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**p089r**

Powder of Ox Bone and Rock Salt

BnF. Ms. Fr. 640, fol.89r

**Annotation**

This recipe on fol. 89r outlines a material called “sand” to be used for sand casting. Here, the author of BnF. Ms. Fr. 640 uses “sand” to designate a mixture of the powder of ox bone and rock salt. The author-practitioner suggests pulverizing and mixing the two ingredients, and then moistening them with “the moisture of the night, or the [moisture of] the cellar.” This kind of sand, according to the author, is good for casting tin or lead. Several recipes in BnF. Ms. Fr. 640 are devoted to sand casting. Most of these recipes contain a dry component and a wet component. The dry component is the “sand,” and the wet component is the binder that holds the sand together. For example, on fol. 84v, the recipe includes burnt bone of ox hoof and a thick broth of elm root. And on fol.118v, the sand is the powder of plaster, brick, and feather alum, and the wet binder is sal ammoniac, water, and wine.

Other contemporary authors also point to various materials used as sand. According to Biringuccio, sand is usually composed of powders “made of crushed brick, tripoli, vine ashes, tiles, and glazed drainpipes, or burned emerey, calcined tin, straw, and of burned paper and horse dung as well as of young ram’s-horn ashes and many other things,” and the binder is usually a “magistry of salt.”[[1]](#footnote-0) Good sand should be fine and take the metal well, and the binder should make the sand strong and hold together when the sand is dry.[[2]](#footnote-1) Based on comparison of the recipe on fol. 89r with other recipes from the same manuscript, as well as descriptions from Biringuccio, the sand detailed on fol. 89r seems unusual because of the absence of an obvious wet binder other than the mentioned “moisture.” What is the powder of ox bone, and how does one make it? Can the powder of ox bone and rock salt bind together without a liquid binder? If not, what serves as the binder? How fine must the powder be, and is (re)grinding necessary? Additionally, the author-practitioner refers to “fatty sand.” What is the meaning of this?

This annotation first introduces the two components in this recipe and their preparation methods; then it turns to analyze what serves as the binder in this recipe. It concludes with an analysis of the concept of fat and lean/dry. As will become clear, our reconstruction process gave answers to the questions raised by this seemingly implausible “sand.”

**The Making of Powder of Ox Bone**

Fol. 89r does not give any information about the composition of the powder of ox bone, but clues appear in other recipes in BnF. Ms. Fr. 640; for example, on fol. 67v, a recipe mentions the bone should be “well burnt two times and pulverized.”[[3]](#footnote-2) This informed our assumption that the powder of ox bone should be calcined and ground into bone ash.

Bone ash seems to have been a common material for sand casting. In addition to the recipe on fol. 89r, the author-practitioner also mentions the use of bone ash on fol. 67v, “Ox hooves for sand”; fol. 69r, “sand”; and fol. 84v, “Sand, for the most excellent lead of all, for large and small reliefs”. The author-practitioner seems to regard bone ash as an ideal material for casting because he claims that it enables easy removal of the cast objects from the mold. Fol. 67v states that bone ash “is the cleanest sand one can find for firing,” and in the recipe on fol. 89r, the author claimed that bone ash is an ideal sand for casting since he had “*Et nen ay point trouve qui despouille plus net que cestuy cy Il veult estre asses humide* (never found [one] which can be removed more cleanly from the mold)”, further noting that the bone ash takes fine lead and tin better than any other materials. Our experiment, as detailed in this annotation, shows that bone ash and rock salt take tin well and can be removed cleanly, while, in contrast, cast sulfur objects cannot be removed cleanly from molds made according to fol. 89r.

The source of bone ash, according to fol. 89r, should be ox hoof bone. This refers to the digital bones including proximal phalax, middle phalanx, distal phalanx (coffin bone), proximal sesamoid bones, and distal sesamoid (navicular) bone ([fig. 1](https://drive.google.com/open?id=0BwJi-u8sfkVDVnBtdnlZLXlVWW8)). Similarly, in the recipe given on fol. 67v, the author-practitioner also chose the bone of ox hoof to make bone ash. Contemporary sources point to other kinds of bone used for bone ash. Cennini mentions that bones from the second joints and the wings of fowls are good for using on panels.[[4]](#footnote-3) Biringuccio mentions ash made of young ram’s horn, leg bones of horses, donkeys, and mules.[[5]](#footnote-4) Interestingly, the author of BnF. Ms. Fr. 640 points out on fol. 69r that “[t]he human bones are the best for casting when they are calcined…[s]heep foot bones are even better than the ox foot bones.” But since the author-practitioner of BnF. Ms. Fr. 640 particularly chose ox hoof bone in two recipes concerning casting, it seems that ox hoof bone was a commonly used material for bone ash. Since ox hoof proved hard for us to obtain, we chose to use bovine hoof bone and calf leg bone for our experiment.[[6]](#footnote-5) By comparing the bone in the hoof and the leg bone, we found that the hoof bone is much denser and harder than the leg bone, so we concluded that the hoof bone was a better source of bone ash ([fig. 2](https://drive.google.com/open?id=0BwJi-u8sfkVDX054OEF3cE1IVDg) and [fig. 3](https://drive.google.com/open?id=0BwJi-u8sfkVDb0RkLTVqMEJ1QkU)).

The process for calcination is not provided in the manuscript. In recipes in which calcination is mentioned, such as on fol. 67v, the author-practitioner does not give any information about such factors as the temperature and the time needed for this process. Other recipes from the same period are similarly opaque about the process. For example, Cennini describes the production of bone ash: “put them into the fire; and when you see that they have turned whiter than ashes, draw them out, and grind them well on the porphyry.” [[7]](#footnote-6) Biringuccio mentions using a furnace to calcine the bone and then pound and sift the bone ash, but he does not provide any information about time or temperature. The absence or the simplicity of description of calcination may suggest that the knowledge about this process was common in the sixteenth and seventeenth centuries. For example, a 1678 publication of *The Royal Pharmacopœa* by Moyse Charas describes calcination as occurring with an “ordinary” fire.[[8]](#footnote-7) The wide usage of bone ash in other kinds of craft and medicine also points to the process of calcination as a common practice among artisans. Cennini mentions using burnt and pulverized bone ash for treating the panels,[[9]](#footnote-8) and Biringuccio mentions using bone ash to make crucibles, the vessels employed in the process of refining metals.[[10]](#footnote-9) Charas’s pharmacopoeia records a recipe of a styptic ointment that includes calcined bone ash as one of the ingredients.[[11]](#footnote-10)

We found that the production process of bone ash in the bone china industry served as a point of reference. Here, bones are calcined at up to 1250°C to produce commercial bone ash for bone china manufactory,[[12]](#footnote-11) with the main component of the resulting bone ash being tri-calcium phosphate in the form of hydroxyapatite Ca5(OH)(PO4)3.[[13]](#footnote-12) According to the scientists Sergio Galeano and Mari Luz Gracia-Lorenzo, at over 650°C (1202°F) the organic components are completely removed. The bones turn black at 400°C (752°F) and then turn gray between 450°C (842°F) and 600°C (1112°F). At 650°C (1202°F), the bones become white.[[14]](#footnote-13) Based on Cennini’s description about the color of bone ash, we consider 650°C as the lowest temperature for calcination.

We commenced experimentation by boiling the cow’s hoof ([fig. 4](https://drive.google.com/open?id=0BwJi-u8sfkVDbEwzczZ4U1V2RjA)) purchased from a kosher butcher shop for 104 minutes. We removed the remaining skin, cartilage, and other soft tissues from the bone using knives and brushes. Then we put the cleaned bone in the oven to dry at 200°F (93 °C) for 1.5 hours and 300°F (149 °C) for five hours. For the sake of comparison, we also prepared the leg bones in the same manner. However, the heads of the leg bones became spongy and soft after boiling, and turned gray after being dried in the oven. The hoof bone turned white and hard after being dried in the oven, and its pieces rang like porcelain when tapped. Since the hoof bone was cleaner and denser than the leg bone, we consider hoof bone—as stipulated in the manuscript—to be a better source of bone ash.

We calcined the hoof bone in an electronic ceramic kiln (Paragon Dragon kiln) ([fig. 5](https://drive.google.com/open?id=0BwJi-u8sfkVDRGFpdDI5amxlVVk)). We increased the temperature at a rate of 1100°F (593°C) per hour to 400°F (204 °C), then held the temperature at 400°F (204°C) for 30 minutes, after which we increased the temperature at a rate of 1100°F (593°C) per hour to 1500°F (816°C) and held it there for 60 minutes. At around 692 °F (367 °C), much smoke issued from the kiln, changing color from white to black, and then from black to gray and to white. At around 800°F (427°C) a gust of smoke again issued from the kiln, but by 834°F (427°C) the smoke had almost disappeared. This suggests that the organic components in the bone started to burn above 800°F. Upon opening the kiln, we found the bones had become extremely white, with only some gray parts remaining. These white bones were easy to grind in the mortar. When we ground the bone, we found some bones had a black layer inside of them, although their surface was completely white. This suggests that the bone was not completely calcined and still had some organic components. Overall, the ground bone ash felt like fine sand and was a grayish color. For comparison, we also purchased commercial bone ash. This kind of commercial bone ash is calcined using modern industrial methods; it is extremely white and fine and looks and feels like flour.

The physical characteristics of the bone ash that we made in the kiln—fine and powdery—correspond to the author-practitioner’s description of the powder of ox bone. The author pointed out that the ash of ox hoof bones is dry and crumbles if not mixed with fatty sand. On fol. 84v, the author mentions that ox hoof bone is very dry and lean and needs to be “well wet and humidified with a thick broth with elm root.” Therefore, we can deduce that the ox hoof bone ash is too dry a substance to bind together by itself.

**Rock Salt**

Rock salt is the mineral form of sodium chloride (NaCl). It is mined from mountains (major salt mines in Europe include the salt mine of Berchtesgaden in Rheinberg, southern Germany), and Biringuccio states that it is “made by Nature in the form of stone.”[[15]](#footnote-14) According to Biringuccio, Hungary was an abundant source of rock salt.[[16]](#footnote-15) Although the color of rock salt varies in each mine, the main component, sodium chloride, is the same. Because it was easily available, we chose Himalayan salt from the Khewra Salt Mine in Pakistan for our experiment ([fig 6](https://drive.google.com/open?id=0BwJi-u8sfkVDSjM2dkZ5MmFUc2c)). The chemical composition of Himalayan salt includes 95–96% sodium chloride and iron oxide, which gives the salt a pink color.

**What is the Binder?**

Folio 89r stands in contrast to other recipes for sand casting as no liquid binder or magistry[[17]](#footnote-16) is mentioned. Instead the author-practitioner instructs the reader to place the sand made from bone ash and rock salt in a sheet of paper folded in a moist napkin, and then allow the sand to dampen by means of the “moisture of the night” or “the moisture of the cellar.” On fol. 88v, the author uses a similar method to moisten sand containing rock salt. Here we can see that in recipes that use rock salt as the sand, the author-practitioner advises moistening it in the air or paper instead of directly adding liquid into the sand. Insight concerning this technique appears on fol. 88v, where the author states that “rock salt, like all other salts, dissolves in dampness.” Our experiment sought to replicate the cool moisture of the night and/or cellar by using a specially set up humidifier to both imitate and accelerate this process. We enveloped our “sand” in a damp piece of paper, laid it on a glazed ceramic plate, then wrapped it in a piece of linen, wet it with just enough water that it no longer dripped. ([Fig. 7](https://drive.google.com/open?id=0BwJi-u8sfkVDdFh3QU0yN1NvT2M) and [fig. 8](https://drive.google.com/open?id=0BwJi-u8sfkVDV2JmQU5PWE5LUDA)). Then we put the plate on an improvised open grill shelf system so that it could receive the steady stream of cool moist air from a cold vapor humidifier below ([fig. 9](https://drive.google.com/open?id=0BwJi-u8sfkVDLXFtSTVJV3FTc1k)).

The author did not specify the type of material from which the paper and napkin were made. In the early modern period, cotton was a luxury item from Asia, and household textiles were commonly made from hemp or linen; thus we used a 100% linen cloth for the napkin. Early modern paper was made from rags that contained raw flax and hemp fibers;[[18]](#footnote-17) however, current conservation of rare books has shown that “cotton and hemp blends provide us a paper that has the right color and is sympathetic to the original papers.”[[19]](#footnote-18) Therefore, we used paper made by the Center for the Book at the University of Iowa that contained a fifty/fifty cotton-linen blend.[[20]](#footnote-19)

The ratio of the rock salt and the bone ash was not mentioned in the recipe on fol. 89r; rather, the author ambiguously advised to mix “all of one with the other.” In the recipe on fol. 88v, the author-practitioner mentioned that he used same quantity of rock salt and sand from a mine to make the molding material. From this, we concluded that his subsequent statement (i.e., to mix “all of one with the other”) might well indicate a mixture of equal proportions. Therefore we used equal quantities of bone ash and rock salt in our experiment.

We allowed the mixture (encased in paper and linen) to absorb the damp air from the humidifier for around one hour.[[21]](#footnote-20) We experimented with two kinds of mixtures: one was a mixture of commercial bone ash and rock salt (“commercial sand”), and the other was a mixture of the bone ash that we calcined in the lab combined with rock salt (“homemade sand”) ([fig. 10](https://drive.google.com/open?id=0BwJi-u8sfkVDcFpaTjl5cXVvSDg)). The homemade sand turned gray after being moistened and felt like beach sand ([fig. 11](https://drive.google.com/open?id=0BwJi-u8sfkVDakpIclotbi1IRlk)). It was also quite coarse compared to the commercial sand, which was likely due to incomplete calcination.[[22]](#footnote-21)

We made five different molds in order to test four properties: the strength of the sand, the relationship between regrinding and the quality of casting, the separation agent used on the mold and the casting objects, and the proper material for pouring ([chart 1](https://drive.google.com/open?id=0BwJi-u8sfkVDRzVaTloydkpmeHM)). Our experiment showed that both the sands made from commercial sand and from homemade sand bound together well and formed a good impression. When the molds dried, both homemade and commercial sands hardened like cement, creating a solid mold. This result proved that sand made from bone ash and rock salt as described in fol. 89r binds with humidity from the air. The question then becomes which ingredient acts as the binder?

From the foregoing examination of bone ash, we know that the bone ash cannot be the binder since it is too dry and crumbly. And the rock salt? Interestingly, in BnF. Ms. Fr. 640, rock salt is used both as sand and as a binder in casting. On fol. 88v, the author-practitioner also mentions sand composed only of pulverized rock salt. In a preceding recipe on fol. 84r, rock salt is employed as an ingredient for the “magistry,” or liquid binder. Indeed, here the author of BnF. Ms. Fr. 640 notes that the rock salt solution can provide the sand “with a binding to enable several castings.” Furthermore, just as on fol. 89r, the recipe on fol. 88v only mentions the dry components of the sand, i.e., rock salt and sand from a mine, which the author-practitioner then dampens with water. In the manuscript, then, our author-practitioner either used rock salt water as a wet binder, or used dampened rock salt as a sand that binds by itself. We therefore concluded that it is the combination of rock salt and water that binds the sand. Without salt, water holds the sand together by its viscosity and hydrogen bonding when the sand is damp. But when the water evaporates, the sand falls apart again into grains because there is nothing to hold the grains together. But, by adding salt to the sand, as the water evaporates, the salt begins to crystallize. The main content of rock salt, sodium chloride (NaCl), forms hydrohalite (NaCl • 2H2O), and develops an elongated crystal structure during the crystallization process.[[23]](#footnote-22) The crystallized salt around the grains of sand hold the mold together.[[24]](#footnote-23) And, indeed, our molds made from rock salt and bone ash became very hard and durable when they dried.

**Is Regrinding Necessary?**

In our experiment, we tested the effect of multiple grindings of the sand. Mold No. 1 with only once-ground sand left a rough surface on the cast, suggesting that regrinding is necessary ([fig. 13](https://drive.google.com/open?id=0BwJi-u8sfkVDYjJkS1liSTNmcDQ)). Because of the crystals it formed, the binder created by rock salt and moisture forced us to regrind the sand each time to get rid of coarse grains in the sand before using it. By regrinding, we mixed the bone ash and the rock salt more thoroughly. In comparison to the objects cast in Molds No. 2 and No. 6, we found the commercial sand left a sharper and more detailed cast ([fig. 14](https://drive.google.com/open?id=0BwJi-u8sfkVDSXBXemFwUl9HcTQ)). The feathers and the letters were cast more clearly in Mold No. 6 than in Mold No. 2 ([fig. 15](https://drive.google.com/open?id=0BwJi-u8sfkVDUGt3OXoxeno3Tnc)). This suggests that the finer the sand, the better and more detailed the resulting cast. Therefore we can say that the regrinding process has at least three effects: first, to mix the bone ash and rock salt well; second, to make the sand finer so that the cast has more details; and third, to break down the clumps in the sand and enable the rock salt to crystallize more evenly.

Following the manuscript, we tried brandy and charcoal powder as separating agents to keep the pattern from adhering to the sand. Brandy had little effect. In contrast, charcoal powder was effective in separating the pattern, as well as in separating the two halves of the double-sided mold. We then carried out trials in which we poured tin into the mold. In order to test the author’s statement that this mold “took tin well,” we also poured sulfur into the mold. The sand took tin well and molded cleanly, while in the case of sulfur, the sand stuck to the sulfur and could not be removed ([fig. 16](https://drive.google.com/open?id=0BwJi-u8sfkVDX0ZKM0FyVFFlaHM)).

**What is Fatty Sand? The Concept of Fat and Lean/Dry**

As we have discussed above, it is the rock salt and its exposure to water in the form of mist that created the binding power in the sand. In the manuscript, the author-practitioner attributes the binding power to “fatty sand”: “The bone of an ox hoof is always dry, that is why you must mix it with fatty sand, so it will bind, like tripoli, salts, felt, ashes and similar materials.” In the recipe on fol. 89r examined above, the fatty sand refers to rock salt. Although the rock salt is crumbly when it is dry, when moistened with water, the salt binds together. On fol. 84r, the author mentioned using rock salt as one of the ingredients for magistry, which served as a binder for sand. It seems clear that in these two recipes, moistened rock salt serves as a binder.

The paradigm of fat and lean was used to describe many phenomena of nature in the early modern period. In agriculture, fat and lean were used to describe productive or poor soils respectively; in metalworking, fat and lean were used to describe degrees of fluidity in a metal (how well it “ran”); in casting, Biringuccio believed that lean sand received fatty metal well.[[25]](#footnote-24) According to Pamela H. Smith, this paradigm “appears to have arisen not only in observation by and of farmers, but also from the practices of foundrymen in which it played a central part in the making of molds and crucibles, and in the alloying of metals.”[[26]](#footnote-25)

In BnF. Ms. Fr. 640, fatty and lean/dry are used to describe the property of sand. On fols. 84r and 89r, fatty means the sand binds to itself and clumps together when moistened with simple water. In other recipes, fatty designates other qualities. For example, on fol. 143r, calcined slate is fatty so it “always retains its bumpiness and swells.” Bumpiness here may refer to clumps in the calcined slate powder. This suggests that fatty is used to describe materials that always stick together to form clumps. On fol. 69r, the author-practitioner points out that the crumbly sand should be mixed with something fatty that binds, and on fol. 84v he mentions that fat sand “sticks together neatly.” On fol. 88v, he claims that fatty sand does not work for casting metal that is too hot. Moreover, on fol. 84v, fatty sand swells up and does not provide a subtle impression.

In contrast, dry or lean means the sand is crumbly and will not bind together well, like bone ash. For example, fol. 69r mentions that lean and arid sand does not bind at all. However, on fol. 84r, the author indicates that although lean sand is crumbly, it takes fat metal well. All told, the manuscript offers several ways to improve the lean/dry sand in various recipes. One way is to moisten the dry sand with magistry or good pure wine, since the dry sand needs more liquid binder than other sand (fol. 69). Another way is to mix dry sand with fat sand and moisten the mixture with water (fol. 84v, fol. 89r). Therefore, it seems that the moistened “fat” sand may be similar to magistry in terms of its binding action. Indeed, if we parse the contents of magistry, we find that many of its ingredients are common to fatty sand. For example, on fol. 89v, the author understood sal ammoniac (ammonium chloride) as fatty; on fol. 118v, the author used sal ammoniac water as a binder. The rock salt recipe on fol. 89r is used as binder as well as fatty sand. Indeed, we find in the manuscript that many types of salt fall into the category of fatty, such as sal ammoniac, rock salt, saltpeter, and sandever.[[27]](#footnote-26) Interestingly, in the manuscript we find many of these salts also belong to the ingredients for magistry. It appears that the choice of binder is related to the fattiness of the salts. Therefore, we may deduce that the salt used for creating liquid binders may all belong to the category of “fatty.”

The designations “lean” or “dry” and “fat” in sand casting might be related to ways of “rectifying” soil through fertilization. For example, on fol. 69r, the author notes that “you will also find sand in lean soils … much better than those from fat and strong soils.” As we have discussed above, lean sand is better than fatty sand in casting as long as it is moistened with a binder, so we may assume that dry/lean soil produces dry/lean sand, while fat soil produced fat sand. While Aristotelian categories inform Biringuccio’s definition of salt as of a hot and dry nature, the fattiness of rock salt and ammonia salt as defined in the manuscript is based on some other paradigm, which bears further investigation.[[28]](#footnote-27) It seems clear, however, that the binary pair of fat and lean was employed by early modern metalworkers both as an explanatory “theory” as well as a means by which they could make choices about the kinds of sands, binders, and metals they selected, and the manner in which they expected them to interact.

1. Vannoccio Biringuccio, *The Pirotechnia of Vannoccio Biringuccio*, trans. and ed. Cyril Stanley Smith and Martha Teach Gnudi (New York: Dover Publications, 1990), 324. [↑](#footnote-ref-0)
2. Biringuccio, *Pirotechnia*, 324. [↑](#footnote-ref-1)
3. Biringuccio, *Pirotechnia*, 137. [↑](#footnote-ref-2)
4. Cennino d’Andrea Cennini, *The Craftsman’s Handbook “Il Libro dell’ Arte,”* trans. Daniel V. Thompson, Jr. (New York: Dover Publications, 1960), 5. [↑](#footnote-ref-3)
5. Biringuccio, *Pirotechnia*, 137. [↑](#footnote-ref-4)
6. Ox means castrated male bovine animal kept for draft purposes. Male oxen usually have denser bones than females, and the draft labor might make the bone even denser. It seems that denser bones were preferred by early modern craftsman for the production of bone ash. [↑](#footnote-ref-5)
7. Cennini, *The Craftsman’s Handbook*, 5. [↑](#footnote-ref-6)
8. Moyse Charas, *The Royal Pharmacopœea,* *Galenical and Chymical: according to the practice of the most eminent and learned physitians of France: and publish'd with their several approbations* (London: Printed for John Starkey and Moses Pitt, 1678), 129. [↑](#footnote-ref-7)
9. Cennini, *The Craftsman’s Handbook*, 5. [↑](#footnote-ref-8)
10. Biringuccio, *Pirotechnia*, 137. [↑](#footnote-ref-9)
11. Moyse Charas, *The Royal Pharmacopœea*, 129. [↑](#footnote-ref-10)
12. “Production of Bone Ash for the Manufacture of Bone China,” *Industrial Ceramics*, 843 (1989): 767-770. [↑](#footnote-ref-11)
13. “Ceramic Materials Overview,” Digitalfire Ceramic Materials Database, http://digitalfire.com/4sight/material/bone\_ash\_123.html. [↑](#footnote-ref-12)
14. Sergio Galeano and Mari Luz García-Lorenzo, “Bone Mineral Change during Experimental Calcination: An X-ray Diffraction Study,” *Journal of Forensic Sciences* 59, no. 6 (2014): 1602-6. [↑](#footnote-ref-13)
15. Biringuccio, *Pirotechnia*, 107. [↑](#footnote-ref-14)
16. Biringuccio, *Pirotechnia*, 112. [↑](#footnote-ref-15)
17. For the definition of magistry, see annotation on “p084r magistry.” [↑](#footnote-ref-16)
18. Timothy Barrett, “European Papermaking Techniques 1300-1800,” The University of Iowa Center for the Book. Paper through Time: Nondestructive Analysis of 14th- through 19th-century Papers, http://paper.lib.uiowa.edu/european.php. [↑](#footnote-ref-17)
19. Timothy Barrett, e-mail message to Diana Mellon on 11/11/14. [↑](#footnote-ref-18)
20. Our special thanks go to Professor Timothy Barrett, who offered great help to us in understanding early modern paper production. He also provided the paper used in this experiment. [↑](#footnote-ref-19)
21. This is an estimated time. After about one hour, water began to drip from the mixture. But in order to keep the mixture moist, we kept the humidifier on. We did not observe further changes after the bone ash was moistened. [↑](#footnote-ref-20)
22. Unfortunately we did photograph the dry rock salt and bone ash mixture for comparison. [↑](#footnote-ref-21)
23. See <http://rruff.info/doclib/hom/hydrohalite.pdf>, also <http://www.mindat.org/min-1975.html>. Our thanks go to Sonia Xin Gai, MSc, Stanford University for providing information about the crystallization process of salt. [↑](#footnote-ref-22)
24. Our thanks go to Professor Lawrence Principe from Johns Hopkins University, who helped us understand the reason why salt can bind the sand together. [↑](#footnote-ref-23)
25. Biringuccio, *Pirotechnia*, 324. [↑](#footnote-ref-24)
26. Pamela H. Smith, “The matter of ideas in the working of metals in early modern Europe,” in *The Matter of Art: Materials, Practices, Cultural Logics, c. 1250-1750,* ed. Christy Anderson et al. (Manchester University Press, 2014), 64. [↑](#footnote-ref-25)
27. See annotation on fol. 84r for Eau magistra. [↑](#footnote-ref-26)
28. Biringuccio, *Pirotechnia*, 108 [↑](#footnote-ref-27)