STONE BUILDING AS MATERIAL AND METAPHOR
IN SOUTHERN EUROPE (1050–1300)

THE MEDIEVAL COUNTRYSIDE

VOLUME 28

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VOLUME 4

Stone Building as Material and Metaphor in Southern Europe (1050–1300)

Edited by
THERESE MARTIN

BREPOLS

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Cover image: Detail of cloister capital, masons shaping blocks of stone; full view shows a bishop overseeing the works. Girona Cathedral, west gallery, *c.* 1170–1190. Photo: Federico Del Tredici.

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Petrified Power

An Initial Report on the Use of Hard-Stone Roman Spolia *in Norman Sicily (Twelfth–Thirteenth Centuries)*

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Introduction

In 1130, Roger II was proclaimed king of the newly formed kingdom of Sicily, and the decade of the 1140s were clearly the apex of his reign, which lasted until his death in 1154. Completely re-organizing his kingdom under his sole authority, the king launched a counter-propaganda campaign against Pope Innocent II (r. 1130–1143) that aimed at establishing his figure as a Christian ruler with sovereign power over both the Church and the State. As part of this political propaganda, King Roger II sponsored a lavish decorative programme in the main religious and secular buildings of his kingdom,[1] which showcased extensive use of Roman hard-stone *spolia*, especially red porphyry,[2] imported from Rome.[3] This was one of the largest and most ambitious projects of a systematic reuse of Roman *spolia* in the medieval world.

The use of red porphyry, also called Imperial or Egyptian porphyry, was of prominent and extraordinary importance among the general reuse of *spolia*. First, porphyry was extremely rare, one of the most expensive and highly prized stones in the Imperial Roman world. The stone came from a single source, the quarries at Jabal Abu Dukhan, in the eastern Egyptian desert.[4] Furthermore, the mining of this stone was limited to the first three centuries of the Common Era; already by the beginning of the fourth century it was virtually unobtainable.[5] The stone was also highly valued for its symbolic associations with the emperors of ancient Rome and Byzantium.[6] Red porphyry is an igneous stone, which is exceptionally hard (Mohs 7)[7] and therefore especially difficult to carve. The sum of these specific characteristics made porphyry the stone of choice for showcasing the wealth and political power of the Norman dynasty in Sicily.

Hard-stone *spolia* was used in newly made artefacts requiring various degrees of transformation of the original blocks. A large number of porphyry items, especially column shafts, were sliced, cut, and polished to create new two-dimensional decorations, such as rectangular or rounded slabs, and series of thin veneers for marble inlay (*opus sectile*), employed to create pavements

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1 On the relationships between artistic patronage and political propaganda, see Bongianino, 'The King, His Chapel, His Church'. See also Tronzo, *The Cultures of His Kingdom*; Longo, *Lo scrigno di re Ruggero*.

2 Besides red porphyry, they mainly used *spolia* of *lapis lacedaemonius* (commonly known as 'green porphyry', originally from the quarries at Krokees in the Peloponnese), and granite.

3 Bacile, 'A Porphyry Workshop'. See also Müller, 'Black Box in Red'.

4 Maxfield and Peacock, *The Roman Imperial Quarries*.

5 Corcoran and De Laine, 'The Unit Measurement of Marble'.

6 Delbrück, *Antike Porphyrwerke*; Reinhold, *History of Purple as a Status Symbol*; Malgouyres and Blanc-Riehl, *Porphyre. La pierre pourpre*; Hansen, *The Eloquence of Appropriation*; Greenhalgh, *Marble Past, Monumental Present*.

7 The Mohs scale is used to measure the hardness of minerals. It establishes a classification, from 1 to 10, of a series of reference minerals, depending on their ability to scratch each other. Diamond, with Mohs 10, is the hardest mineral on earth.

and to embellish walls and screens of Norman buildings. In Palermo, such decorations appeared first in the church of Santa Maria dell'Ammiraglio (known as the Martorana), founded in the first years of the 1140s, and, in the same period or immediately after, in the royal chapel of Roger II, the Cappella Palatina.[8] Porphyry and other hard stone *spolia* were also employed for the pavement in the cathedral of Palermo and later, in the cathedral of Monreale.[9] At the very apex of this extensive use of classical *spolia* are four porphyry tombs, located today in the cathedrals of Palermo and Monreale, which are believed to house the remains of the Norman and Hohenstaufen rulers (Figures 4.1a–d).[10] These exceptional monuments are characterized by relief-carved decorations and are undoubtedly among the most important and spectacular monuments commissioned by the Norman-Swabian rulers between the twelfth and thirteenth centuries.

The history of Norman sarcophagi is a tumultuous one, to say the least, and many questions on the dating and patronage of the tombs remain unsolved; in fact, it is as yet impossible to establish with any certainty which ruler was buried in which sarcophagus. The narrative traditionally starts with the decision taken by Roger II in 1145 to convert the cathedral of Cefalù into a mausoleum for himself and his successors.[11] According to the 1145 donation charter, Roger II gave two porphyry sarcophagi, one for his body, and the other — as stated by the king — was for 'the august memory of my name and the glory of the church itself'.[12]

Joseph Deér saw the adoption of porphyry *spolia* by King Roger as evidence of his rivalry with the papacy, imitating Pope Innocent II who, shortly before 1143, had appropriated as his own tomb the ancient monumental porphyry sarcophagus of the Roman Emperor Hadrian (r. 117–138). Thus, the Normans would have adopted a Roman Imperial tradition as restored by the papacy, re-converting it yet again into a secular fashion.[13]

However, the project of King Roger to be buried in Cefalù and convert the cathedral into a burial place for the rulers of Sicily failed. In 1215, Roger's grandson, the Emperor Frederick II (d. 1250), moved the sarcophagi to the cathedral of Palermo. Deér indicates that Frederick II used the tomb that

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8 Both workshops were completed *c.* 1143. See Longo, '*Opus sectile* a Palermo nel XII secolo'. For more on *opus sectile* pavements and the use of porphyry in Norman South Italy, see Longo, 'L'*opus sectile* in Sicilia'.

9 Krönig, *Il Duomo di Monreale*; Longo and Scirocco, 'Frammenti perduti e contesti recuperati'.

10 Deér, *The Dynastic Porphyry Tombs*.

11 Valenziano, 'La basilica cattedrale di Cefalù', and Gandolfo, 'Le tombe e gli arredi liturgici' assumed that the basilica would have been intended as a mausoleum only for Roger himself, but see recently Capitummino and Longo, '*Rogerius structor*'.

12 Deér, *The Dynastic Porphyry Tombs*, p. 1.

13 Deér, *The Dynastic Porphyry Tombs*, pp. 126–65. On the question of royal memory, see also in this volume Verónica Abenza, 'Plausible Patronage: Petrifying the Female Patrons Whose Memory Was Worth Perpetuating'.

was originally intended by Roger II as his own for his burial monument (Figure 4.1a); the second commemorative sarcophagus would be used for Frederick's father, Henry VI, who died in 1197 (Figure 4.1b).[14] The group of tombs in Palermo also includes a sarcophagus for the Empress Constance of Hauteville (d. 1198), daughter of Roger II and his third wife Beatrice of Rethel (d. 1154), wife of Henry VI, and mother of Frederick II (Figure 4.1c), as well as the original porphyry tomb of Roger II, arranged after his death in Palermo.[15] The monuments in this Palermo group are covered by canopies in different styles.[16] Finally, in the cathedral of Monreale is the porphyry sarcophagus that presumably holds the body of King William I (d. 1166), son of Roger II and his first wife, Elvira of León-Castile (d. 1135) (Figure 4.1d).[17]

Although there is little doubt that the tombs were made in the twelfth century, it is difficult to determine their exact dates of manufacture. The relative chronologies proposed by various scholars cannot be verified by the scarce and fragmented written evidence or the analysis of iconography alone.[18] Therefore, dating the making of the sarcophagi remains extremely problematic and, in the absence of new clear data, will not be discussed here beyond our acceptance that all were carved in the twelfth century.

The skilful carving of hard stone in the medieval period also poses a wide range of caveats, especially regarding the technology employed to work this unforgiving stone. Although the technical knowledge of how to cut and polish two-dimensional porphyry slabs and thin *opus sectile* veneers survived throughout the Middle Ages,[19] it is generally assumed that the know-how and tools necessary to sculpt high-relief items of porphyry had disappeared in the western Roman Empire after the fifth century of the Common Era, only to be 'rediscovered' during the Renaissance.[20] Yet, for the brief period from the coronation of Roger II in 1130 to the death of his grandson Frederick II in 1250, the presence in Sicily of a small group of relief-carved monuments

14 Daniele, *I regali sepolcri*; Deér, *The Dynastic Porphyry Tombs*.

15 Gandolfo, 'Le tombe e gli arredi liturgici'. The porphyry chest holding the marble sarcophagus of Roger II is not included in this article as the tomb is composed of twelve plain panels without relief-carved ornaments. However, some technical observations have been carried out on its marble supports. See below, and fig. 4.13.

16 For the canopies, see Deér, *The Dynastic Porphyry Tombs*. A comprehensive study of these lavish marble objects has yet to be done.

17 Krönig, *Il Duomo di Monreale*.

18 Deér, *The Dynastic Porphyry Tombs*, pp. 1–17, argued that the sarcophagi holding the bodies of Constance and William I were commissioned by Emperor Henry VI and made around 1195–1197. By contrast, Joachim Poeschke suggested that they could all have been manufactured in the late twelfth to early thirteenth centuries: see Poeschke, *Regum Monumenta*, pp. 19–42. A third option, proposed by Bacile, 'A Porphyry Workshop', is that all were made around the mid-twelfth century.

19 Guidobaldi and Guidobaldi, *Pavimenti marmorei di Roma*; Claussen, 'Marmo e splendore'.

20 Zobi, *Notizie storiche*, esp. pp. 87–100; Delbrück, *Antike Porphyrwerke*; Butters, *The Triumph of Vulcan*; Waters, 'Reviving Antiquity with Granite'; Longo, *Lo scrigno di re Ruggero*, pp. 206–07.

Figure 4.1. The relief-sculpted sarcophagi of a) Frederick II;
b) Henry VI; c) Constance, all in the cathedral of Palermo;
d) William I, in the cathedral of Monreale. Photos: Peter Nagy.

belies this assumption. These royal sarcophagi challenge the traditional narrative that only ancient sculptors were able to produce tools of tempered steel, supposedly the only metal hard enough to carve granite and porphyry.

In this paper, we present the initial results obtained during a first-year scoping study in 2018–2019 on the technology employed to carve the relief decorations on the Norman sarcophagi.[21] Using an interdisciplinary approach, we are able to suggest a first identification of the know-how developed, its possible origin, and how it emerged in the medieval workshops. The analysis of this medieval technology also allows us to suggest new hypotheses on the history of the sarcophagi.

Interdisciplinary Analysis of Hard-Stone Technology and Experimental Work

The Norman porphyry tombs have received considerable attention and, with the partial exception of Rosa Bacile's work, no scholar has yet attempted a systematic and scientific analysis of the stones and the techniques of their manufacture.[22]

It is challenging to identify the equipment and techniques employed in this industry due to the absence of archaeological evidence for workshops or tools. Therefore, we have employed an interdisciplinary method, which draws largely upon the one we developed during our previous research on lapidary industries.[23] The basic premise of this approach is that each operation in the chain of production (sawing, hammering, chiselling, drilling, polishing, etc.) leaves macro- and micro-traces on the surface of a given object, which are specific to the tools employed and the way in which the workers handled and

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21 The main objectives of this preliminary study were to design and test our method of investigation and develop a project on the use of porphyry in Norman Sicily. This project, funded by the *Gerda Henkel Stiftung* and the *John Fell Fund*, was based at the Khalili Research Centre (University of Oxford). Also at the Khalili Research Centre, Peter Nagy is owed a debt of profound gratitude for his tremendous help during the field studies, particularly for his high-quality photographs of the monuments. For supporting this project, we would also like to thank the Prefettura di Palermo, Ufficio Territoriale del Governo, Patrimonio del Fondo Edifici Culto; Soprintendenza Beni Culturali e Ambientali di Palermo; Arcidiocesi di Palermo, Ufficio Beni Culturali; Arcidiocesi di Monreale, Parrocchia Santa Maria Nuova; Soprintendenza Speciale di Roma, Archeologia Belle Arti Paesaggio; Ministero per i beni e le attività culturali e per il turismo, in particular Parco Archeologico del Colosseo; Galleria Borghese; Musei Vaticani; Louvre Museum; Ministry of Culture and Tourism of Turkey General Direction of Cultural Heritage and Museums.

22 Gandolfo, 'Le tombe e gli arredi liturgici'; Gandolfo, 'Il porfido'; Herklotz, 'Lo spazio della morte', pp. 320–26; Bassan, 'Federico II e le sepolture'; Andaloro and others, eds, *Il Sarcofago dell'Imperator*; Bacile, 'The "Dynastic Mausolea"', and 'A Porphyry Workshop'; Poeschke, *Regum Monumenta*.

23 Morero, *Méthodes d'analyse des techniques lapidaires*; Morero, 'The Digital Microscope'; Morero and others, 'Relief-Carving on Medieval Islamic Glass'.

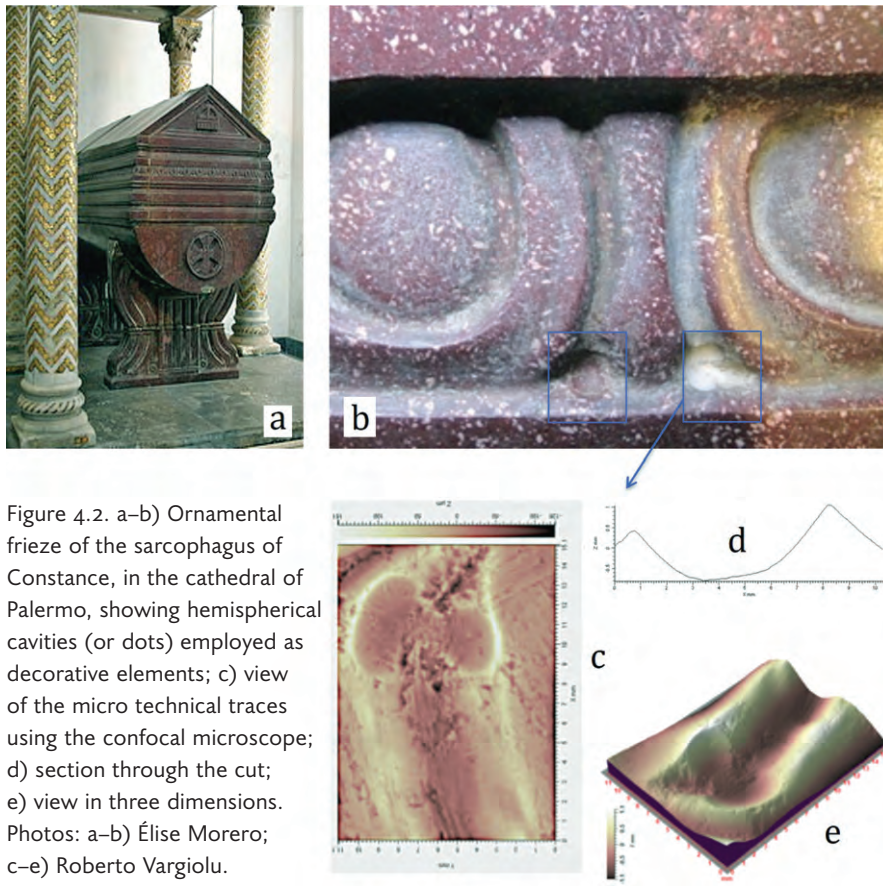

Figure 4.2. a–b) Ornamental frieze of the sarcophagus of Constance, in the cathedral of Palermo, showing hemispherical cavities (or dots) employed as decorative elements; c) view of the micro technical traces using the confocal microscope; d) section through the cut; e) view in three dimensions. Photos: a–b) Élise Morero; c–e) Roberto Vargiolu.

applied them to the stone.[24] On the porphyry sarcophagi, these tool traces were examined at different scales of observation, first *in situ* at low magnification (generally ×30–50), with a digital microscope (Dino-Lite). We then analysed small silicon casts[25] of the surfaces, bearing tool traces, at a higher magnification in the Laboratory of Tribology and Systems Dynamics (LTDS) of the École Centrale of Lyon (France), using both a confocal microscope and a handheld scanner.[26] This method allowed us to obtain precise measurements along with detailed two- and three-dimensional pictures of the morphology of the traces and micro-traces (Figures 4.2a–e).

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24 For example striations, pits, holes, chipping, surface polishes, etc., which appear with specific size, depth, and density over the surface.

25 We employed a low viscosity silicon solution (SILFLO).

26 On the method of analysis in the LTDS, see also Morero, *Méthodes d'analyse des techniques lapidaires*; Morero, 'The Digital Microscope'.

Data from archaeological studies of ancient Egypt and ethno-archaeological studies of non-automatized, or 'traditional', workshops, mostly linked to the working of granite and other hard stones in India, also represented an essential source of information for us.[27] Furthermore, we analysed 524 objects made of porphyry or *lapis lacedaemonius*, dating from the second to the sixteenth–eighteenth centuries, in order to compare data on the technologies developed at different periods to work porphyry and potentially identify the preservation and/or transfer of processes.[28]

The data obtained through this approach enabled us to generate hypotheses regarding the tools and techniques employed for the carving of the porphyry sarcophagi, which required subsequent testing and experimental reproduction. At this early stage of our research only some of these technical hypotheses could be tested, and the rest will be completed in the next phases of our study. Therefore, we decided to focus this initial phase on the investigation of two processes related to the carving of the relief decorations of the sarcophagi: 1) hammering techniques, with points, employed in the removal of limited portions of material, and 2) drilling techniques.

To date, it had been generally believed that hard stones like porphyry (Mohs 7) could only have been carved using hardened steel points (Mohs 7–8)[29] and that the knowledge required for manufacturing such tools had been lost from the Latin west in Late Antiquity.[30]

In general, the tools used in abrasion processes, especially saws or drills, were made of soft metals, such as iron (Mohs 4). Indeed, sawing or drilling operations implied the addition of hard abrasive sands (e.g., crushed emery or corundum, Mohs 8–9) and water.[31] However, the tools involved in hammering processes need to be stronger and made of harder materials. Therefore, for

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27 Procopiou, 'Techniques, sens et émotions'; Procopiou and others, 'Tactile and Visual Perception'. See also Kalter, *The Arts and Crafts*; Murari and others, *Madras: Handicrafts and Artisans*.

28 For the Roman and late Antique periods the sculpted items on which we especially focused were statues, busts, urns, and sarcophagi in the Roman Forum in Rome, the Louvre Museum in Paris, and the Archaeological Museum of Istanbul. Particular attention was paid to the study of sarcophagi, including those of Helena and Constantina (Musei Vaticani), the possible fragment of the tomb of Constantine the Great, and four monuments in Istanbul made for Byzantine emperors. In addition we studied a group of statues, busts, vases, and other items made or modified in the sixteenth to eighteenth centuries in France and Italy held by the Louvre and the Gallery Borghese in Rome. Regarding the sample of two-dimensional works, we studied the slabs and *opus sectile* pieces in the Cappella Palatina and the Martorana in Palermo.

29 The measurements of a metal's hardness using the Mohs scale are estimates.

30 For the production of hardened steel tools in Roman Antiquity, see for example Lang, 'Roman Iron and Steel'.

31 Our previous research on hard stones revealed that soft metals enable the particles to become embedded in the surface of the tool, thus improving the efficiency of the drilling or cutting operations. It is the abrasive sand that actually cuts the stone, and the metal tool that acts essentially as a vector to carry the abrasive particles. See Morero, *Méthodes d'analyse des techniques lapidaires*.

Steel points				Hardened steel points			
No.	Alloy	Points after hammering	Groove made in the block	No.	Alloy	Points after hammering	Groove made in the block
1	I			4	I		
2	II			5	II		
3	III			6	III		

Figure 4.3. Hammering tests with the experimental points. Photos: Élise Morero.

this preliminary series of tests, it seemed appropriate to start with steel, an alloy constituted of iron and 0.2 to 1.5–2% of carbon. The hardness, but also stiffness and brittleness, of the metal increase according to the quantity of carbon found in the alloy and the amount of other elements that can occur naturally in the iron ore. Thus, depending on its composition, unquenched steel (about Mohs 4–5) can be a little harder than pure iron.

It appears that the production of really good quality steel was re-established in Europe towards the end of the twelfth century or beginning of the thirteenth. Nevertheless, steel seems to have been employed at least in some areas of Europe, and in the Islamic world, during the twelfth century.[32] Thus, we decided that our preliminary series of tests should aim to determine if points made in unquenched steel could be employed to carve porphyry.[33] To this end, we

32 For Europe see, for instance, Theophilus on the manufacture of steel files: Dodwell, *Theophilus, De Diversis Artibus*, III. 17–20, pp. 72–73; Gearhart, *Theophilus and the Theory and Practice*. For the Islamic world, see Hoyland and Gilmour, *Medieval Swords and Swordmaking*.

33 Tests carried out by Denys Stocks on granite indicated that flint chisels may have been employed to sculpt granite in Ancient Egypt; see Stocks, *Experiments in Egyptian Archaeology*, pp. 74–99. Following this data, and with the help of Frédéric Abbes (CNRS, Archéorient – UMR 5133), we tested the ability of a flint chisel, hammered with a wooden mallet, in carving of red porphyry. The process is very long and the active part of the chisel is quickly damaged, yet we were able to make a groove in the stone. However, it seems

commissioned two blacksmiths to manufacture six points in a traditional forge in the Deux-Sèvres (France).[34]

The tools were made using three different steel alloys containing different levels of carbon, all rather low. Alloy I has almost no carbon (inferior to 0.02%) in its composition, consequently its nature is almost the same as iron (est. Mohs 4). Alloy II is stronger, with 0.24% of carbon and 0.6% of silica. Alloy III is the hardest, containing 0.35% of carbon, plus 0.1–3% of silica and 0.4–1.2% of manganese. Three tools, one from each group of alloy, were employed as steel points (Figure 4.3, nos 1–3). The latter are relatively soft (all est. inferior to Mohs 5). Three others points of each set were subsequently quenched to make hardened steel, ranging between Mohs 6–8 (Figure 4.3, nos 4–6). We employed the six steel points with a mallet in metal to carve a shallow groove on the surface of a red porphyry block. As expected, the three steel points (Figure 4.3, nos 1–3) could not be employed for longer than a few minutes before their ends became too worn to work efficiently. We had to employ the three tools successively on the same area to be able to create a shallow groove on the stone, a task we carried out very quickly using only the stronger point in hardened steel (no. 6). Indeed, the latter specimen was the most resistant to the percussion, and the active part of the tool remained unaltered after more than ten minutes of hammering.

These results were well within expectations, but they do not exclude the possibility of the use of steel points for carving a limited quantity of porphyry, such as that required for sculpting the ornaments in relief. The process is feasible although extremely time consuming and fastidious, indicating that the use of steel tools in the medieval period would have required a specific organization of the workshops. As we saw, the points grew dull very quickly and the sculptors would have needed easy access to a forge that repeatedly re-sharpened their tools, ready to be used again and again. In the Middle Ages, workshops were organized in just this way on large building sites. Thus, the presence of blacksmiths and a forge next to the stonemasons, working together, must have been well-established practice for multiple tasks, including the repair of stonemasons' tools.[35] In the present-day region of Mahabalipuram (Tamil Nadu, India), there are a large number of workshops producing sculptures in granite. To carve this hard stone, the stonemasons employ a series of steel points they themselves produced (Figure 4.4).[36] These tools have to be reshaped relatively frequently at the forge, and it seems that repeating this process makes the tools gradually harder and harder.

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probable that the Siculo-Norman sculptors used metal points. Unlike flint tools, metal tools can be reshaped and recycled indefinitely, which probably made them a preferable medium.

34 Our thanks are owed to Jérémie Vosges and Xavier Rivault, specialists in experimental archaeology and ancient metallurgy, who made the experimental tools.

35 Aubert, 'La construction au Moyen Âge'.

36 Procopiou, 'Techniques, sens et emotions', pp. 44–48.

Figure 4.4. Hammering of a granite block with a steel point in Mahabalipuram, India. Photo: Haris Procopiou.

With regards to the drill bits used to make the shallow hemispherical cavities (D. 0.5–0.8 cm), observed especially in the decoration of the sarcophagi of Constance and Frederick II (see Figure 4.2), we had no doubt that the drill bits were made of a soft metal such as iron.[37] However, we still needed to identify the shape of the tool. We therefore employed a bow-drill to run solid drill bits made of the softer alloy (I) together with a mix of hard abrasive sand (made of crushed corundum) and water.[38] We selected a drill bit with a rounded convex extremity (drill 1) and a second with a flat end (drill 2), both with a diameter of 0.5 cm. The results obtained indicated that the most efficient method was to use the flat end tool (drill 2). Indeed, to start grinding down the surface of porphyry, the drill bit has to present a surface large enough to keep the maximum of corundum grains in contact with the porphyry surface. Unlike the convex end of drill 1, at the beginning of the process, drill 2 creates a flat bottom cavity allowing the necessary contact. The relatively soft metal is rapidly worn so that the end becomes quickly conical with a convex end, giving the hole a hemispherical morphology such as the one observed for the decoration of the Norman sarcophagi and the architectural elements of their canopies. Drilling a dot of about two millimetres in depth with drill 2 took about thirty to forty-five minutes. However, the craftsmen who made these sarcophagi were certainly more experienced than us, and it would have taken them less time. Moreover, the observation of some specific and repetitive

37 Morero, *Méthodes d'analyse des techniques lapidaires*, pp. 64–98.

38 In the medieval period, the sculptors could have employed various types of drilling tools, such as strap or pump drills, already used in Roman Antiquity. See Bessac, *L'outillage traditionnel*, esp. p. 246, with bibliography; for Roman Antiquity, see Wootton and others, *The Art of Making in Antiquity*; Russell, *The Economics*, esp. pp. 92–93, fig. 7.20.

minor variations in the execution of the frieze decorating the sarcophagus of Frederick II suggests that several carvers might have worked simultaneously on one item. We can thus imagine two stonemasons executing the drilling operations, side-by-side, on the same part of the monument, while two others were performing the same task on the other side of the sarcophagi. Such an arrangement would reduce the still considerable amount of time needed to sculpt the ornamentation.

Recreation of the Manufacturing Techniques

During this first phase of investigation, we focused on the identification of the techniques employed in the sculpting of the decoration on the sarcophagi. Although many aspects remain unknown about the tools and the know-how involved in preliminary operations of roughing out, shaping, and hollowing out the tombs, nevertheless, we can suggest some preliminary observations regarding these phases of the manufacturing sequence.

All the sarcophagi are formed by several elements cut from diverse works of *spolium*, which were assembled together to create the tombs. The number of pieces varies for each tomb. The sarcophagi of Frederick II, Henry VI, and William I are each made of four elements (lid, trough, and two supports), while Constance's tomb is made of thirteen joined parts. We can be certain that both the troughs and lids of the sarcophagi of William I, Frederick II, and Henry VI were made by reusing ancient Roman columns. With regards to Constance's tomb, only the main part of the trough can be clearly identified as a part of a column shaft. The maximum diameters of three of the troughs (1 m–1.07 m) are comparable to those of porphyry columns surviving in Rome, for example, the sections of four column shafts reused in the porch of the Basilica of Maxentius, in the Roman Forum. The trough of the sarcophagus of Henry VI is wider (1.11 m), suggesting that it was made from a column of very large size but well within the attested range, such as the columns of Aswan granite in front of the Pantheon (1.51 m).[39] The shape and size of the sarcophagi, but also the fact that the tomb's covers do not systematically fit the top of the troughs, especially in the case of William I's tomb, suggest that each part was made from different column shafts.

Very little evidence has survived to document the early part of the manufacturing process of the sarcophagi. However, our preliminary examination in the Cappella Palatina and the Martorana of the hard-stone slabs and *opus sectile* pieces suggests that the same basic processes and tools were employed for the cutting and rough shaping of the flat parts of the Norman tombs, especially their lids. Indeed, both red and green porphyry slabs seem generally to have been worked using an elementary technology, mainly based

39 See also Bacile, 'The "Dynastic Mausolea"', and 'A Porphyry Workshop'.

on abrasion processes, which involved sawing and different degrees of abrasion of the surfaces (from rough smoothing to polishing). Our analysis of the tool traces still preserved on some of the slabs indicates that the first cutting operation of the original *spolium* was performed using metallic toothless saws, employed as a vector to carry strong abrasive sands such as crushed emery or corundum. Water was continuously added during the operation. The repeated passages of these abrasive particles during the sawing process leave striation marks in the stone surface. Such traces are especially visible on the set of seven rectangular panels decorating the apse wall in the Cappella Palatina. An examination of their main petrographic characteristics allowed us to confirm that they were all cut from the same original item.[40] It was certainly a column, sawn longitudinally, as suggested first by the slightly convex shape of the lower part of some of the panels. The irregular progression of the saw in such a very hard stone also generated an undulation of the surface, which remains visible on the finished objects. Despite the fact that the surfaces of the tomb lids of Henry VI, Constance, and William I have been very well polished so that most of the tool traces were erased, the different flat parts composing these lids undulate slightly, just like the slabs in the Cappella Palatina, suggesting that the exact same tools and processes were employed to cut and then shape these straight surfaces.

However, for shaping the curved parts of the monuments, such as their troughs, another method was needed. The stonemasons tried to keep the work of transforming the half-column shaft to a minimum. Indeed, the circumference of the original column had to be reduced in order to leave bands of material protruding off the surface, in which the relief decoration would subsequently be carved. Similarly, the craftsmen had to keep thicker areas for creating the four stoppers on the sides of the troughs, under which the end of the supports would be placed. The removing of material, in the appropriate areas, did not leave clear tool marks. However, several irregularities and deep pits appear, which might suggest that the hammering operations were carried out using a succession of tools of decreasing size, so that the portions of rock removed from the block surface would also diminish successively. We have not yet been able to identify the exact tools employed for such an extended hammering sequence. The use of a series of very thick steel points, with a large end, whose wear would be slower, can possibly be considered for the part of the removals that did not require great precision. But the hypothetical use of such tools suggests also that a preliminary phase to prepare the surface of the stone was probably required, such as through a superficial controlled thermal shock. The workers could have employed fire to weaken the surface of the hard stone and facilitate the detachment of

40 It has been possible to link separate items, cut from the same block of porphyry, by comparing specific petrographic macro-details of the stone, such as the veins, the repartition, shape, size, colour, and orientation of the phenocrysts, and the texture of the matrix.

Figure 4.5. Blocks of porphyry with cavities drilled using a tubular drill (cathedral of Monreale). Photo: Élise Morero.

Figure 4.6. Hammering traces. Photo: Élise Morero.

superficial lumps of material, using steel tools. This method, known by the ancient Egyptians to quarry and rough out granite items, is still employed today in the working of granite in Madagascar.[41] Nevertheless, other possible tools, such as hammers of decreasing sizes, made of stones harder than porphyry (e.g., emery is Mohs 8), must also be considered.[42] In much the same way as the hammering sequence, the surface was next roughly regularized by a succession of abrasion and smoothing operations executed with rubbers and abrasive sands of decreasing coarseness and hardness.

Using this operating mode, the craftsmen did not create a surface with a constant diameter. Indeed, at the approach of the underside of the trough, the topography of the surface changes progressively and the diameter becomes slightly larger. This part being hidden from sight, the workers stopped progressively removing the unwanted material.

In his work on the manufacturing processes employed in ancient Egypt to make sarcophagi in granite, Denys Stocks indicated that the sequence of hollowing out of the trough starts with the execution of a series of tubular drillings next to each other, with abrasive sands and water, to remove the main part of the unwanted material.[43] Next, the cavity was expanded and regularized using hammering techniques. Our examination in the museum of Istanbul of four sarcophagi belonging to Byzantine emperors seems to suggest the use of a very similar procedure. And in Sicily, there is no doubt that the workshops made use of the tubular drill to work porphyry. The specific annular groove left by the end of this tool was observed in a series of items, for instance, a group of octagonal slabs, cut from the same original *spolium*, in the Cappella Palatina and the Martorana. But the most obvious evidence of its use in Norman Sicily is the presence of the characteristic cylindrical cavities bearing annular striations that appear in fragments of capitals preserved in deposits at Monreale Cathedral (Figure 4.5). The use of tubular drilling, as a first step for the hollowing-out sequence of the hard-stone sarcophagi, seems the most likely hypothesis. However, the only way to confirm this would be by direct observation of the interior of the tombs, which is not possible at present.

Unlike the first phases of shaping and hollowing out of the sarcophagi, the carving of their decoration is better documented by the tool traces. The stonemasons carved the relief decoration into the protruding designated areas on the exterior surface. The same tools and processes were employed on all the sarcophagi: limited percussion, using points (Figure 4.6), but above all tools involving abrasion processes such as saws, drills of various type including tubular and solid drill bits, files, and rubbers, all probably in

41 For the use of this technique in Madagascar, see Paillet, 'L'extraction et la taille'; for ancient Egypt, see Burgos, 'Les techniques de mise en oeuvre'.

42 Hard-stone hammers were employed in ancient Egypt. See examples in Engelbach, *The Aswân Obelisk*; Goyon, *Le secret des bâtisseur*, pp. 112–13.

43 Stocks, 'Stone Sarcophagus Manufacture'.

Figure 4.7. Traces left by the use of a solid drill bit employed for the carving of the decoration on Frederick II's tomb. Photos: Élise Morero.

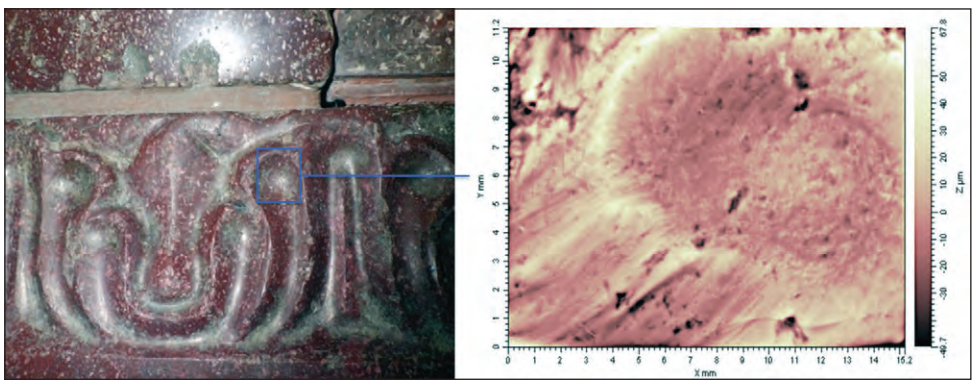

Figure 4.8. Traces left by the use of a solid drill bit employed for the carving of the decoration on Frederick II's tomb. Photos: Élise Morero.

iron or steel. Indeed, given that the sculptors were using hammering tools likely made of soft unquenched steel, it is to be expected that they would have focused a large part of the fine carving process toward a technology based on the use of abrasive sands made from stones harder than porphyry (as noted, emery or corundum).

However, variations in the carving approach can be observed, which informed us about the organization of the tombs' production. It is clear that several stonemasons, probably divided in two teams, were responsible for the execution of these monuments. Although both teams employed the same basic tool kits and techniques, each group of workers seems to have privileged different sets of tools and processes. Therefore, we were able to identify each team's responsibility for the carving of two sarcophagi. The tombs of Constance and Frederick II form the first pair, as they present technical similarities. The execution of their decoration is characterized by a significantly greater use of the solid drill bit, both to carve the relief ornaments (Figure 4.7) and to create motifs such as the series of small hemispherical cavities, especially visible on the friezes (Figure 4.8). By contrast, the decorations created by the team responsible for the second pair, composed of the sarcophagi of William I and Henry VI, were essentially executed by saws, files, and rubbers, showing little use of the solid drill bits in the carving of the decoration (Figures 4.9a–b).

At the end of the process, the workers executed a series of abrasion and polishing operations to smooth the surfaces and erase the tool marks generated by the successive operations of shaping. Traditionally, stonemasons employed for this a series of abrasive sands or blocks of stone of successively decreasing hardness and coarseness. The process of abrasion necessary to achieve a high-quality polish on such hard stone was certainly long and time consuming. To reinforce the impression of uniformity and smoothness of porphyry items, at the very end of the manufacturing process, the craftsmen rubbed the surface with a fatty substance. This operation produced a darker and shiny surface, giving an illusion of homogeneity despite the presence of tool traces (mainly striations).[44] Here beeswax and oil were the main substances used to coat the surfaces of the sarcophagi, as indicated by our analyses performed on the layers of materials using a portable XRF.[45] Although successive coating operations could have been executed, perhaps even very recently in order to restore the surface shine, it is quite possible that the same task was carried out in the twelfth century.

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44 Such techniques were still employed in the twentieth century in lapidary workshops in Egypt and Iran. See Hester and Heizer, *Making Stone Vases*, p. 20; Wulff, *The Traditional Crafts*, p. 133.

45 We wish to express our gratitude to Renato Giarrusso (†), Angelo Mulone, and all the staff of the Geolab s.r.l. Palermo for their support and availability in carrying out these analyses.

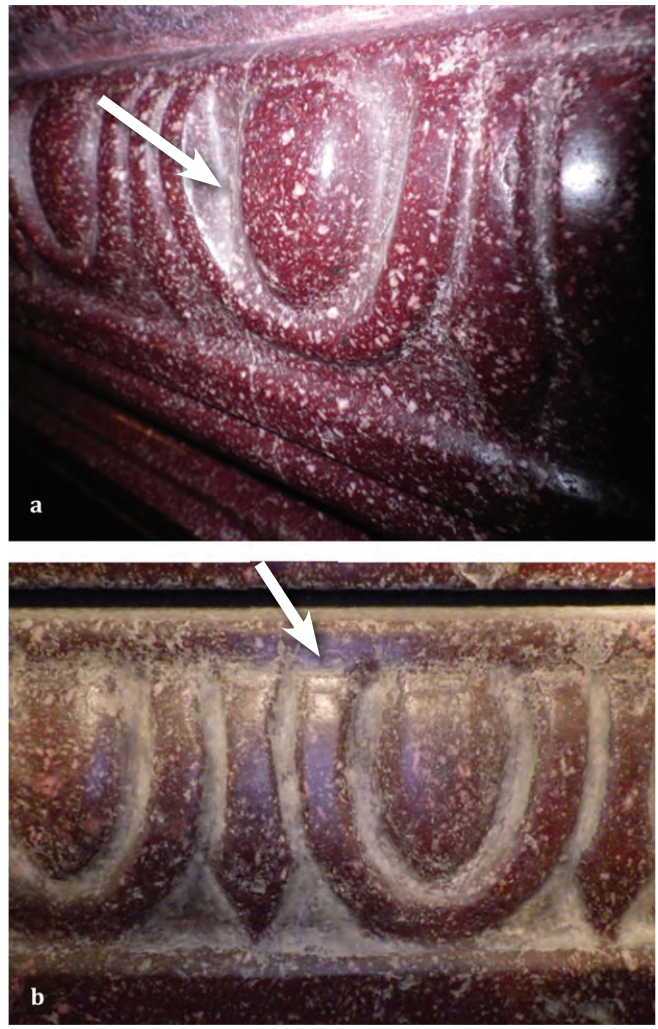

Figure 4.9. Sawing and filing traces on the sarcophagi of a) William I and b) Henry VI. Photos: Élise Morero.

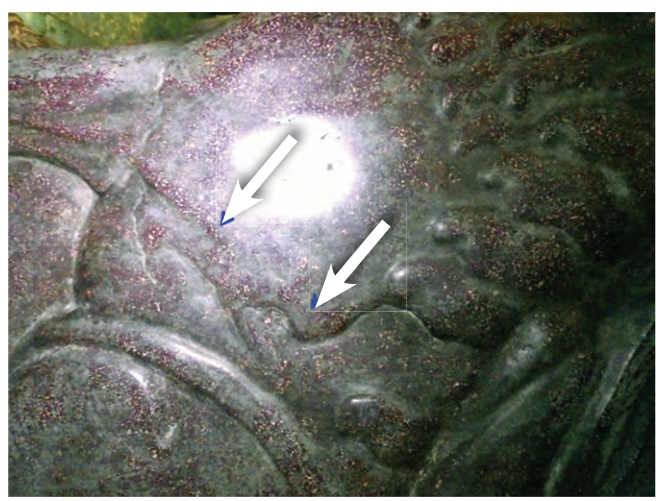

Figure 4.10. Breakage that happened during the carving of Frederick II's tomb. Photo: Élise Morero.

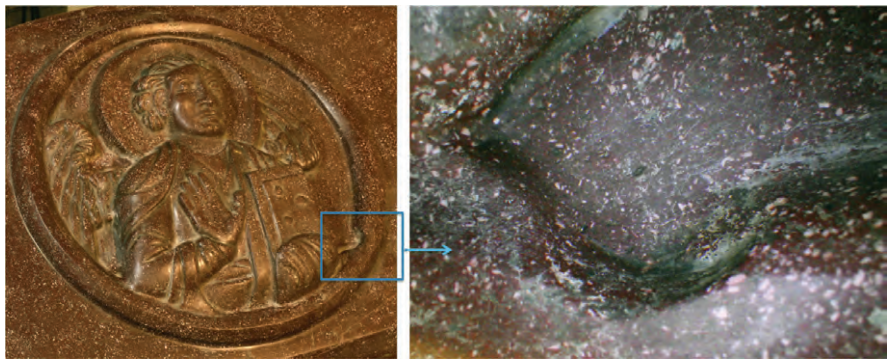

Figure 4.11. Cavity accidentally (?) produced with a tubular drill during the carving of Frederick II's tomb. Photos: Élise Morero.

Re-Examination of the Porphyry Sarcophagi's History through New Technical Data

The generally accepted narrative for the tombs is that the sarcophagus originally made for Roger II now holds the remains of Frederick II, while the second 'memorial sarcophagus', given by Roger to Cefalù, holds the remains of Henry VI.[46] However, our division of the sarcophagi into two technical groups — 1) the tombs of Constance and Frederick II, and 2) the monuments of Henry VI and William I — gives evidence that a different narrative is needed. Besides the technical specificities, common to the decoration of the sarcophagi of Frederick II and of his mother Constance, there are what appear to be traces of experiments in the carving techniques on the two monuments. Such trial-and-error progression is especially visible on the supports of Frederick II's tomb. In addition to the series of minor mistakes, such as the wrong position of small drilled cavities, there are damaged areas visible on the south face of the southern support. In fact, we identified a large break that happened during the work (Figure 4.10). It is possible that this breakage was an accident due to weaknesses in the stone structure. Stone carvers, skilled or not, cannot always predict the existence of such flaws. However, the traces of hammering we observed on the damaged area of the sarcophagus seem to suggest that this particular stonemason was not experienced enough to solve the issue. He tried unsuccessfully to hide the mutilation by a rather crude re-carving operation.

Although especially well achieved, another type of problem appeared during the carving of the lid. It seems that a stoneworker employed the tubular drill for removing part of the unwanted material and started to rough out the contours of the medallions in relief. However, the artisan appears to have drilled in the wrong place and accidentally removed part of the protruding rim of the future medallion (Figure 4.11). We cannot entirely exclude that

46 Deér, *The Dynastic Porphyry Tombs*, pp. 70–71.

this hole was what remained of a cavity that had already been present in the original Roman column; however, an experienced carver, confronted by such an issue, would surely have arranged the positioning of the decoration to disguise this inconvenient hole, so it would not interrupt the relief medallion.

On the sarcophagus of Constance, the creation of the relief for the eagle, on the south side of her tomb, seems also to have caused problems for the sculptor. Indeed, on all the sarcophagi, the motifs appear in relief protruding from the surface. But on Constance's tomb, the eagle was mainly dug at the same level as the surface of the trough. This specificity suggests that the craftsman did not manage to leave a layer of material thick enough to sculpt the motif in high relief. Consequently, the artisan had to dig into the surface around the motif. This series of problems on the sarcophagi of Frederick II and Constance might suggest that the craftsmen were still experimenting, trying to develop and adapt the technology to sculpt porphyry. By contrast, the relief decorations carved on the tombs of William I and Henry VI do not present signs of such trial-and-error progression. On this pair of sarcophagi, the work seems to have been done without serious difficulties. Although the work would have been facilitated by the fact that the designs of these monuments are simpler, we also suggest that they were made soon after the sarcophagi of Constance and Frederick II, when the carvers had already sufficient training.

Therefore, we propose that the sarcophagi today of Frederick II and his mother were made first. Furthermore, the fragile and precarious structure of Constance's tomb, compared to the massive configuration of Frederick II's monument, suggests that the latter was originally made for Roger II. Moreover, despite Deér's conclusions, we hold that the tomb of Constance, not that of Henry VI, would have been the second sarcophagus made for Roger II's memory and originally given to the church of Cefalù. The workshop seems to have employed as a priority the massive porphyry blocks to make the sarcophagus intended for Roger II, and then used what was left of this shipment of *spolia* to create the second memorial sarcophagus. Indeed, to make Constance's tomb, the craftsmen added a series of eight thin plaques vertically, on the top of the short trough, to give it additional height. This arrangement seems rather weak for a proper funerary monument and it is possible that, in accordance with Roger's request, this sarcophagus was originally not a true tomb but a cenotaph in monument to his memory.

The Origin of the Technology Employed

Thus, the study of these carving techniques has allowed us to tentatively identify how hard-stone carving technology emerged in medieval Sicily following centuries of absence in both western and eastern worlds. We began with several initial hypotheses. The first was the preservation and transmission of Roman technology. Therefore, we compared the traces of carving on porphyry items attributed to Imperial Rome and Late Antiquity

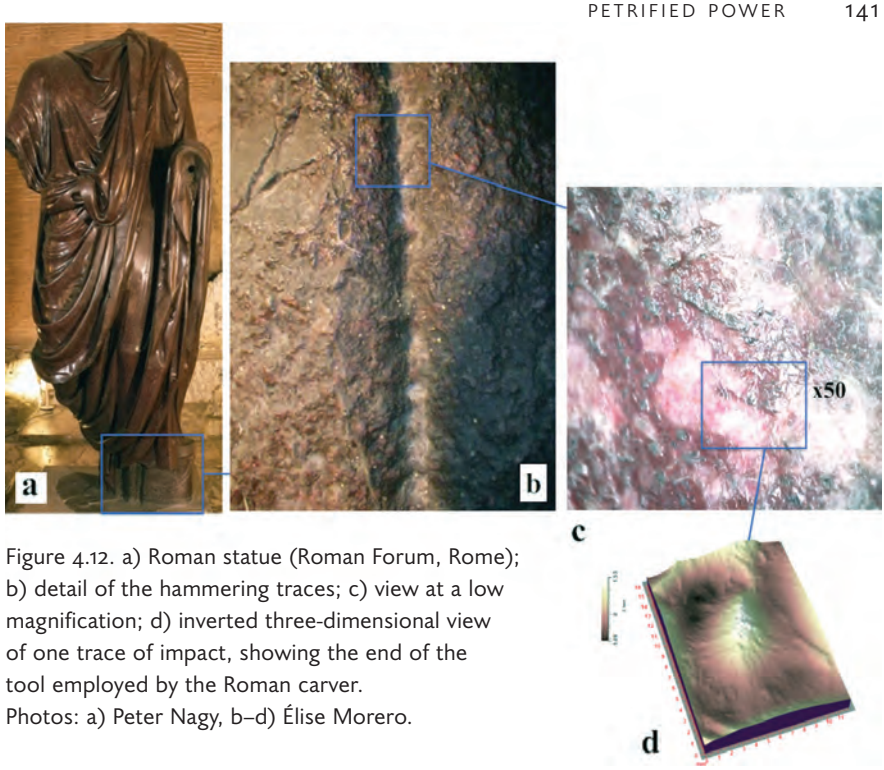

Figure 4.12. a) Roman statue (Roman Forum, Rome); b) detail of the hammering traces; c) view at a low magnification; d) inverted three-dimensional view of one trace of impact, showing the end of the tool employed by the Roman carver.
Photos: a) Peter Nagy, b–d) Élise Morero.

or early Byzantine periods with those preserved on the Norman sarcophagi. Tellingly, the two groups of relief-carved monuments revealed the use of two different technical approaches. Roman and Late Antique stonemasons relied primarily upon points and picks (Figure 4.12a–d), while the stonemasons working in Norman Sicily made little use of percussion for the carving of the decoration; rather, the latter relied primarily on abrasive operations using a variety of tools to bring hard abrasive powders into contact with the stone. Therefore, it seems that this group of stonemasons did not inherit the technology from their Roman and Late Antique predecessors, which would have been somehow preserved for centuries. The absence of evidence that three-dimensional elements, or objects with relief decoration, were carved from porphyry *spolia* in twelfth-century Rome, or for that matter, in the rest of Europe and Comnenian Byzantium, seems at present to suggest that the Normans developed a technology based on other sources.

Turning to the Islamicate world, an industry of hard-stone working is attested in the region, with the production of relief-carved rock crystal vessels. It has also been suggested that the latter was then transferred to Norman Sicily at the end of the twelfth century.[47] However, it is clear that the technology and tools employed to sculpt such small-scale objects are really

47 Shalem, 'The Rock-Crystal Lionhead'.

quite different from those used to sculpt our monumental porphyry tombs. For the carving of small pieces in rock crystal, equipment that remained fixed in place was used, such as the bow-lathe with removable cutting discs and cutting wheels, while the craftsman manipulated the small stone. As it was obviously impossible to hold up the large blocks of porphyry, the carvers had to employ mobile handheld tools (drills, points, picks, saws, files, etc.) to sculpt the ornaments on the sarcophagi.[48] We can, therefore, once and for all, definitively exclude the hypothesis of a transfer of know-how from the crafting of relief-carved rock crystal objects to the workshops that made the porphyry sarcophagi of the Norman kings.

Rather, as suggested by our analysis of the carved decoration of the tombs of Constance and Frederick II, it seems that the stonemasons who sculpted the sarcophagi developed by trial-and-error a new process that drew upon two pre-existing local technologies. The first one came from the marble sculpture industry, which made the same extensive use of the solid drill bit to shape and decorate the pieces; this tool reappeared in European stonemasons' toolkit between the eleventh and thirteenth centuries.[49]

We studied the tool traces preserved on the surface of three marble monuments made in Sicily in the twelfth century: the two supports of Roger II's porphyry chest (Figures 4.13a–c) and the Paschal candleholder in the Cappella Palatina. This analysis revealed the use of operations based on abrasion (drilling, sawing, polishing, rasping, etc.) as well as hammering (percussion with chisels, etc.).[50] It seems that identical technical approaches were used to create closely related motifs on the two types of stone. For instance, the stonemasons used on both stones multiple drilling operations performed with a solid drill bit to generate grooves or large cavities.

Nevertheless, we also observed significant differences between the two industries. Some of the tools used for sculpting marble were not used on porphyry.[51] One of the reasons for such absence is the difference of hardness between the two stones. Marble presents a hardness of Mohs 3–4, while porphyry is Mohs 7. Therefore, although a diversity of hammering tools, especially different flat chisels could be employed on marble, their use was more difficult on porphyry and the equipment related to the operations of percussion seemed limited to the points with narrow ends.[52]

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48 See Morero and others, 'The Manufacturing Technique'; Morero and others, 'Relief-Carving on Medieval Islamic Glass'.

49 Bessac, *L'outillage traditionnel du tailleur de pierre*.

50 For general information on the toolkit of the marble sculptors in Roman Antiquity and the medieval period, see Claridge, 'Sulla lavorazione dei marmi bianchi'; Rockwell, 'Stone-Carving Tools'; Durnan, 'Stone Sculpture'; Cuomo, *Technology and Culture*.

51 For instance, we did not identify the use of flat chisels or rasps on porphyry, although such tools were clearly employed on marble.

52 The harder the stone, the more the proportions of the edge of the tool must be reduced. See also Bessac, *L'outillage traditionnel du tailleur de pierre*, pp. 109–15, 175–76.

Thus, as already mentioned, a large part of the porphyry-shaping process had to be realized with very hard abrasive powders, while these materials were not systematically required for marble. Consequently, another local industry played an important role in the emergence of hard-stone carving technology in Sicily. This was the manufacture of shaped and polished pieces of hard stones for the slabs and the tesserae of the *opus sectile* pavements and decorations displayed on other two-dimensional vertical elements and furnishings. This industry seems to have had a number of tools and processes in common with those employed in the workshops that made the sarcophagi, especially the saws, files, and rubbers used with abrasive sands and powders to shape and polish elements derived from hard-stone *spolia*.

Therefore, at this stage of our research, we can suggest that the technology employed to carve the Sicilian sarcophagi was mainly the result of local innovation. Part of the know-how was adapted from local marble industry, certainly in cooperation with the craftsmen involved in the production of hard-stone *opus sectile* items. It seems that works involving collaboration between the two types of industries would have been frequent in Norman Sicily, as attested by the presence of architectural ornaments achieved with marble structures and supports, inlaid with small porphyry pieces and tesserae.[53]

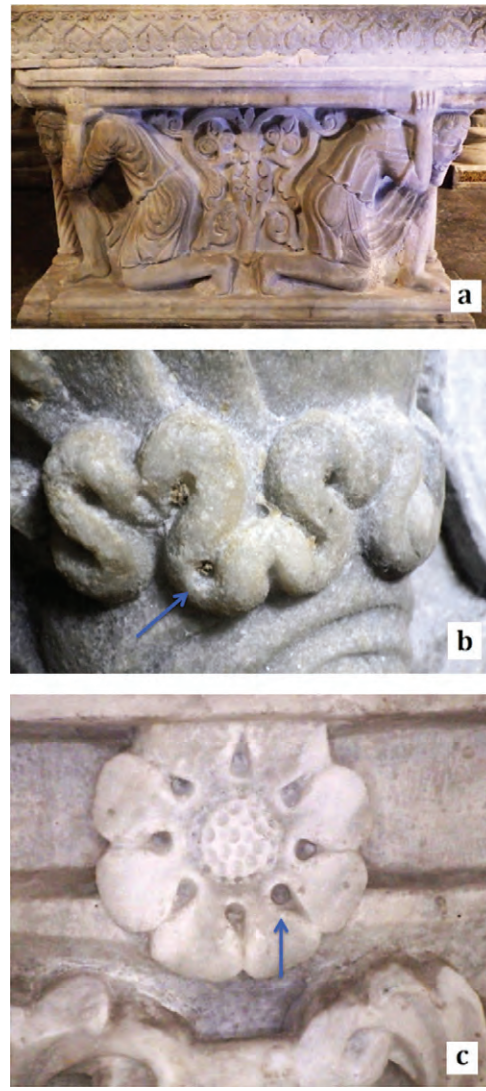

Figure 4.13. a) Southern support of Roger II's porphyry chest; b–c) details of the decoration showing cavities made with a solid drill bit. Photos: Élise Morero.

53 For example, the *opus sectile* marble panels composing liturgical furnishings, such as ambos and chancel barriers, usually framed by a sculpted frieze of acanthus leaves in the Cappella Palatina and the church of the Martorana in Palermo.

This technology, developed for carving porphyry, seems to have been both unique to the Norman kingdom of Sicily and short-lived. The early modern artefacts we examined were primarily made by percussion, almost certainly using hardened steel tools.

Preliminary Conclusions on the Supply of Porphyry and Organization of Production

Several shipments of porphyry *spolia*, essentially sent from Rome, were certainly necessary for supplying the diverse construction projects that took place in twelfth-century Palermo. It can be suggested that somewhere, probably in Rome, a real industry existed that was dedicated to dismantling Roman monuments and pre-cutting the *spolia* before selling them and exporting the stock. This behaviour is clearly demonstrated in Antiquity, with the abandonment of columns and unfinished Roman sarcophagi in the porphyry quarries of Mont Porphyrites.[54] This strategy is certainly likely for large items such as the unfinished sarcophagi, which would be lighter (and less expensive) to transport semi-empty than as a solid column shaft. Therefore, it is possible to imagine that the Norman sarcophagi might have been first pre-cut, and maybe roughed out, in Rome, near the place of supply of the material, and then finished in Sicily.

Besides the involvement of the *opus sectile* makers in the development of the carving techniques of porphyry, it can also be suggested that a link existed between the workshops for the management of the materials. Indeed, it seems obvious that every tiny portion of a material as expensive as red porphyry would have been fully used up. In much the same way as the fragile sarcophagus of Constance was partly made with the leftovers of material employed to make the sarcophagus of Frederick II, the waste materials generated during the production of these large items would have certainly been reused as smaller *opus sectile* tesserae. Therefore, it is likely that the workshops would have kept all the small un-used fragments, to be re-employed in future compositions or, perhaps, to repair future damage to the pavements. However, we observed in both the Martorana and the Cappella Palatina that, when necessary, some portions of a slab had been recut several times in order to complete its shape. It is not established yet whether these tasks were exclusively linked to recent repair works or the original realization of the pavements in the twelfth century. Assuming that such operations could happen already in the medieval period, this suggests that the stocks of porphyry would have been relatively quickly emptied.

54 Maxfield and Peacock, *The Roman Imperial Quarries*.

This initial phase of our research allowed us to establish the validity of our method of analysis, based on the study of manufacturing techniques. Although these first outcomes must be investigated further, the approach enabled us to suggest hypotheses concerning the technology employed in medieval Sicily and re-evaluate part of the history of these exceptional monuments. Thus, it seems that it was thanks to the cooperation of craftspeople, operating across different industries, that a hard-stone carving technology could be developed in medieval Sicily. Nevertheless, it cannot yet be determined whether the two teams responsible for the creation of the two pairs of sarcophagi worked side-by-side in a single workshop or two distinct workplaces, and if they were all in Palermo-Monreale. Still, the study of manufacturing techniques of porphyry in medieval Sicily has allowed us to argue that the two sarcophagi commissioned by Roger II were those today of Frederick II and his mother, with those of Henry VI and William I made soon after.

Thus, beyond the intrinsic value of the material used and the immense logistical and financial effort involved in the realization of these monumental works, the very execution of these porphyry monuments, which required the mobilization of ingenious artisans able to adapt their technical skills for sculpting a very hard stone, also constitutes striking evidence of the manifestation of power and the wealth of the Norman kings in the context of twelfth-century Europe and the Mediterranean region.