a relatively small amount of quartz (Aston et al. in Nicholson and Shaw [eds.], *Ancient Egyptian Materials and Technology*, 2000, p. 30). However, De Putter and Karlshausen (*Pierres de l'Égypte ancienne*, 2022, pp. 110–12) note that stones from the diorite/quartzdiorite/gabbro group can be difficult to distinguish from the granite/granodiorite/tonalite group, and they reference Klemm and Klemm, who point out that many objects previously catalogued as diorite were found to be predominantly granodiorite. While it is possible that the fragment in question is carved from what de Putter and Karlshausen refer to as “diorite porphyrique”, the fragments have yet to be properly analyzed. Therefore, I will continue to use the term diorite in this paper, in order to be consistent with the objects’ current records.
- ⁶⁷ Aston et al. in Nicholson and Shaw (eds.), *Ancient Egyptian Materials and Technology*, 2000, p. 53.
- ⁶⁸ Stocks, *Experiments in Egyptian Archaeology*, 2003, p. 88.
- ⁶⁹ Aston et al. in Nicholson and Shaw (eds.), *Ancient Egyptian Materials and Technology*, 2000, p. 53.
- ⁷⁰ Kozloff et al., *Egypt’s Dazzling Sun*, 1992, p. 140.
- ⁷¹ It is also possible that the surface of the kneeling figure in [Fig. 19b](#) was prepared in a particular manner to help secure a preparation layer and paint, though no traces of either were observed.
- ⁷² Sist, *Museo Barracco*, 1996, pp. 38–42. Sist states that this work is certainly not the product of a provincial workshop, but rather made in an environment more exposed to the artistic tendencies of the royal court, noting its refined execution, sense of balance and harmony between the different forms, and attention to geometry.
- ⁷³ Kozloff et al., *Egypt’s Dazzling Sun*, 1992, p. 137.
- ⁷⁴ Wootton et al., “[Stoneworking Tools and Toolmarks](#)”, 2013.
- ⁷⁵ Adam, *The Techniques of Greek Sculpture*, 1966, pp. 8–11.
- ⁷⁶ Note that often statues labeled as dolerite by Egyptologists are actually made from basalt. See Aston et al. in Nicholson and Shaw (eds.), *Ancient Egyptian Materials and Technology*, 2000, p. 23; De Putter and Karlshausen, pp. 49–57.
- ⁷⁷ This argument stands to benefit greatly from a highly accurate geometric study of the shapes of these fine lines, perhaps with high resolution scanning, photogrammetry or confocal microscopy.
- ⁷⁸ There is some archaeological evidence of the use of copper alloy rasps and files in Greece in the middle of the 2nd millennium (see note in Blackwell, *AJA* 118/3 [July 2014], p. 453), so presumably once iron

was readily available these tools would have been produced in iron.

⁷⁹ Gagarin and Fantham, *The Oxford Encyclopedia of Ancient Greece and Rome*, 2010, p. 30.

⁸⁰ This observation is made by Sheila Adam in reference to Archaic Greek sculpture, but it can almost certainly also be applied to sculpture produced at the same time in Egypt. Adam, *The Technique of Greek Sculpture in the Archaic and Classical Periods*, 1966, p. 9.

⁸¹ Wootton et al. citing: Hirt, *Imperial Mines and Quarries in the Roman World*, 2010, p. 211.

⁸² See: Harrell, Gemstones, 2012; Gwinnett and Gorelick, *Expedition* 22, 1979; Sax and Meeks, *Archaeometry* 37/1, 1995; and Stocks, *Experiments in Egyptian Archaeology*, 2003.

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