Dying Azur: The Death of Blue in Ms. Fr. 640

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"Death," "dying," and "killing" are recurrent descriptions of craft processes in early modern manuscripts.[1] These terms fit within a broader common lexicon on colors in terms of "body," "movement," and "transformation." In Ms. Fr. 640, *azur*—a non-specific pigment notable for its vibrant blue—is one pigment described in personified terms of life and death.[2] Despite its ubiquity, the meaning of a pigment's "death" is seldom if ever clarified in these treatises. This essay explores the shared cultural vocabularies and practices regarding the "death" of colors in early modern Europe. Through the reconstruction of period terms and conduct of artisanal experiments, this study questions what visual cues correlated with a color "dying"?[3] And how did those observations of color "death" compare to the description of color "death" in artisanal manuscripts?

I offer a preliminary reconstruction of the early modern term "death" as related to color in both theory and practice. The first half of this essay focuses on the literary contexts in which the "death" of azur appears, both within Ms. Fr. 640 and broader European treatises. The second half is dedicated to reporting the results from experiments on the "death" of azur, including the unpublished observations from the Making and Knowing Project's 2018 experiment on grinding azur, as conducted by Pamela Smith, Tianna Uchacz, Tillman Taape, and Sophie Pitman. Finally, I report the data yielded by my own re-creation and adaptation of the 2018 experiment, which extends research on the "death" of sixteenth-century pigments in the Making and Knowing Project's Critical Edition, *Secrets of Craft and Nature in Renaissance France*. Jo Kirby and Marika Spring introduced the "death" of pigments as an "undesirable change," noting also the issue of azur's confusing identity.[4] Marika Spring determined that *azur d'esmail* in Ms. Fr. 640 referred to smalt (ground glass colored with cobalt), while *azur* might also have referred to

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[1] Thanks to the Rare Books and Manuscript Library's conservation team at Columbia University, especially Alexis Hagadorn, for providing me access to the magnification and photography equipment, as well as their perspectives on color change from a conservation perspective. Additional thanks to Pamela Smith and Caroline Surman for their accommodation and guidance in overseeing my lab experiments, as well as Tillman Taape and Naomi Rosenkranz for their insights on the 2018 Making & Knowing Project's pigment-grinding experiments. Unless otherwise noted, transcriptions and translations of Italian and French have been respectively sourced from Mary Merrifield, *Medieval and Renaissance Treatises of the Arts of Painting* and Making and Knowing Project, et al., *Secrets of Craft and Nature in Renaissance France. A Digital Critical Edition and English Translation of BnF Ms. Fr. 640*.
[2] See Making and Knowing Project, et al., *Secrets of Craft and Nature in Renaissance France.* Other colors and substances are also referred to in terms of "death" and "killing" in Ms. Fr. 640, including Aspic oil [Fol. 6r], lavender [Fol. 4r], and red [Fol. 118v].
[3] See Michael Baxandall, *Painting and Experience* on the "Period Eye," a concept that encourages scholars to reconstruct the phenomena of a given period on its own socially constructed terms.
[4] Jo Kirby and Marika Spring, "Ms. Fr. 640 in the World of Pigments in Sixteenth-Century Europe," in *Secrets of Craft and Nature in Renaissance France*. See Alexis Hagadorn, "An Investigation into the Use of Blue Copper Pigments in European Early Printed Books."

smalt, rather than azurite.[5] Other essays in the Making and Knowing Project's Critical Edition, *Secrets of Craft and Nature in Renaissance France* have understood the pigment *azur* in Ms. Fr. 640 as azurite, lapis lazuli, smalt, and/or verditer.[6] The Making and Knowing Project's research has also focused on the liveliness of color for pictorial subjects, such as the effects of "flesh color," as well as how the term "body" used to describe pigments was ambiguous and applied to several different media.[7] This study aims to encourage more thorough investigations of the rhetoric of colors in late Medieval and early modern Europe.[8]

Engaging with hands-on embodied knowledge presents a variety of challenges for historians of material culture. By contrasting literary excerpts with pre-existing data and first-hand observations from experimentation, this research interrogates the authenticity of reconstruction and the level of certainty that experiments can reveal about knowledge of the past. Where does the knowledge of early modern craft lie in modern reconstruction? Conducting an azur-grinding experiment based on Ms. Fr. 640's text raises interesting questions about how we interpret texts that are trying to convey a type of knowledge about *doing* something. By what means can we measure the success or failure of a recreation that attempts to reconstruct textual accounts? What kinds of obstacles might stand in our way as we try to understand these sources? The reconstruction of pigment grinding experiments reveals the discrepancies between the nature of azur's "death" in literary and material contexts. While modern scholarship tends to prioritize textual sources as a way to make sense of visual and material evidence, by contrast, this research considers to what extent experimental results can guide an understanding of textual accounts of azur's "death" and the broader network of craft knowledge on the nature of blue.

Segreti per Colori: An Early History of Azur's Color Loss

Decades prior to Ms. Fr. 640's creation, artisanal manuscripts in Europe were already equipped with language that described azure's color change. The "Secrets for Colors" [Ita. *Segreti per Colori*] is a mid-fifteenth-century manuscript written in latinized Italian and preserved in Bologna.[9] Its anonymous author began with a chapter "On preparing various kinds of natural azures," which provided the reader with a "test" [Ita. *la sperientia*] to evaluate the quality and nature of lapis lazuli.[10] The author instructed the reader to place the stone into fire and then assess its quality based on the observable change as it cooled: "If the stone retains its colour [Ita.

[5] Kirby and Spring, "Ms. Fr. 640 in the World of Pigments in Sixteenth-Century Europe."
[6] Carl Garris, "What is *Azur* in Ms. Fr. 640?" in *Secrets of Craft and Nature in Renaissance France.*
[7] Ruilin Fan, "'Flesh Color' and Race Making in Early Modern Painters' Manuals," in *The Making and Knowing Project, Research and Teaching Companion*; Cleo Nisse, "Shadows Beneath the Skin," in *Secrets of Craft and Nature in Renaissance France*; Jenny Boulboullé and Maartje Stols-Witlox, "Working (with) the *Corps*," in *Secrets of Craft and Nature in Renaissance France.* See also Roberta Panzanelli, *The Color of Life*.
[8] See Michel Pastoureau, *Blue: The History of a Color*, Chapter 1, "An Uncommon Color" and Marcia Hall, *Color and Meaning* on the symbolic language of color.
[9] Mary Merrifield, *Medieval and Renaissance Treatises on the Arts of Painting*, "Bolognese Manuscript," 518-21. "Death" in this manuscript can be compared to the equally vivid description of blood yielded from a "calf fresh killed" [Lat. *morbido*] and a necessary ingredient for the softening of crystal, *Ad lapides anullorum componendos*, "To soften crystal previous to stamping or carving it like wax."
[10] Merrifield, 340–43.

sta in suo colore] and does not become pale [Ita. *non smortisca*], it is good. But if it both improves and retains [Ita. *migliorasse, mantenga*] its colour, it is both good and perfect."[11] The status and monetary value of the lapis stone was contingent on its ability to retain its deep blue hue. The desire for lapis to preserve and even improve its blue color is echoed in later treatises as a quality of liveliness. In the same passage, the inverse is described, wherein the lapis stone's loss of color was an indication of a lesser and unusable quality:

> If it happens that the stone loses all its colour [Ita. *perdesse tutto el colore*], …it is not ultramarine and is not fine, and consequently you cannot procure ultramarine azure from it.[12]

First, the explicit reference to azure as ultramarine indicates that there are different material blues. The author-practitioner warned that the stone which lost color contained little substance and was not worthwhile investing time or money into it as an artistic material. In these passages, Italian words *sta*, *migliorasse*, and *mantenga* characterize azure that retains its color. The verb *Stare* is defined as "stand," "stay," or "endure"; *Migliorare* as "improve," "better"; and *Mantenere* as "maintain," "sustain."[13] Azure's color loss is characterized by the Italian words *non smortisca* and *perdesse*, which correlate to *Smorto,* defined as "pale" or "deadly," and *Perdere* as "lose."[14] The binary terms of "lose" and "remain" only hint to the vocabulary of "death" and "life" made more explicit in Ms. Fr. 640. Nonetheless, the described preservation and loss characterized a similar positive and negative relationship to life and death.

While the first chapter of *Segreti per Colori* diagnosed azure's color loss as negative, it also introduced an exception to this rule, where an instance of color loss could have indicated high-quality stones:

> As for those stones which change [Ita. *mutano*] the beauty of their primitive colour, we must consider how many degrees [Ita. *in quanti gradi*] they have changed [Ita. *mutano*], because there are some stones which the more they lose [Ita. *piu* <gap>*montano*] the finer they are.[15]

Notable is the author's mention of evaluating the "degrees" to which the stone changed color.[16] The loss and preservation of color was described as a cumulative process, where gradation could be visually observed and measured to some extent. The following sentence indicated that the author supposed that color loss could be due to "the quantity of earthy matter" [Ita. *La quantita de la terra*] contained in the stone, referencing the inclusions that would have been necessary to

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[11] Merrifield, 342–43: "*se la dicta petra sta in suo colore che non smortisca e bona*."
[12] Merrifield, 342–43: "*Ma se devinisse che la petra perdesse tutto el colore…non sonno de ultramare e non sonno fini e per consequential non ne poresti cavare azurro ultramarine...*"
[13] John Florio, *Dictionarie of the Italian and English tongues*, 300, 314, 530.
[14] Florio, 368, 505.
[15] Merrifield, 342–43: "*Ma quelle che mutano la bellezza dal primo collore e da considerer in quanti gradi se mutano per che ce sonno de quelle che quanto piu montano tanto sonno piu fini.*"
[16] See Ms. Fr. 640, fol. 118v on red, where the term "death" is used rather in a neutral, if not positive, sense to describe the craft of letting the redness of heated vessels die.

remove.[17] While the author did not elaborate further on the calculation of the degrees nor the beneficial loss of color, they did seem to suggest that the evaluation of whether the "loss" of a stone's color was positive or negative was dependent on the ratio between "earthy matter" and azure. The retention, loss, and change of color described in this chapter reinforced the author's prescription that observation of blue was necessary prior to its preparation for use. While the author did not describe the visual differences of azure's color change, nor why these changes occurred, they did reinforce that training the eyes was a crucial skill for evaluating the quality, value, and usability of azure.

"Dying" and "Killing" Colors in Seventeenth-Century Manuscripts

In the seventeenth century, the language of "death" and "killing" became more pervasive in artisanal manuscripts, including Belgian painter Pierre Lebruns' "Collection of Essays on the Wonders of Painting" [Fr. *Recueil des essaies des merveilles de la peinture*, 1635], French painter Roger de Piles's "The First Elements of Practical Painting" [Fr. *Les premiere élémens de peinture pratique*, 1684], and French physician Sir Théodore Turquet de Mayerne's "Mayerne Manuscript" [Lat. *Pictoria Sculptoria & qua subalternarum artium*, 1620].[18] Each author described various pigments and colors in terms of dying and killing.

First, the authors used the language of death to characterize the appearance of colors on canvas. In Lebrun's manuscript's section "Many Painting Secrets" [Fr. *Plusieurs Secrets de Peinture*], he related a color dying to its application on the canvas: "The colour of the primed canvas is called '*couleur mate*,' that is to say, 'dead,' [Fr. *mort*] on account of the fat oil."[19] The description of death was indebted to the appearance of sheen on the canvas, rather than as part of its preparation. In de Piles's manuscript, he also described the impact of the artisanal process on the death of color:

> There are painters who prefer canvases that have only one layer who prefer them to those which have two, because they make the colors die less [Fr. *moins mourir*] and they roll more easily when one wants to transport them.[20]

A double-layer application of paint thickened the color and reduced its "death," which could have referred to the thinness of its appearance or quick fading. The Mayerne Manuscript also adopted the language of death to describe the reaction of individual materials, such that "esmail

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[17] Merrifield, 342–43.

[18] Transcriptions have been respectively sourced from Roger de Piles, *Élémens de peinture pratique* (A Amsterdam et a Léipsick: Chez Arkstée & Merkus, 1776) via HathiTrust digital copy from the Getty Research Institute, and Théodore de Mayerne, *Pictoria sculptoria & quae subalternarum artium* (1620–46) via ARTECHNE's revised transcription of British Library MS Sloane 2052. All translations are by the author. Thanks to Tillmann Taape for introducing me to the Mayerne Manuscript.

[19] Merrifield, 814–15: "*Le couleur de la thoille imprimee se dit couleur mate, c'est-a-dire, qui est comme mort, a cause de l'huile grasse*." See Kirby and Spring, "Ms. Fr. 640 in the World of Pigments in Sixteenth-Century Europe."

[20] De Piles, *Élémens de peinture pratique*, 128–29: "*Il y a des Peintres que aiment mieux les toiles qui n'ont qu'une seule couche / de couleur & qui les préferent à celles qui en ont deux, parce qu'elles sont moins mourir les couleurs & qu'elles se roulent plus facilement quand on veut les transporter.*"

dies [Fr. *meurt*] easily" and "Cyanus blue is worthless and dies [Fr. *meurt*] uncontrolled."[21] In addition, Mayerne understood that enamel pigments were especially prone to "dying":

> The death of colors is when the oil swimming above dries up and forms a skin, which blackens in the air. There are some colors, and the other enamels which do not mix easily with the oil, but always go deep without binding, and thus die [Fr. *meurent*] easily [&?] blacken.[22]

Here, Mayerne attributed the death of pigments not only to the individual pigments but to their temperament when prepared with various media. He also described that the durability of blue pigments was contingent on painterly techniques, such that "The Blue can be laid down with tempera with glue on your oil primer then when dry apply a good subtle varnish & strong drying. Thus you blue never dies [Fr. *ne meurt jamais*]."[23] The Mayerne manuscript continued with specified instructions on avoiding the death of azur, including "When working with Blue, if you add a little Aspic oil to the ash of Azure, the color does not die [Fr. *ne meurt pas*]."[24]

Next, Lebrun and de Piles both called upon the vocabulary of "killing" [Fr. *fait mourir*], derived from "death" [Fr. *mourir*] to characterize specific pigments and binders. In *Recueil des essaies*, Lebrun described the green pigment verdigris as having the capacity to "kill": "Verdigris…is used only with the shadows, for it is a poison in painting, and kills [Fr. *fait mourir*] all the colours with which it is mixed."[25] Lebrun noted verdigris' inherent properties as capable of "killing," which he described as an action rather than a visual result. De Piles described the pigment-binder turpentine oil as a source of killing, "These paintings appear in the future only as a colored fog and without any vivacity because the excessive quantity of oil, mainly that of turpentine, absorbs and kills [Fr. *fait mourir*] the colors."[26] In terms of verdigris, while de Piles did not describe the pigment as "killing," he did describe the pigment's negative qualities at length:

> Verdigris is the plague [Fr. *la peste*] of all colours, and is capable of ruining [Fr. *perdre*] a whole painting if the least part of it were to enter into the printing of a canvas…Sometimes it is calcined to remove its malignancy [Fra. *malignite*] and make it more durable, but it is as dangerous [Fr. *dangereux*] to calcine as stonecrop; and however

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[21] MS Sloane 2052, Fol. 11r *NB. L'esmail meurt facilement…*; Fol. 23v "*Le bleu de Cyanus ne vaut rien & meurt incontinent.*"

[22] MS Sloane 2052, fol. 9v: "*La mort des couleurs est quand l'huyle nageante au dessus se seiche & faict une peau, qui noircit à lair. Il y a quelques couleur, et les Esmaulx entraultres qui ne se meslent pas aisement avec l'huyle, ains vont tousjours à fonds sans se lier, & ainsi meurent facilement* [&?] *noircissent.*"

[23] MS Sloane 2052, fol. 11r: "*Le Bleu peult estre couché a destrempo auec colle sur vostro imprimeure a huyle (frottés auec suc d'ail) puis estant sec appliqués un bon vernix subtil & fort siccatif. Ainsi vostre bleu ne meurt jamais.*"

[24] MS Sloane 2052, fol. 4v: "*Quand on trauaille auec Bleu si on adjouste à la cendre d'Azur vn peu d'huyle d'Aspic, la couleur ne meurt pas.*" See also MS Sloane 2052, fol. 9v; 11r.

[25] Merrifield, 823: "*Le verd-de-gris…et fait mourir tous les couleurs permy lesquelz il est meslez.*"

[26] De Piles, 113: "*En effet ces tableaux ne peroissent plus dans la suite que comme un brouillard coloré & sans aucune vivacité, parce que la trop grand quantité d'huile, principalement celle de thérébentine, absorbe & fait mourir les couleurs.*"

> purified it may be, it should only be used alone, for it would spoil [Fr. *gâterois*] the colours with which it could be mixed.[27]

His descriptions of verdigris were reminiscent of the lexicon of "death" and "killing," as he described the pigment as "plague" and "dangerous" [Fr. *la peste*; *dangereux*] with qualities of "malignancy" [Fr. *malignite*] that was capable of "ruin" and "spoil" [Fr. *perdre*, *gâterois*].[28]

Finally, Lebrun used the lexicon of "death" to describe the pictorial effects of a painting: "At the present time, painters are obliged to write under the figures 'these are painted,' lest the spectator should fancy that they are dead [Fr. *morts*] figures glued to a canvas."[29] Lebrun commented on the state of painting and its imitative capacity, using the language of "death" to contrast the lively appearances of figures to which painters aspired. This survey of early modern artisanal manuscripts demonstrates that a lexicon of death was used to describe the actions and identities of diverse colors.

The Death of Azur in Ms. Fr. 640

In Ms. Fr. 640, the "death" of azur was described both in terms of its inherent properties, its lack of "body," and the painter's intervention to prevent its death in pigment preparation. The author-practitioner communicated the results apparently observed from his own painterly experience, notably the *undesirable* results in preparing azur blue. Through the written word, he attempted to preserve knowledge of azur's unpredictable material qualities.[30] The preparation of paint involved a pigment and binder being ground into a paste, which ideally had three requirements: it handled well on the brush, it adhered to the painted surface, and it remained stable over time. In several instances, the manuscript highlighted azur's temperamental nature when ground and mulled. As documented in Ms. Fr. 640, the variable results yielded from preparing azur suggested the repetitive experimentation with blue led by numerous artisans.[31] Azur's reactions are described in several contexts, including its variable reactions when mixed with oil and water.[32] The lexicon on color in Ms. Fr. 640 appears to have referred to both material properties and the gestural movements the artist conducted when dealing with them.

Under the heading "Azur," the death of azur d'esmail (i.e., smalt) is described: "*Azur d'esmail* hates more than any other to be ground, especially with water, for it dies & loses all its

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[27] De Piles, 124: "*Le verd-de-gris est la peste de toutes les couleurs, & il est capable de perdre tout un tableau s'il en entroit la moindre partie dans l'imprimure d'une toile… Quelquefois on le calcine pour lui ôter sa malignité & le render le plus durable, mail il est dangereux à calciner aussi-bien que l'orpin; & quelque purifié qu'il puisse être, il ne faut l'employer que fuel, car il gâteroit les couleurs avec lesquelles on pourroit le meler.*" Cf. André Félibien's *Des principes de l'architecture, de la sculpture* (1699) for the same passage reproduced.

[28] See Roy, *Artists' Pigments: A Handbook of Their History and Characteristics* on verdigris. See also Neil Murphy, *Plague, Towns and Monarchy in Early Modern France*; Nükhet Varlik, *Plague and Empire in the Early Modern Mediterranean World*; Rebecca Totaro and Ernest B. Gilman, *Representing the Plague in Early Modern England*.

[29] Merrifield, 824–25, entry 4: "*maintenant il faut mettre dessous, qu'un tel peignoit de peur qu'on ne crut que ce sont des morts qu'on a collé sur la toile…*"

[30] See Pamela Smith, *From Lived Experience to the Written Word*, chapter 9, "Reconstructing Practical Knolwedge," 204–6.

[31] Michael Price, "Two Author-Practitioners in Dialogue across Time," in *Secrets of Craft and Nature in Renaissance France*.

[32] See Marjolijn Bol, *The Varnish and the Glaze* on early modern treatments of oil in painting.

color [Fr. *se meurt & perd toute sa couleur*]" [Fig. 1].[33] Azur d'esmail's "death" [Fr. *meurt*] was communicated as being akin to its "loss" [Fr. *perd*] of color, though the qualification of the change is unclear, whether it altered hues, darkened, or made some other change. The author-practitioner continued with a suggestion for azur d'esmail's preparation that avoided undesirable change: "However, because it cannot be worked if it is coarse, grind not with water but with oil & grind it thickly, and in this way it will not die as much [Fr. *il ne se mourra pas tant*]."[34] The author evaluated oil as the suitable substance with which azur should have been prepared as opposed to water. "Death" [Fr. *meurt, mourra*] was characterized as a cumulative and inevitable process for azur, similar to the description of "degrees" of azur's color change in *Segreti per Colori*. The early modern French verb *Meutrir* was defined as "to bruise" though its earlier use was "to kill," and *Mourir* as "to cease to live."[35] While "death" was not qualified nor its definition elaborated on in these passages, it presumably referenced azur's fading, darkening, or changing color tone.[36] The author-practitioner's suggested strategy for mitigating azur's "death" was contingent upon their embodied knowledge about its temperament towards and reaction with various substances.

Elsewhere in Ms. Fr. 640, particularly under the heading "Painting in esmail d'azur in oil" [Fol. 11r], the author-practitioner agreed that oil was the ideal medium to prepare azure pigment. The text described that "Azure ash are only good for landscapes because they die [Fr. *meurent*] in oil. Only true azure holds on [Fr. *tienne*]."[37] Azure's ability to not "die" and "hold on" in oil indicated its authenticity and high quality. Another excerpt under "Azur *d'esmail* in oil" [Fol. 61v] attested that azur should have been ground with oil as opposed to water: "And if you do not find any that is subtle enough, you can grind it [azure] well, not with water but with oil, & grind it thickly."[38] Despite the author's preference that azur be mixed with oil, they nonetheless warned those painting with azure that the combination could also *cause* its death: "Also, azure ground with oil always remains shiny, which is not a good sign for azure for this causes it to die [Fr. *mourir*]."[39] Here, azur's death was associated not only with color change but with other visual properties—like shininess, the presence of too much fatty oil—as indicative of its demise.

Ms. Fr. 640's commentary on azur's death extended also to the measures that the artist could and must have taken in preparation to prevent its death. As the entry on "Azur *d'esmail* in oil" continued, it reported on the application technique its reader could have employed to

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[33] Figures appear at the end of the text of the essay. Ms. Fr. 640, fol. 58v: "*Lazur desmail haict plus / destre broye que nul aultre / mesmement a leau car / il se meurt & perd toute / sa couleur…*"
[34] Ms. Fr. 640, fol. 58v: "*…Touteffois / pourceque il ne se peult / travailler sil est gros / broye non avecq eau / Mays avecq huile & le broye / espes et en ceste sorte il ne se / mourra pas tant*."
[35] Definitions are sourced from *Le Dictionnaire de l'Académie française*.
[36] Kirby and Spring, "Ms. Fr. 640 in the World of Pigments in Sixteenth-Century Europe."
[37] Ms. Fr. 640, fol. 11r: "*Les cendres* [dazur] *ne sont bonnes que pour les paisages car elles / se meurent a huile Il ny a que lazur vray qui tienne*."
[38] Ms. Fr. 640, fol. 61v: "*Et si tu nen / trouves dasses subtil Tu le peulx bien broyer non a eau / mays a huile & le broyer espes*."
[39] Ms. Fr. 640, fol. 61v. "*Lazur aussy broye / a huile demeure tousjours / luisant Ce qui nest / pas bon signe a lazur / car cela le fait / mourir.*"

mitigate azur's dying: "Azure wants to be layered neatly, which is why it always dies somewhat when, to mend an old panel, one layers it on old, already tarnished, azure."[40] Azur's ability to resist death, according to Ms. Fr. 640's author-practitioner(s), was indebted to its physical property (i.e., "body") and the artist's application: "But this is the best, as long as you re-coat it twice, for in this manner, the colors, having more body, do not die [Fr. *ne meurent*] & are all the more beautiful for it, especially azure, lake, & those do not have body."[41] Here, the author did not specify the preferred medium with which to mix and prepare azure, but rather that the double-coating was necessary for its color to persist.[42]

Azur-Grinding Experiment, 2018

In February 2018, investigators from the Making and Knowing Project—Pamela Smith, Tianna Uchacz, Tillman Taape, Sophie Pitman, and Naomi Rosenkranz—reconstructed Ms. Fr. 640's instruction on and warning against grinding *azur* to its death.[43] The team gathered the four pre-ground pigments, to which azur could refer, to grind and paint out: azurite, smalt, lapis, and verditer. The experiment set out to investigate questions regarding the changing nature and properties of azur in its preparations for painting. "How does the resistance to the muller change over time? What about the sound, does it 'sing'? Does the colour 'die,' i.e. fade or become lighter or greyish?" In this section, I will summarize the methods and results gleaned from the 2018 pigment grinding experiment that sheds light on the understanding of *azur* in Ms. Fr. 640.[44]

The Making and Knowing team's 2018 pigment-grinding experiment was carried out in partial collaboration with another academic project led by Alexander Marr at the University of Cambridge, entitled "Genius Before Romanticism: Ingenuity in Early Modern Art and Science." The project explored the European imagination before the Romantic Concept of "genius," hosting several interdisciplinary events, including a session by Spike Bucklow on "Azurite Crushing and Washing" at the Fitzwilliam Museum.[45] For several pigments, the more they are ground, the more their brightness will be lost.[46] Thus, the Making and Knowing Project's

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[40] Ms. Fr. 640, fol. 61v: "*Lazur veult estre / couche net cest pourquoy / quan il se meurt tousjours / quelque peu quand pour / reparer un vieulx tableau / on le couche sur de / vieulx azur desja / terny*."
[41] Ms. Fr. 640, fol. 65v, "Semi-lively colors": "*Mays cest le meilleur pourveu / que tu recouches deulx fois Car les couleurs en ceste sorte / ayant plus de corps ne meurent point & en sont bien plus / belles, mesmem{ent} lazur la laque & ceulx qui nont point de corps*."
[42] See Marjolijn Bol, et al., ERC-project DURARE, "Dynamics of the Durable" that maps how artisans acquired knowledge about and manipulated the stability and behavior of artistic materials.
[43] See Smith, *From Lived Experience*, 206–7 on the nature of reconstructing early modern experiments.
[44] Documentary evidence for 2018 has been granted by the Making and Knowing Project, namely "SP18 Blues Reconstruction."
[45] See Genius Before Romanticism: Ingenuity in Early Modern Art and Science (2014–2019), CRASSH, University of Cambridge: https://www.crassh.cam.ac.uk/research/projects-centres/genius-before-romanticism/. The workshop also included team members from Sachiko Kusukawa's Making Visible Project and with the support of the Fitzwilliam Museum's curatorial team of the "Madonnas and Miracles" exhibit (March–June 2017).
[46] See Ryoichi Nishimura and Ari Ide-Ektessabi, "The Relation between the Fine Structural Change and Color Fading in the Natural Mineral Pigments Azurite and Malachite" and Leonor Carmo Rosa Mendes Ferrão, "Historical Reconstructions of Raw Materials Based on a Blue Smalt Coating Applied to a Seventeenth-Century Altarpiece" on the fade resistance of azurite and smalt.

experiments have aimed to control a set of factors that influenced a pigment's observable change over the course of its preparation for painting.

Methodology: The experiment was designed in two sections, "Pigment Grinding, Part I (in water)" and "Pigment Grinding, Part II (in oil)." The team conducted only Part I of the projected experiment, which involved four parallel experiments, in which each investigator, with the use of a glass muller, ground and painted out one pigment onto a glass plate and mixed media paper (See Appendix 1). The experiment consisted of the use of four Kremer pigments, namely azurite (#10200), smalt (#10000), lapis (#1056020), and verditer (#10180) (See Appendix 2).[47] The team conducted these four experiments simultaneously and within a shared laboratory space, which permitted shared methodological conventions and vocabularies for describing the observed pigments. They considered several lab actions before the experiment, including the pressure on the pigments from grinding with various sizes of mullers. Together, they agreed on the necessity for each investigator to use the same size of muller to produce consistent results. The team also designated one member to circulate between the four grinding stations, responsible for photographing the individual color charts, timekeeping, and enforcing methodological standards, such as grinding the pigment with the same level of pressure. Consciousness about the replicability and authenticity of reconstruction was at the forefront of the experiment's design.

The first step was to measure and place each pigment on a glass plate. The amount of each pre-ground pigment, a quarter teaspoon by volume of each pigment, was decided together on the day of the experiment. One investigator suggested that working on a smaller scale would be beneficial to the experiment in terms of "grinding until it [*azur*] dies," since the grinding would occur consistently on a small amount of pigment. They acknowledged, however, that working with a small amount of pigment could also pose its own challenges. Next, they placed the glass plate on a piece of white paper so that they could gauge the color change as they ground the pigment. Then they added water in small increments to the piled pre-ground pigment until the consistency was convenient for grinding.[48] They set a timer and began grinding with a large glass muller, with the original intention to photograph the glass plate alongside a color chart every two minutes. During the experiment, this timing convention was altered. Each pigment was ground in water and incrementally painted out with water in 2-minute increments up until minute 16:00. Then, the investigator opted for approximately 10-minute increments between painting the sample out. Each investigator planned to mix a small amount of ground pigment with gum arabic and paint out a small test square onto a labeled and gridded mixed media paper. On the day of experimentation, the team decided to paint out each ground pigment with water between grinding

[47] See Ashok Roy, *Artists' Pigments: A Handbook of Their History and Characteristics* on azurite, smalt, natural ultramarine blue, and blue verditer. In April 2018, two months after the experiment, the team investigated the differences between the blues used in the Making and Knowing experiment at the Morgan Library Conservation Lab.

[48] Both Making and Knowing Project experiments used water from the tap in the laboratory.

intervals and to paint out the ground pigment with gum arabic only after grinding with the final pigment.

Azurite: This pigment appeared to darken over the course of mulling [Fig. 2]. Nonetheless, its robust blue remained. Under raking light, the paint swatches have cracked appearances and have largely flaked off since 2018. Up until minute 10, striations of the pigment particles are visible [Fig. 3], while by minute 16, the swaths appear denser and more cohesive [Fig. 4]. At the grinding conclusion at minute 45, the azurite sample fades into a swath of matte blue, with a tinge of light green [Fig. 5].

Lapis: According to the field notes, from the start, the lapis' difference of particles was very clear, and it faded quickly as it dried [Fig. 6]. With the addition of water, there was no grit against the glass palette. By minute 10, it was smooth pulling and easier to apply at minute 24 [Figs. 7–8]. The tone persisted; however, it appeared to have dampened over the course of mulling into a matte blue. Under raking light, the samples seem to have dried inconsistently, resulting in blotchy appearances. The team member responsible for this sample card painted out the lapis twice at minute 45. The first swatch looks flakey and matte, as if a layer of paint sits on the paper's surface [Fig. 9]. The second sample looks thin and the whiteness of the paper from below is more visible, like this swatch is primarily absorbed into the medium below [Fig. 10].

Smalt: Up until minute 10, the smalt appears vibrant yet thin, whereby the rich blue color is concentrated only on the downstroke of each swatch [Fig. 11]. Between minutes 12 and 16, the smalt appears to hold more "body," demonstrated by its more even application of color [Figs. 12–13]. The larger increments between minutes 24 and 45 reveal smalt's fading color. The short downstrokes at minute 24 preserve the rich blue [Fig. 14], while the horizontal swipe below and within the same box appears faint and blotchy [Fig. 15]. The investigator paints out the pigments four times at minute 45, twice with water, once with arabic gum, and once with walnut oil. The first swatch painted out with water is more vibrant than the previous minutes; however, the swatch seems to have absorbed heavily into the mixed media paper, leaving behind a grainy appearance [Fig. 16]. In the second time painting out this sample with water, the smalt's color appears to fade substantially [Fig. 17]. By contrast, the two painted-out samples with gum arabic and walnut oil significantly darkened. In the 45-minute process of grinding, the smalt revealed characteristics of vitality and decay. While the pigment began thin, the grinding revitalized its "life" halfway through the experiment followed by its "death" into a faint blue by the end.

Verditer: The verditer held a particularly vibrant blue across the grinding experiment duration [Fig. 18]. Upon adding water at minute zero, a filmy layer emerged. Between minutes 2 and 8, the substance was slightly gritty with little difference in grinding texture [Fig. 19]. By minute 10, no grit was present, and it remained smooth to grind until the end [Fig. 20]. While the texture was very smooth by minute 12, its application became far easier to paint out at minute 24 [Fig. 21], increasingly until minute 45 [Fig. 22]. From the observable sample, it appears that verditer retained its bright blue, darkening slightly by the conclusion.

Azur-Grinding Experiment, 2024

In November 2024, I conducted an azur-grinding experiment that re-created Part II of the 2018 grinding experiment by the Making and Knowing team, which introduced walnut oil to the mulling process. This experiment aimed to replicate the 2018 procedure such that the two sets of results could be cross-referenced and visually compared. My objective was to take notes on the textures (course, smooth), application (easy, difficult), and duration (of grinding, drying) of the mulled pigments to attempt to identify when, where, and how the moment of azur's death in oil occurs. Guiding questions behind this experiment included: what constitutes "death" in the mulling of azur with oil? This experiment mulled a quarter teaspoon of the same four pre-ground Kremer pigments used in the 2018 experiment, namely azurite, smalt, lapis, and verditer.[49]

The following procedure was executed once for each of the four pigments [Fig. 23]: First, I poured the 1/4 tsp of pre-ground pigment into a pile in the center of the glass palette. Then, I measured 1.5 ml of Kremer walnut oil in a dropper and dispersed the drops of oil onto the pigment pile.[50] Next, I combined the pigment and oil together by using a large muller. I began with a rough mulling technique, smoothing the contents on the palette together in figure-8 pattern motions. Once the pigment and oil were combined, I started the stopwatch and began concentric mulling—small circular motions—with the large muller. As the pigment-oil mixture covered an increased surface area of the palette, due to the mulling motions, I used the palette knife to scrape the pigment back into the center. I continued this mulling process, stopping and painting the pigment out at the designated minute increments noted on the mixed-media grid, the same intervals as the 2018 experiment (2, 4, 6, 8, 10, 12, 14, 16, 24, 34, 45-minutes).

To "paint-out," I first took the flat oil brush and gathered a swab of pigment from the center of the palette, then, I painted out one horizontal swath in one or two brushstrokes. Then, I daubed a small, pointed oil brush into different sections of pigment and painted out three small, vertical strokes. At each step of the process, I took notes on the texture (course, smooth), application (easy, difficult), and consistency (high or low viscosity) that might have accounted for a change of color and thus pigment "death." The pigment tones appear to have largely stayed the same, and the most observable change derived from the change in particle distribution at various rates. The interpretation of these results was supported by conservation equipment in the Rare Books and Manuscript Library's conservation lab.[51] Magnification was a useful tool for tracing the visible color change and particle distribution change over the mulling period.

Azurite: Mulling azurite began particularly gritty, its particles scratching against the glass palette [Figs. 24–25]. At around minute 18, it began to mix thoroughly and result in a more cohesive texture. The painting-out method I employed, painting the pigment out in a single swipe, was effective for observing its change in particle distribution and viscosity over the

[49] Kremer azurite (#10200), smalt (#10000), lapis (#1056020), and verditer (#10180).
[50] Kremer walnut oil (#73550).
[51] Equipment used to analyze results included Meiji microscope, Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software, and Nikon Camera Control Pro 2.

mulling period.[52] By minute 34 and with the use of a big muller, the azurite was smooth to pull. While the pigment appeared as a dark blue in the mulling process, its painted-out swatches reveal an unexpected green tone. Its greyish-green appearance resembled the tone of Kremer's pre-ground malachite more so than its azurite.[53] Under raking light, the swatches of azurite between minutes 10–12 appear a more intense blue than at minute 45 where it turns darker [Fig. 26]. Magnification of minute 2 makes it apparent that the more the azurite was ground, the more its bright bluish hue darkened and the more a greenish tone prevailed.

Lapis: The lapis sample was the smoothest sample to mull from the start, because its particles were the smallest [Figs. 27–28]. The pigment offered little to no grit or tension in mulling. From the surface, its tone appeared to have remained consistent across the 45-minutes. Likewise, its particle distribution appeared little changed. The lapis samples from minutes 12, 14, and 34 appear to have dense swaths of paint at the ends of each horizontal paint stroke, which demonstrates how the pigment soaked into the multi-media paper and allowed another layer to sit on its surface to reveal a matte film. At the time of painting-out, these films appeared as dark, saturated patches, while their matte appearance revealed themselves only after drying overnight [Fig. 29]. This material evidence might correspond to the shininess described in Ms. Fr. 640 which supposedly was not a good sign for azure and caused it to die.[54] The lapis samples under magnification revealed less color change or "death" than the other three pigments. Its most noticeable change, in addition to the expected reduction in particle size, was the decreased intensity of the blue hue and increased prevalence of a greyish hue [Fig. 30].

Smalt: The smalt samples revealed the most noticeable change in particle distribution over the experiment [Fig. 31]. Mulling this pigment introduced physical resistance between the glass muller and palette. Between minutes 2 and 6, its grainy and coarse particles are apparent, before transforming into more cohesive swaths of blue [Fig. 32]. By minute 45, a noticeable shift in tone was apparent, particularly from a darker, vibrant blue to a lighter and duller blue [Fig. 33].

Verditer: The verditer, similar to its visual results in the 2018 experiment appears a bright blue [Fig. 34]. The pigment was fairly smooth to mull from the beginning, though became more cohesive to pull by minute 24 onwards [Fig. 35]. Between minutes 16 and 30, I experimented with the use of a small muller for changed physical or sonic qualities of the pigment. When returning to the big muller at minute 30, the smooth, gliding pigment began to "sing." Under magnification, a noticeable color change was present. Over the course of mulling, the verditer's bright blue was slowly replaced by darker swaths of grey. The resulting appearance at minute 45 was a wash of dark blue with dots of grey that were brightened to a light purple by the backdrop of the white paper [Fig. 36].

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[52] J. R. J. Van Asperen De Boer, "An Examination of Particle Size Distributions of Azurite and Natural Ultramarine in Some Early Netherlandish Paintings."
[53] Cf. Kremer, Malachite natural (#10300).
[54] Ms. Fr. 640, Fol. 61v.

Conclusion

This research explored the "death" of azur from a multi-faceted approach, reconstructing early modern artisanal history through literary analysis, data interpretation, and first-hand experimentation. Together, these areas of study have informed more nuanced perspectives about embodied knowledge of pigment production. The results yielded in the Making and Knowing Project's azur experiments both align and contest with expectations about results, as indicated by the passages in Ms. Fr. 640. The ground pigments in the 2018 water-based experiment parallelled the subtlety of color change, darkening, and fading in the 2024 oil-based experiment. Azurite darkened over the course of mulling and faded into a greyish-green appearance. Lapis' tone persisted, as compared to the other pigments, but nonetheless revealed slightly darkened and faded results under magnification. Smalt's deep vibrant blue transformed into a dull, lighter tone in both experiments. Verditer's bright blue darkened as it was mulled and showed a slight color change into a greyish purple. The experiments reveal that there was no one type of "death" in the paint preparation of azur. A pigment "dying" could be identified as a color change, darkening, and fading to various degrees.

Notably, Ms. Fr. 640's description of azur's intense "death" when ground was not apparent in the material reconstructions. What does it mean when we fail to capture in a recreation what these authors are saying? Why do we face challenges in reconstructing early modern recipes? The text raised the expectation that major color changes would occur, and a pigment's moment of "death" would be identifiable. The author-practitioner also directed an understanding that results yielded from azur ground in oil would differ greatly from water. As compared to the manuscript's statements, neither drastic color changes nor differences between the same pigments ground with various binders occurred. For example, the 2024 results, which demonstrated that azur ground in oil darkened, disagreed with Ms. Fr. 640's suggestions that azur ground with oil caused its color to "die" *less* than when ground with water.[55] By contrast, the subtle color change and fading in the 2018 results misaligned with other excerpts in the manuscript that cautioned against pigment preparation in oil and opted rather for water.[56] On the other side of the same coin, the text communicated an awareness about azur's color change when ground in either water or oil, which was consistent with the experiments' results. Nonetheless, the qualitative results, which revealed only subtle changes in azur's appearance, did not seem to warrant the rhetoric of Ms. Fr. 640's description of its "death." The lexicon is notoriously difficult to assess, since the evaluation of color change was dependent on an unwritten standard of measurement and on an unknown temporal span. The magnified view of pigment swatches, which allowed the Making and Knowing team to identify minute changes in brightness and particle size, would have been an unnatural perspective for the sixteenth-century painter preparing pigments. The experiments' results might not be representative of the color changes observed by early modern practitioners, or perhaps the lexicon and color descriptions need to be re-defined. The discrepancies between the written word and material evidence signal broader

[55] Ms. Fr. 640, fols. 58v, 61v.
[56] Ms. Fr. 640, fols. 11r, 61v.

issues with scholarly prioritization of textual sources that do not necessarily align with the material processes they describe. One cannot assume that the written word can replace or fully encapsulate practical knowledge.[57]

The results from the azur experiments, which differed from the expectations raised by Ms. Fr. 640, challenge us to question the authenticity of reconstructions and the level of certainty that they can yield about the lived experiences of early modern artisans. Various practical factors could have contributed to the limitations of the experiments and their ability to determine the precise "death" of azur. First, using demineralized water, as opposed to tap water, could have changed the results. Additionally, the walnut oil used in the 2024 experiment added a yellow tone and saturation that, to an extent, limited our ability to identify the optical properties of azur's color change and "death." In response to this issue, one could conduct this same procedure with an increased amount of pigment or a reduced amount of oil, such as doubling the pigment or halving the oil measurement. Consolidation without visual change is difficult; however, another experiment could replicate the mulling process of blue pigments with a different binder (e.g., gum arabic or gelatin) which could reduce the yellowish tinge of the walnut oil that influenced the 2024 experiment results which might reveal the color change more clearly. For instance, the use of gelatin as a binder, in replacement of walnut oil, would eliminate the yellow tinge from the color swatches but compromise the historical accuracy of the experiment given that its use as a paint binder began in the twentieth century.[58]

The effect of paper brightness must also be accounted for when interpreting the results. One could conduct another experiment with repeated application, the "re-coat it twice" technique referenced in Ms. Fr. 640's fol. 65v, for the purpose that solid fields of color could be more effective in assessing color change. In a further experiment, spectrophotometry could measure color by capturing the amount of light a color reflects, and might offer precise scientific data about the color changes in azur in this experiment.[59] The shape and size of the particles affect the optical properties; thus, another experiment could consider grinding the pre-ground Kremer pigments to a standardized measurement.[60] Scanning electron microscopy (SEM) could also be used to identify the change of a pigment's particle size over the course of the grinding experiment.[61] Other Making and Knowing Project reconstructions of textual accounts in Ms. Fr. 640 have also faced difficulties with making dye and pigment colors as anticipated from their descriptions, which suggests that the unexpected results of azur's "death" was not an isolated incident.

To what extent should the written word be the standard by which we should conduct hands-on reconstructions and assess their results? Despite a text's inability to fully encapsulate

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[57] Smith, *From Lived Experience*, 204–6.
[58] See Oleg Mikhailov, "Gelatin as It Is: History and Modernity" on "bloom strength," the measurement of gelatin's firmness.
[59] See E. Mattei et al., "Raman spectroscopic analysis of azurite blackening," 302–6.
[60] Lars Vicum, Marco Mazzotti, and Martin Iggland, "Precipitation and Crystallization of Pigments," in *Handbook of Industrial Crystallization*.
[61] For the use of SEM in artisanal research, see I. M. Catalano et al., "Lapis lazuli usage for blue decoration of polychrome painted glazed pottery."

artisanal experience, written sources are often the surviving evidence we have that reveal glimpses of knowledge embedded in physical practices. While the written manuscript necessarily distanced a reader from and abstracted the material processes described, they nonetheless attempted to preserve an understanding of artisanal making and doing. Perhaps scholars should continue to interrogate period terms but with a more precise awareness of their limitations. For instance, terms such as "azur" and color "death" can be understood as mere guideposts about pigment qualities—such as their volatile nature in paint preparation—rather than guidelines for expected experimental results—such as the degrees to which a pigment should retain its color. Yielding results that did not necessarily align with, and even contradicted, the textual tradition within which the experiment was documented is significant and encourages us to think critically about the ontological categories with which we label the world in binary terms, such as theory and practice.[62] Hands-on reconstructions inform greater understanding about how pre-modern actors interacted with the material world and the conventions by which they documented their observations. The reconstruction of azur's "death" draws awareness to the tacit dimension of knowledge that emerges from hands-on history.[63] Experiments that center embodied knowledge challenge the priority that our academic culture has bestowed upon writing and, instead, indicate reciprocity between practitioner and materials.[64]

[62] See J.J. Bono, "Making Knowledge: History, Literature, and the Poetics of Science."
[63] See Michael Polanyi, *The Tacit Dimension*.
[64] See Karen Barad, "Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter."

Figures

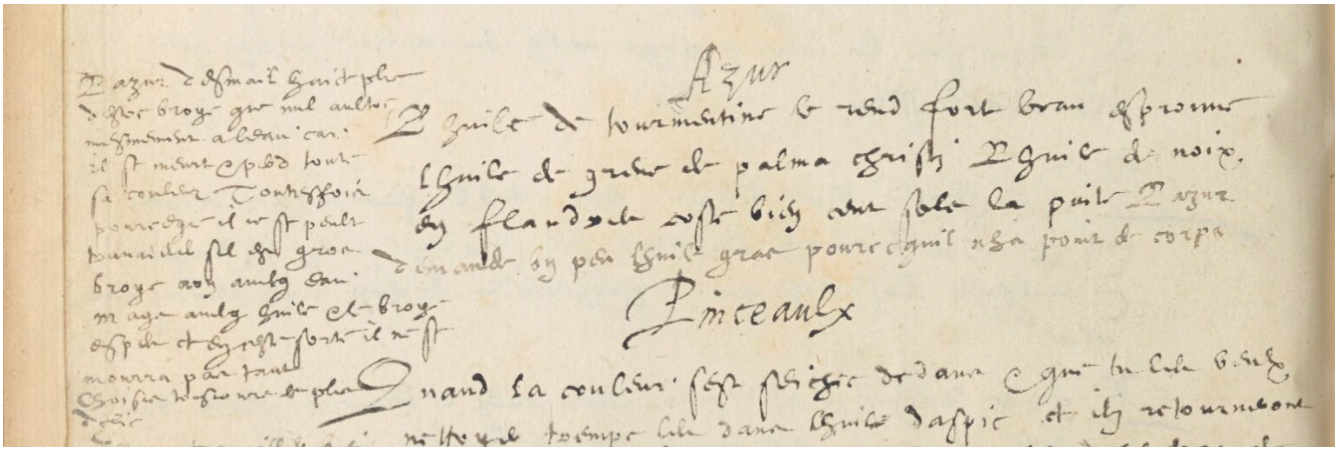


Figure 1. Detail of Fol. 58v, Ms. Fr. 640, in Pamela H. Smith et al., *Secrets of Craft and Nature in Renaissance France. A Digital Critical Edition and English Translation of BnF Ms. Fr. 640*.

Photo: Sourced from Pamela H. Smith et al., *Secrets of Craft and Nature in Renaissance France. A Digital Critical Edition and English Translation of BnF Ms. Fr. 640*

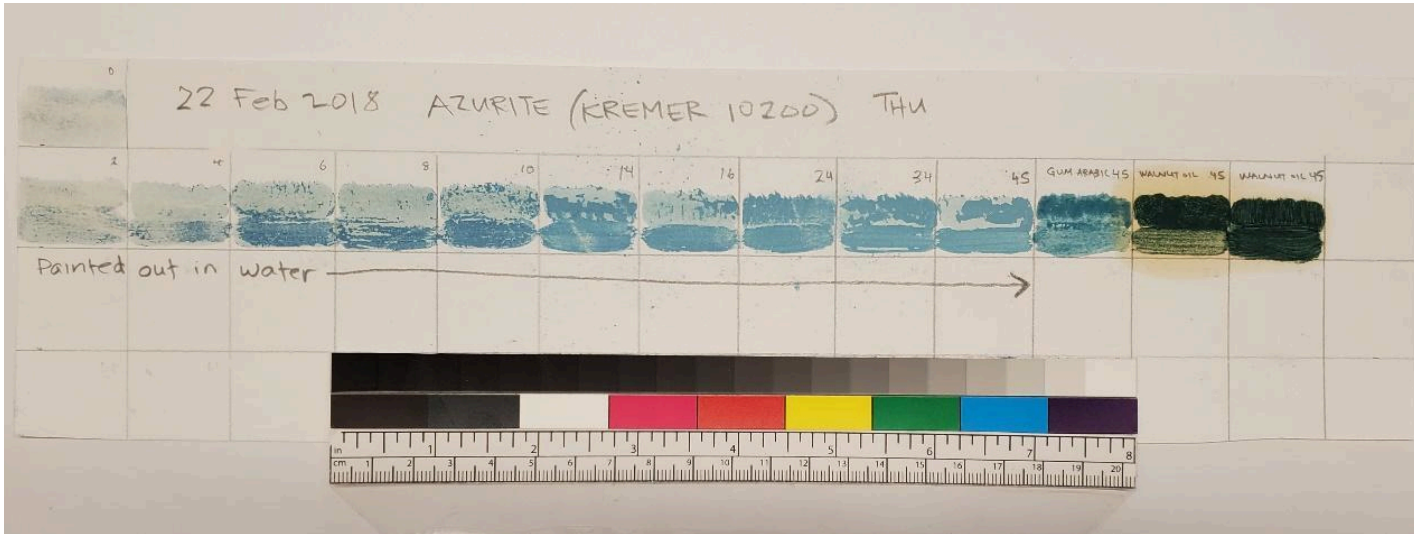


Figure. 2. Azurite (Kremer #10200) sample card, azur-grinding experiment 2018, The Making and Knowing Laboratory, Columbia University.

Photo: Sheena McKeever.

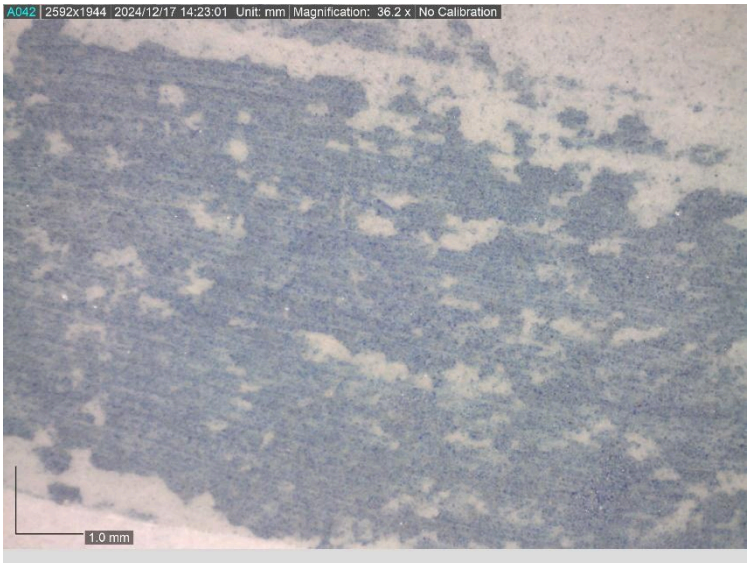


Figure 3. Detail of minute 10, Azurite (Kremer #10200) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

Figure 4. Detail of minute 16, Azurite (Kremer #10200) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

Figure 5. Detail of minute 45, Azurite (Kremer #10200) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

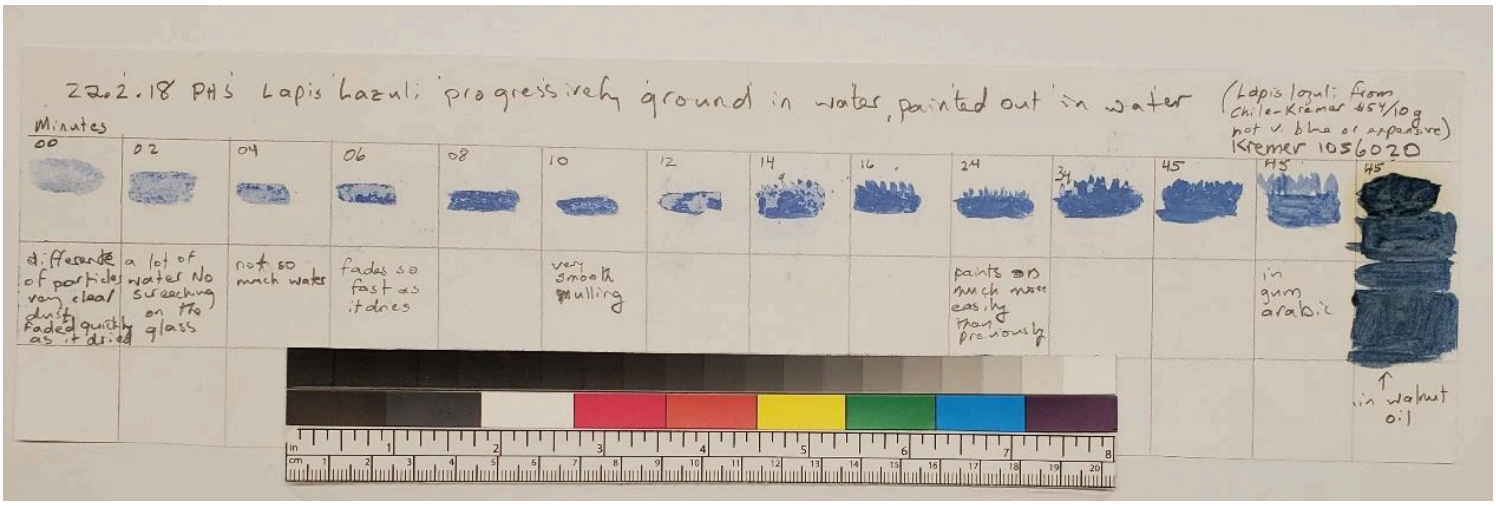


Figure 6. Lapis Lazuli (Kremer #1056020) sample card, azur-grinding experiment 2018, The Making and Knowing Laboratory, Columbia University.

Photo: by Sheena McKeever.

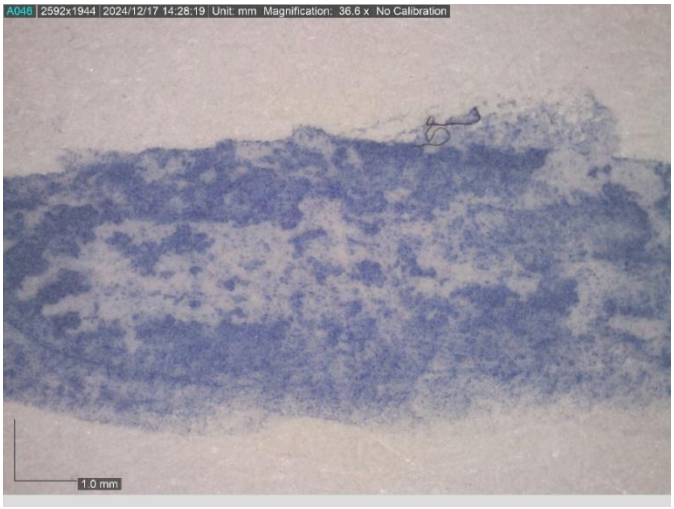


Figure 7. Detail of minute 10, Lapis Lazuli (Kremer #1056020) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

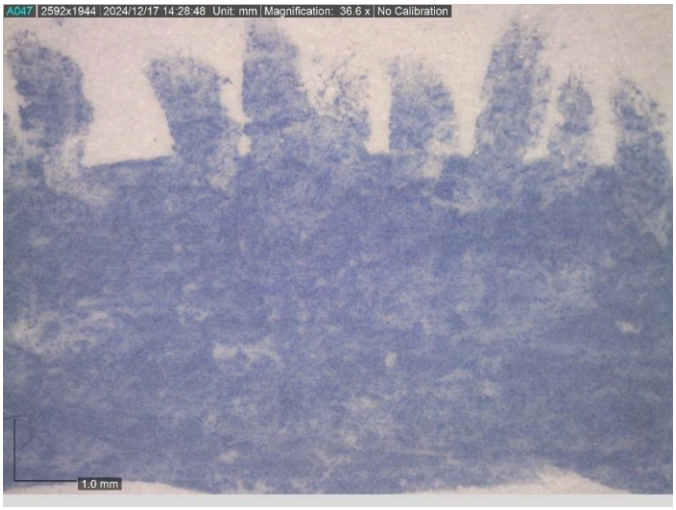


Figure 8. Detail of minute 24, Lapis Lazuli (Kremer #1056020) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

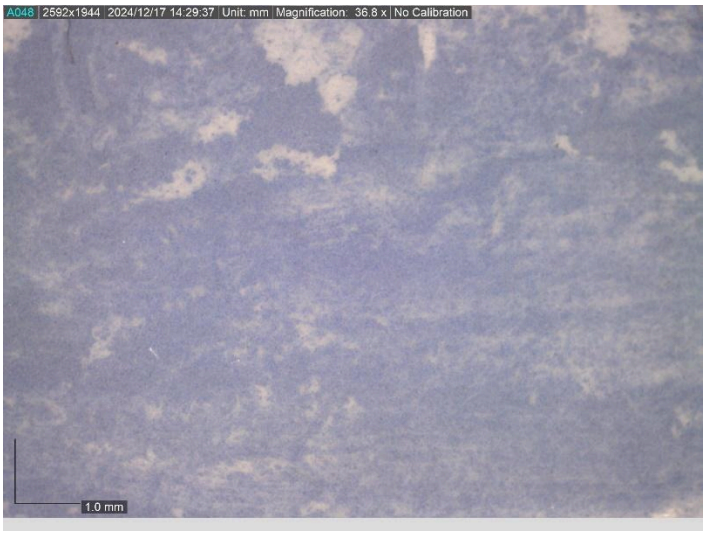


Figure 9. Detail of minute 45 (1), Lapis Lazuli (Kremer #1056020) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

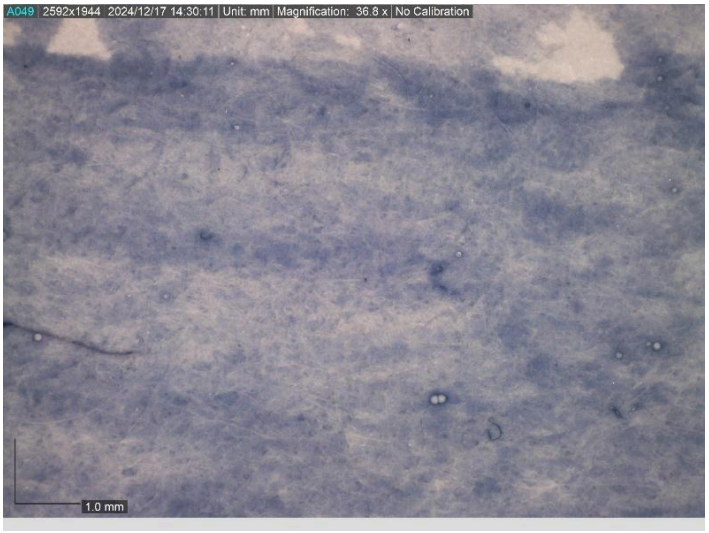


Figure 10. Detail of minute 45 (2), Lapis Lazuli (Kremer #1056020) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

Figure 11. Smalt (Kremer #10000) sample card, azur-grinding experiment 2018, The Making and Knowing Laboratory, Columbia University. Photo: by Sheena McKeever.

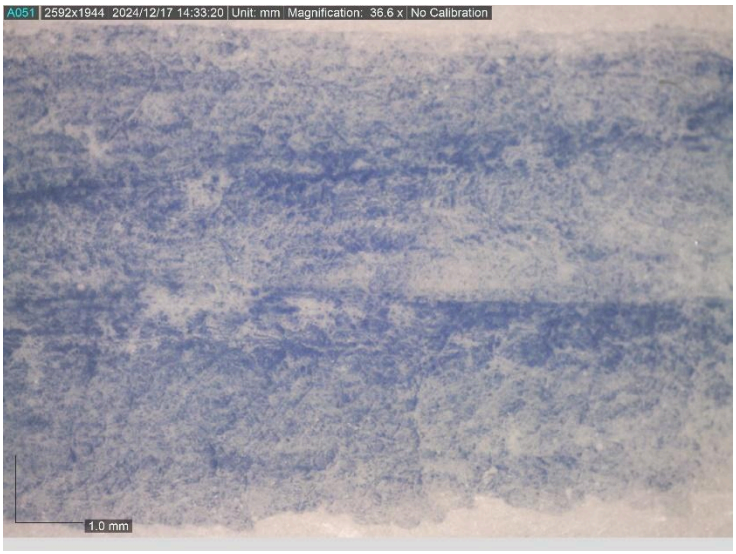


Figure 12. Detail of minute 12, Smalt (Kremer #10000) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

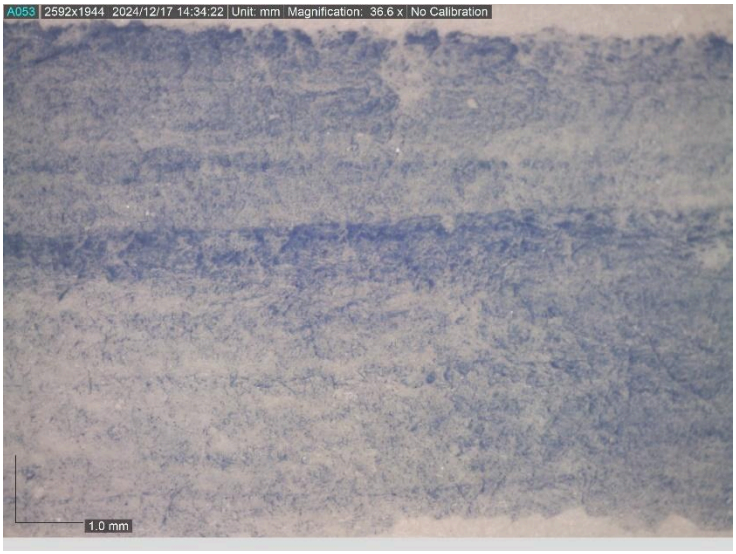


Figure 13. Detail of minute 16, Smalt (Kremer #10000) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

Figure 14. Detail of minute 24 (1), Smalt (Kremer #10000) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

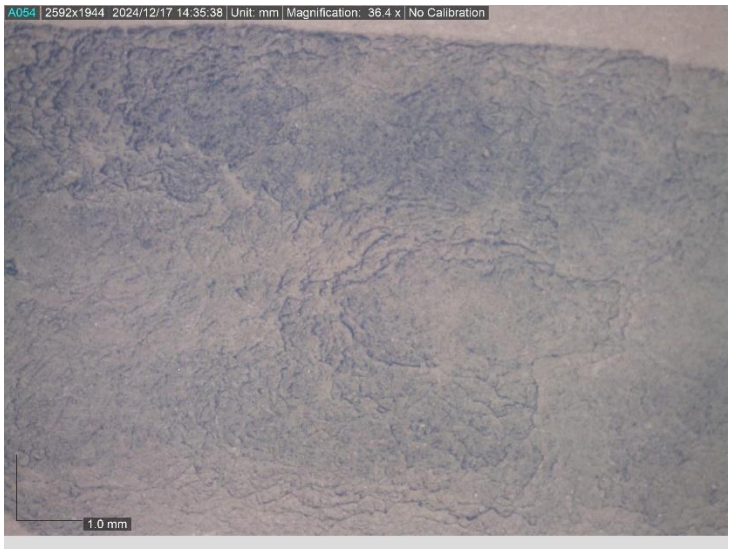


Figure 15. Detail of minute 24 (2), Smalt (Kremer #10000) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

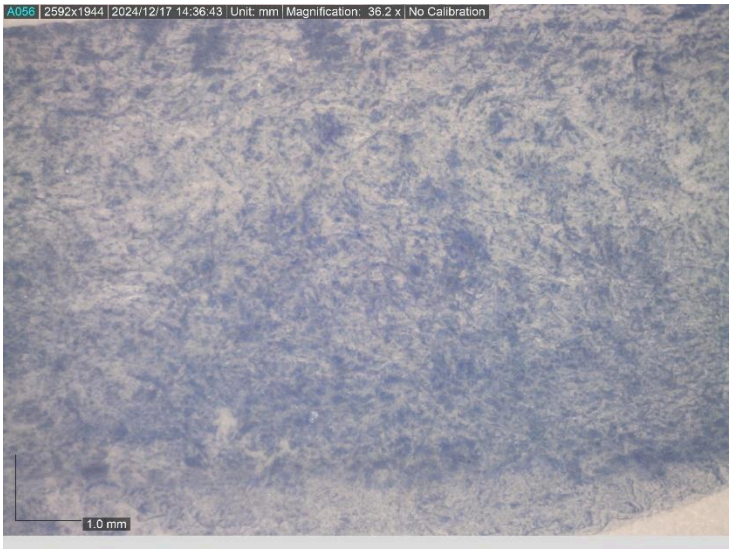


Figure 16. Detail of minute 45 (1), Smalt (Kremer #10000) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

Figure 17. Detail of minute 45 (2), Smalt (Kremer #10000) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

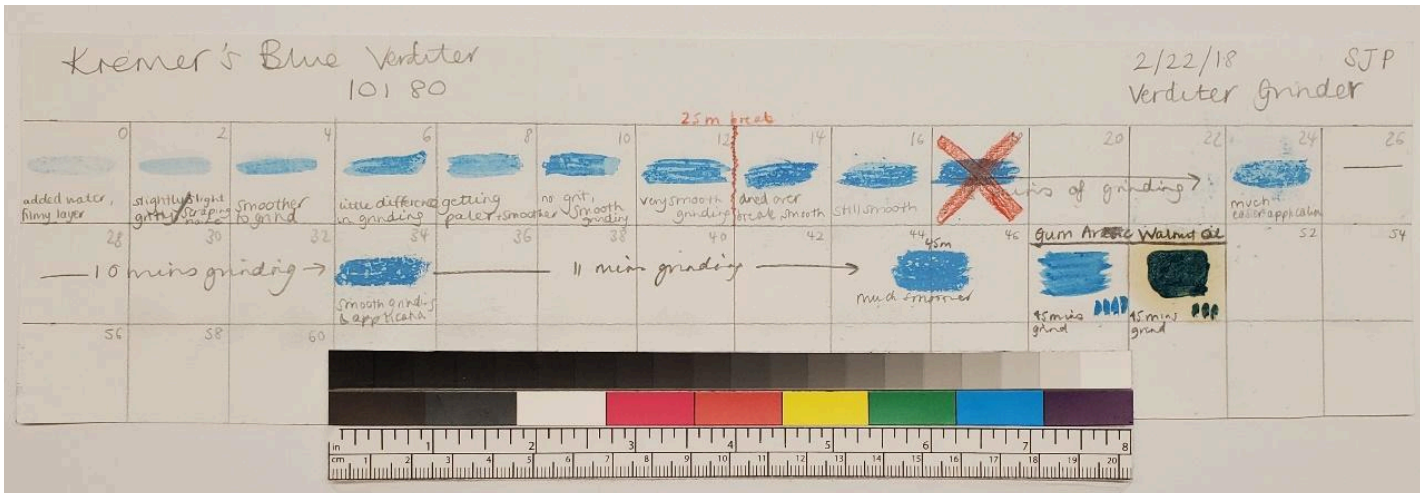


Figure 18. Verditer (Kremer #10180) sample card, azur-grinding experiment 2018, The Making and Knowing Laboratory, Columbia University.

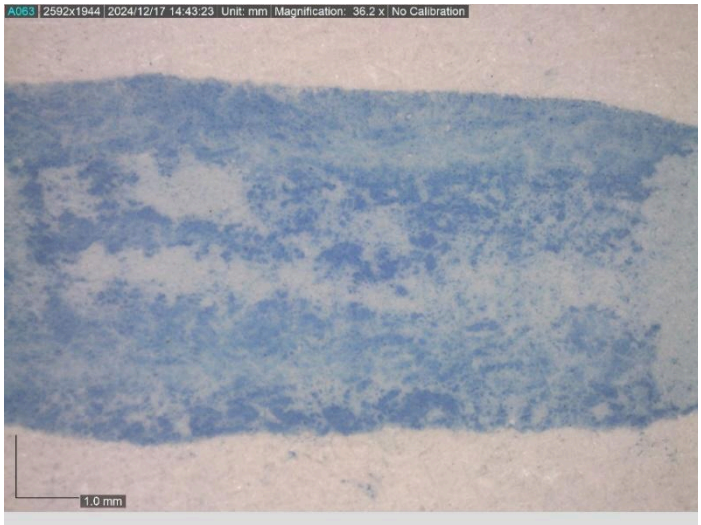
Photo: by Sheena McKeever.

Figure 19. Detail of minute 8, Verditer (Kremer #10180) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

Figure 20. Detail of minute 10, Verditer (Kremer #10180) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.



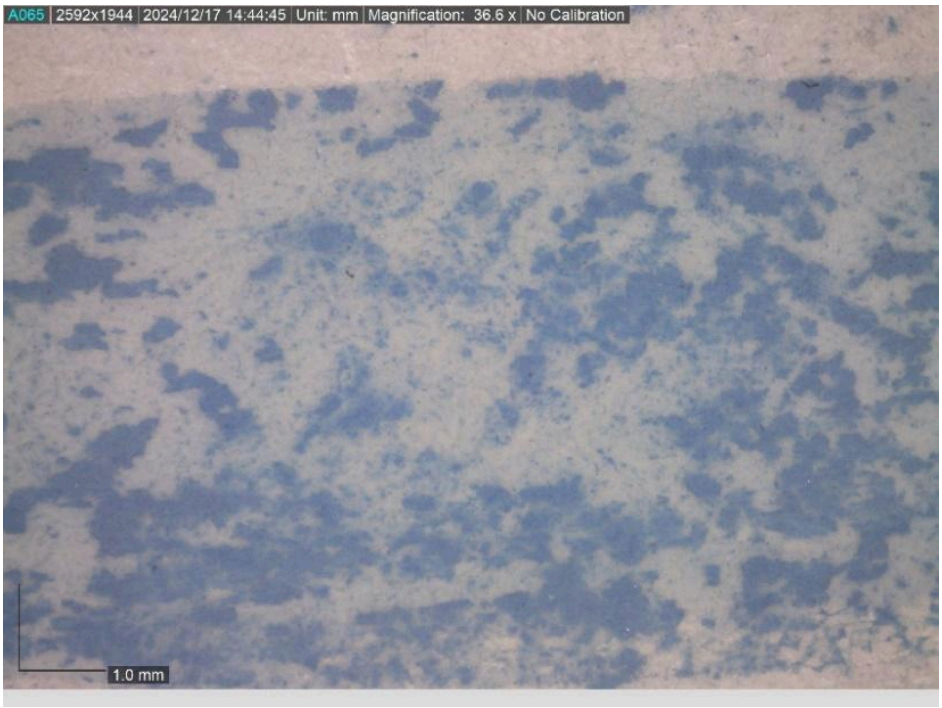


Figure 21. Detail of minute 24, Verditer (Kremer #10180) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

Figure 22. Detail of minute 45, Verditer (Kremer #10180) sample card, azur-grinding experiment 2018.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

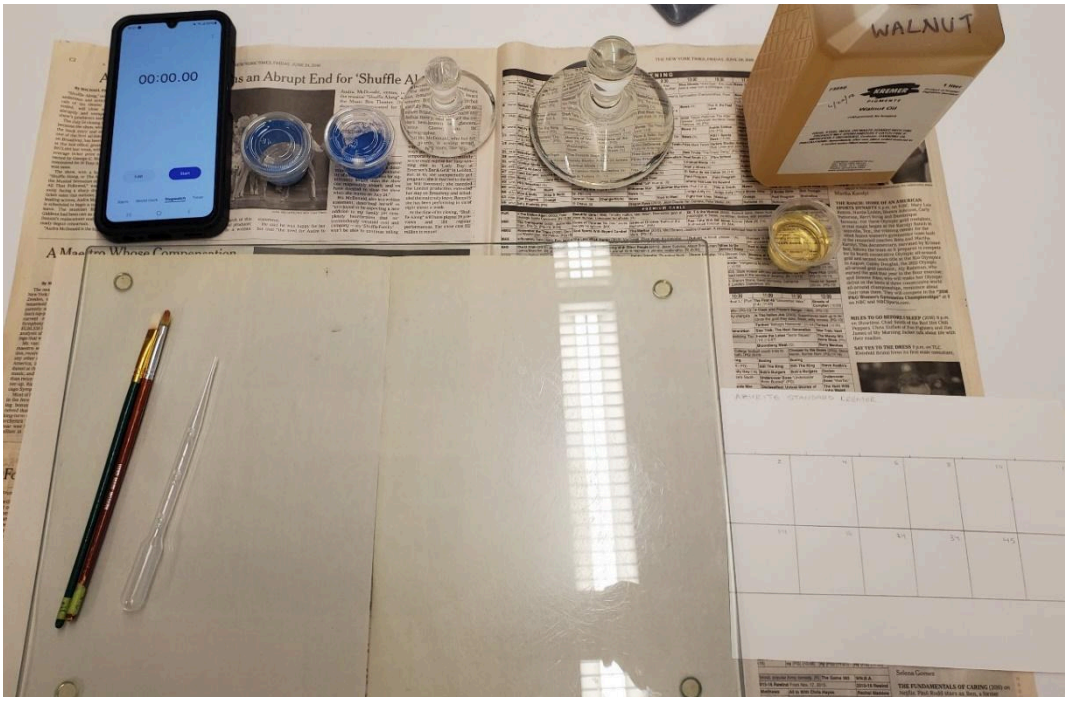


Figure 23. Materials and instruments for 2024 azur-grinding experiment, November 2024, The Making and Knowing Laboratory, Columbia University.

Photo: by Sheena McKeever.

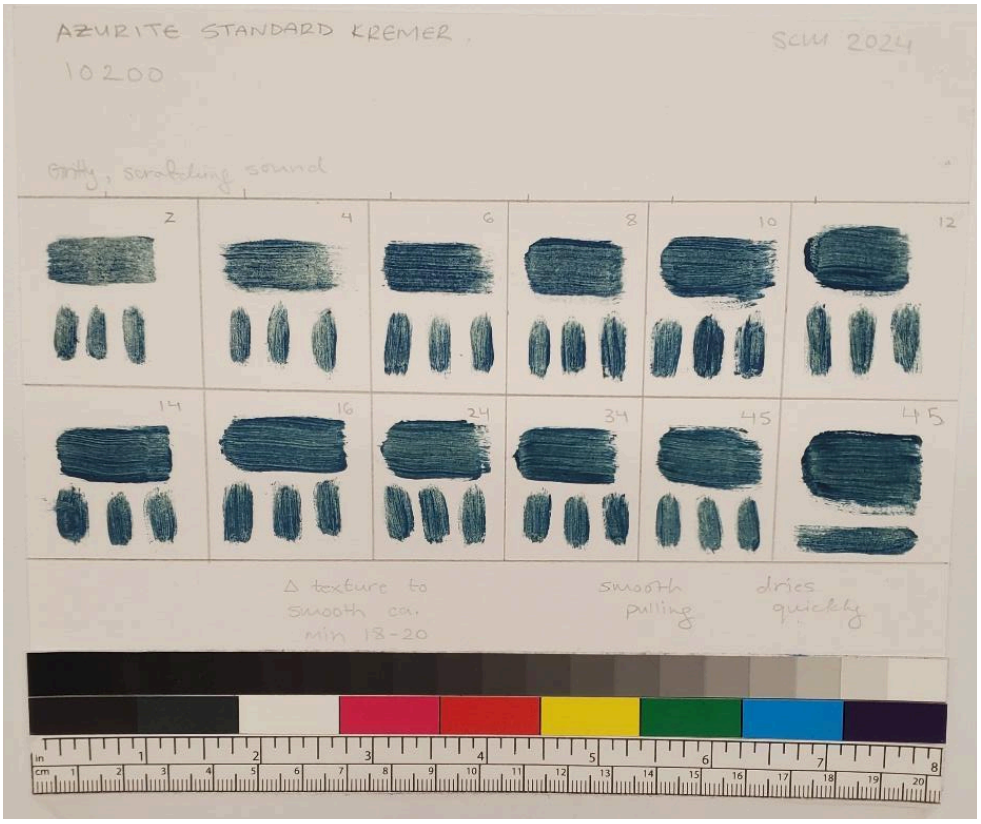


Figure 24. Azurite (Kremer #10180) sample card, azur-grinding experiment 2024, The Making and Knowing Laboratory, Columbia University.

Photo: by Sheena McKeever.

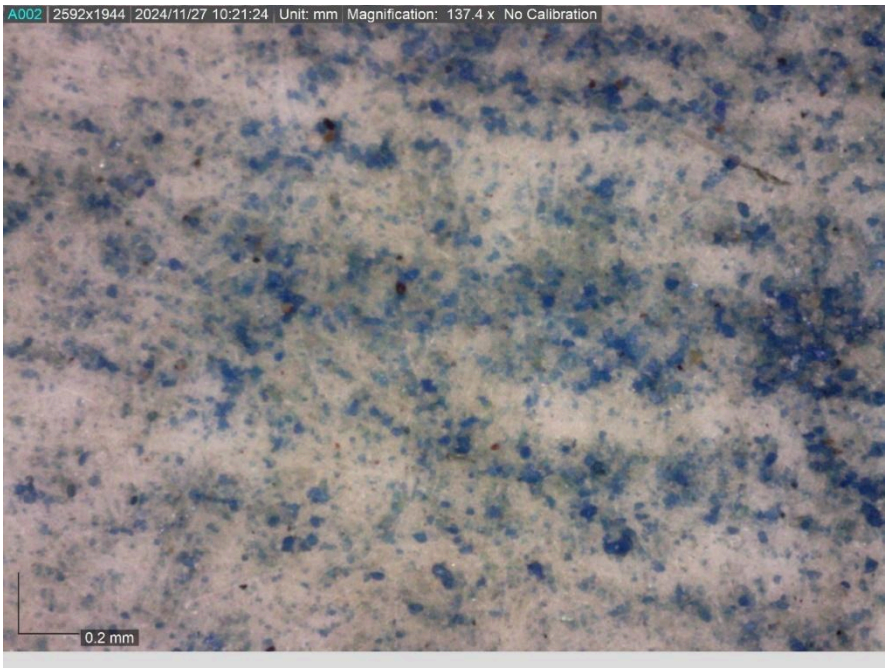


Figure 25. Detail of minute 2, Azurite (Kremer #10200) sample card, azur-grinding experiment 2024.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

Figure 26. Detail of minute 45, Azurite (Kremer #10200) sample card, azur-grinding experiment 2024.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

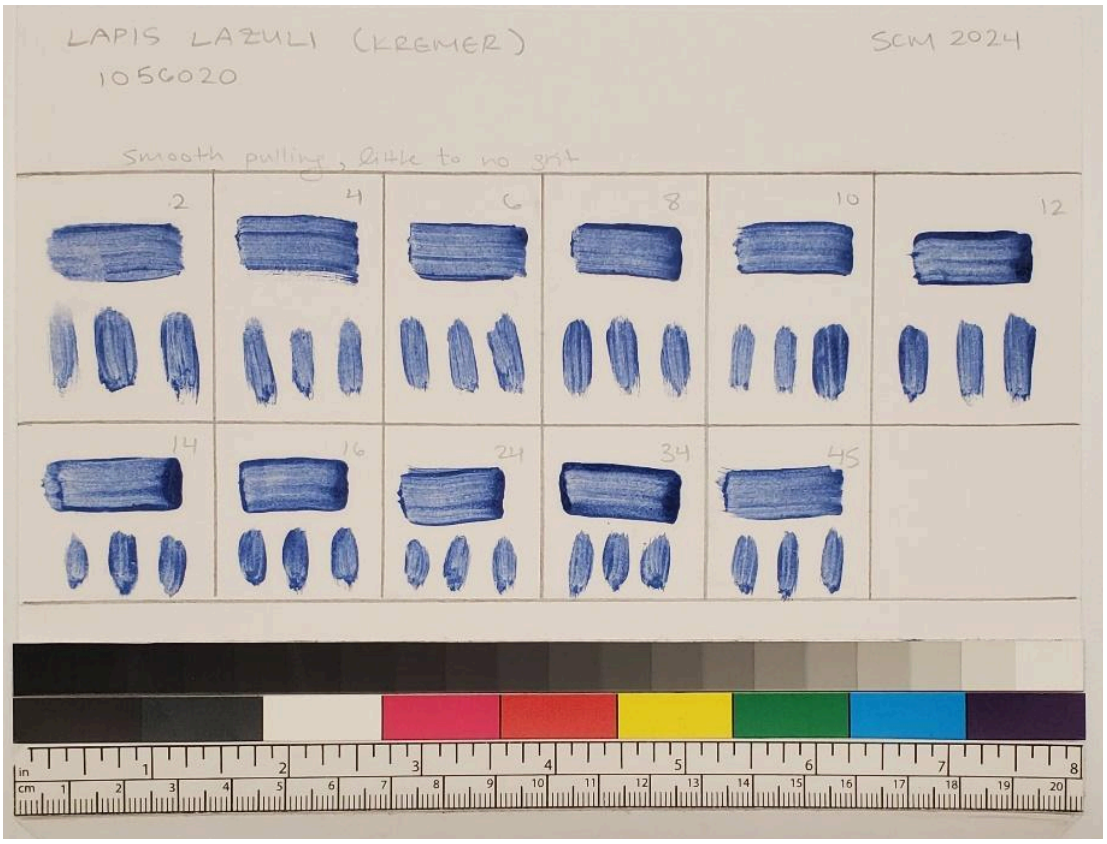


Figure 27. Lapis Lazuli (Kremer #1056020) sample card, azur-grinding experiment 2024, The Making and Knowing Laboratory, Columbia University.

Photo: by Sheena McKeever

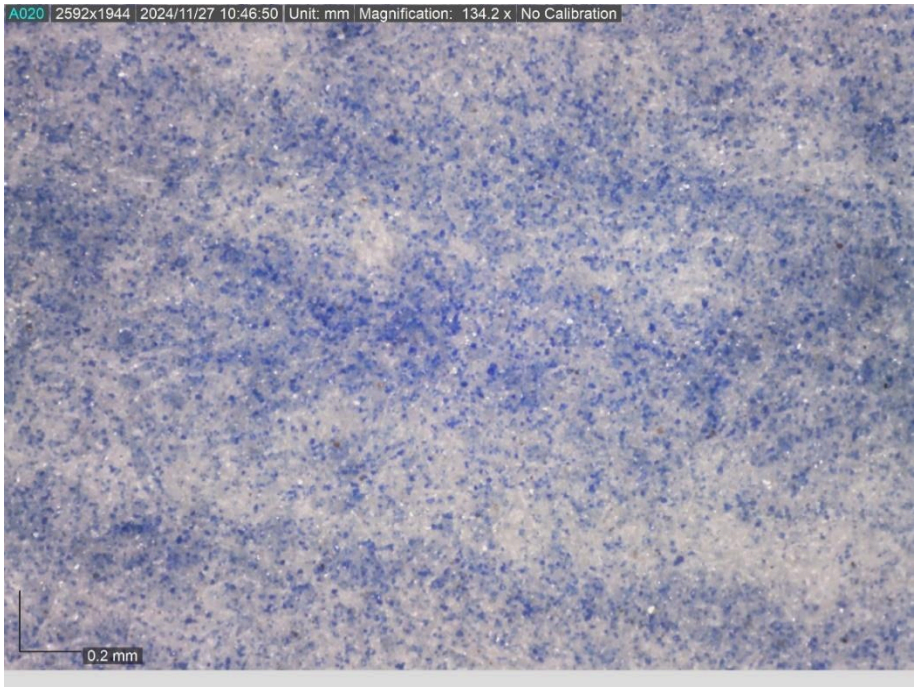


Figure 28. Detail of minute 2, Lapis Lazuli (Kremer #1056020) sample card, azur-grinding experiment 2024.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

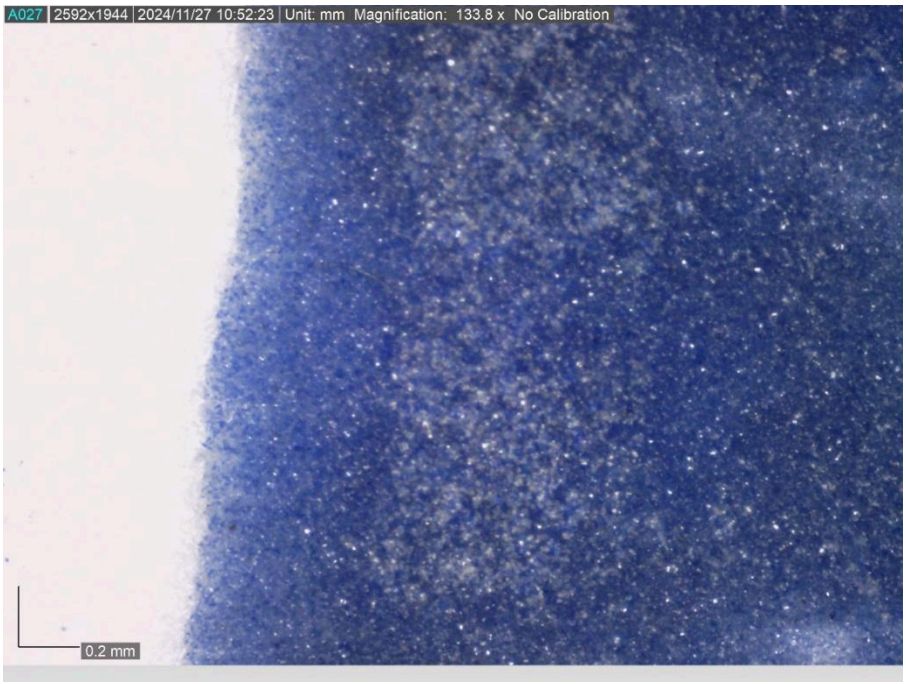


Figure 29. Detail of left-edge film at minute 34, Lapis Lazuli (Kremer #1056020) sample card, azur-grinding experiment 2024.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

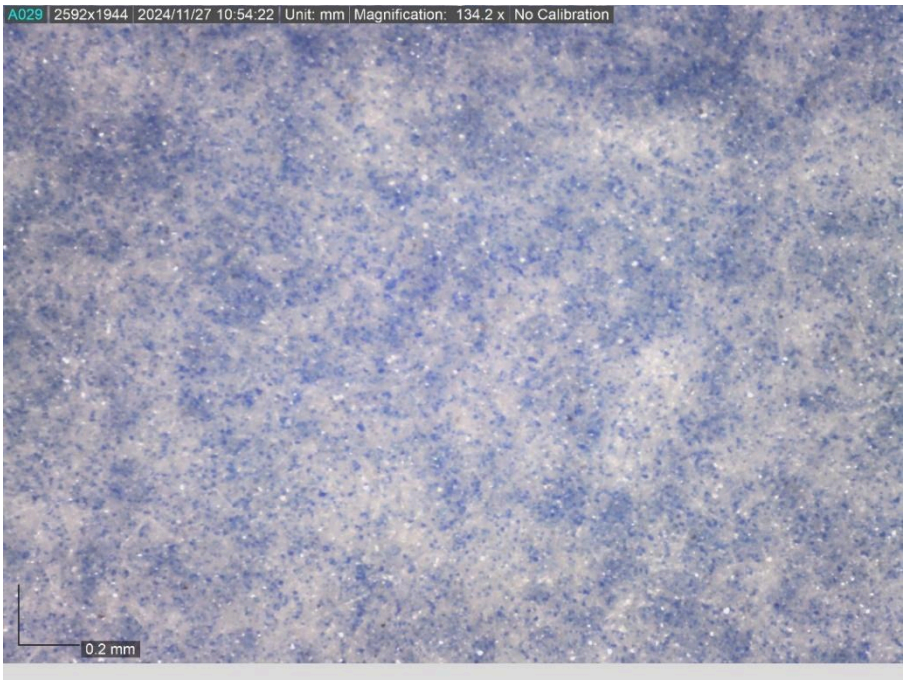


Figure 30. Detail of minute 45, Lapis Lazuli (Kremer #1056020) sample card, azur-grinding experiment 2024.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

Figure 31. Smalt (Kremer #10000) sample card, azur-grinding experiment 2024, The Making and Knowing Laboratory, Columbia University.

Photo: by Sheena McKeever.

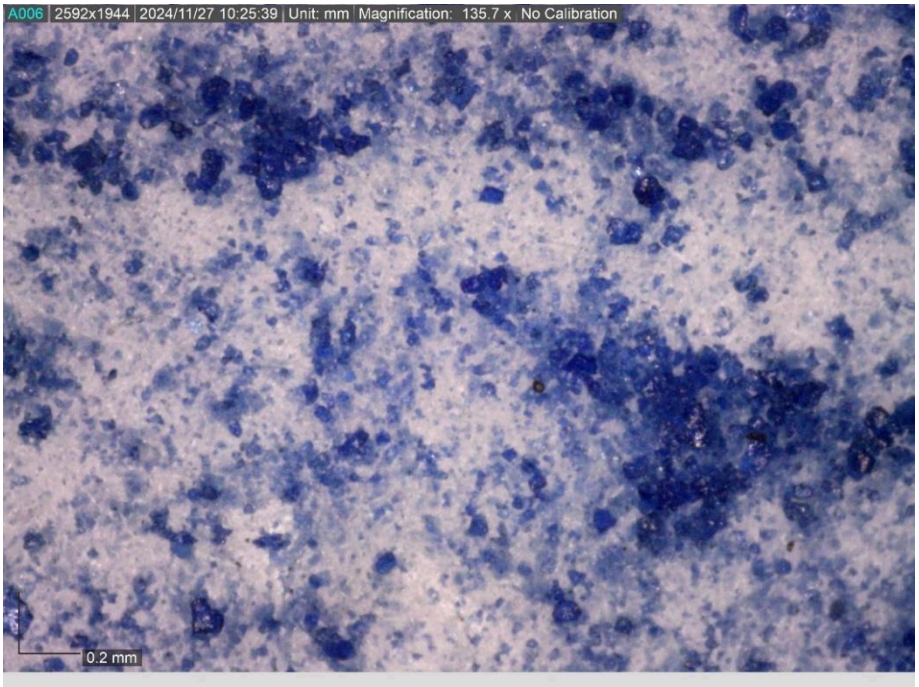


Figure 32. Detail of minute 2, Smalt (Kremer #10000) sample card, azur-grinding experiment 2024.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

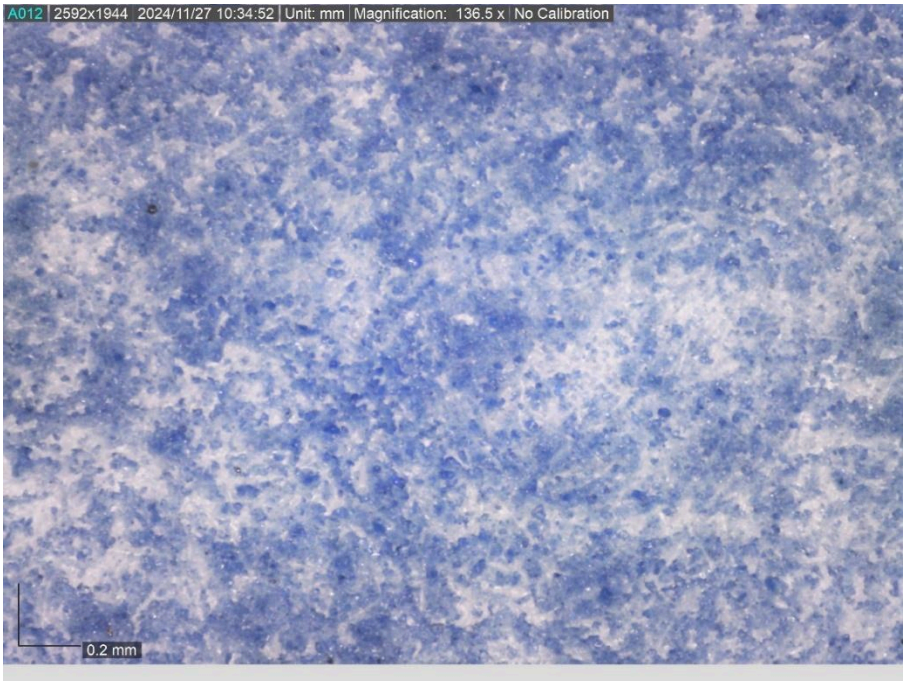


Figure 33. Detail of minute 45, Smalt (Kremer #10000) sample card, azur-grinding experiment 2024.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

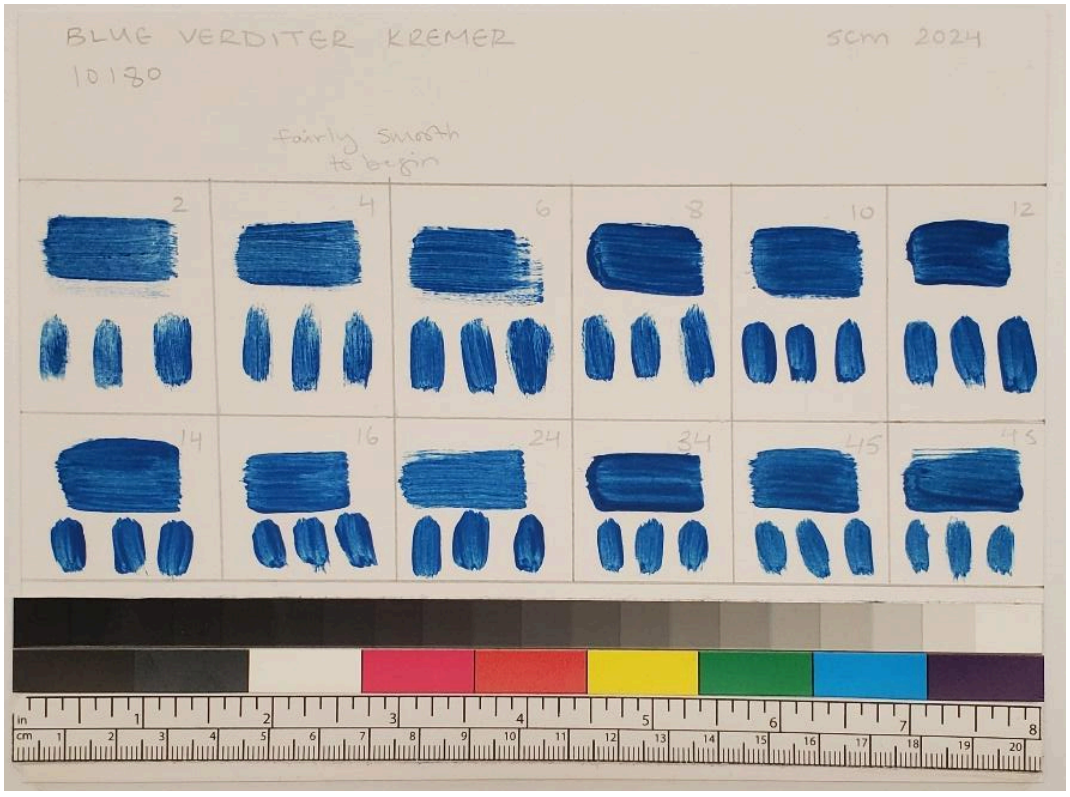


Figure 34. Verditer (Kremer #10180) sample card, azur-grinding experiment 2024, The Making and Knowing Laboratory, Columbia University.

Photo: by Sheena McKeever.

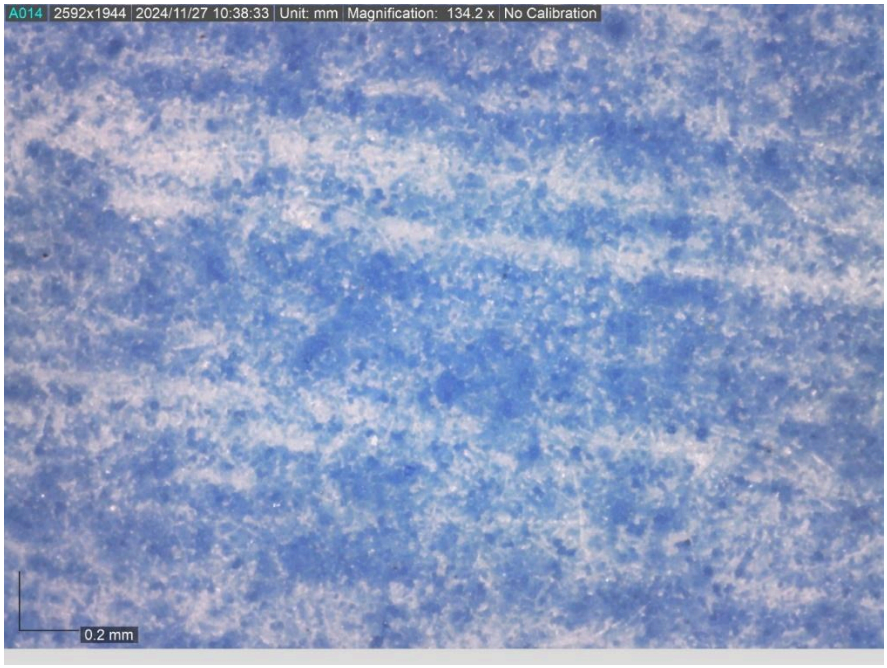


Figure 35. Detail of minute 2, Verditer (Kremer #10180) sample card, azur-grinding experiment 2024.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

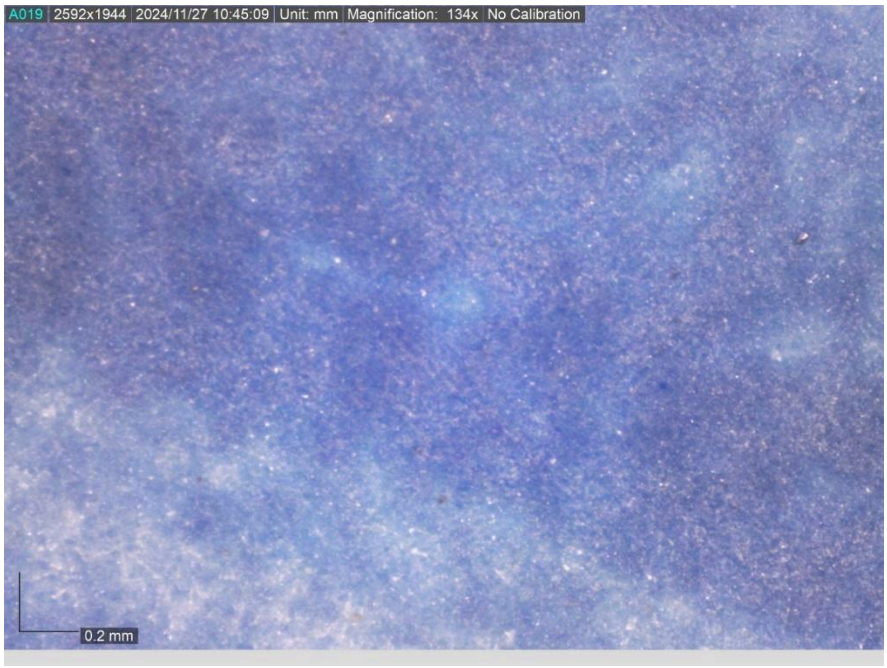


Figure 36. Detail of minute 45, Verditer (Kremer #10180) sample card, azur-grinding experiment 2024.

Photo: by Sheena McKeever using Dino-Lite Edge / 5MP AM7515 Series, Dino-Lite Edge computer software.

Appendix 1: Materials and Instruments

- Azurite (Kremer standard, 10200), quantity: 1/4 tsp
- Lapis (Kremer, 1056020), ultramarine, quantity: 1/4 tsp
- Smalt (Kremer standard, 10000), quantity: 1/4 tsp
- Verditer (Kremer, 10180), quantity: 1/4 tsp
- Walnut oil (Kremer, 73550), quantity: 6 ml
- Water (tap, sourced from The Making and Knowing laboratory)

- Glass mullers (large, small)
- Glass palette
- Small plastic container (for oil)
- Dropper (for measuring oil)
- Mixing palette knife
- Oil brushes
- Mixed media paper (made gridded sample cards in advance)
- Color ruler
- Stopwatch (smartphone clock app)

Appendix 2: Hazards Identification (MSDS)

Azurite natural standard, Copper hydroxide carbonate:

> Classification according to EC Regulation 1272/2008: Acute toxicity (oral), hazard category 4. H302 Harmful if swallowed.
>
> Hazardous Ingredients: Cupric carbonate basic (Xn; R22; H302)

Natural Lapis Lazuli, sodium-aluminium-silicate, Ultramarine Blue Pigment 29, C.I. 77007:

> Classification according to EC Regulation 1272/2008: This product does not require classification and labeling as hazardous according to CLP/GHS.

Smalt, standard, Cobalt potassium silicate glass, Pigment Blue 32, C.I.77365:

> Classification according to EC Regulation 1272/2008: This product does not require classification and labeling as hazardous according to CLP/GHS.

Blue Verditer, CuCO3ïCu (OH)2 basic copper carbonate:

> Classification according to EC Regulation No.1272/2008 GHS Classification: Acute toxicity (oral), hazard category 4.
>
> Hazardous ingredients: Cupric carbonate basic (Xn; R22; 302)

Walnut Oil, Juglans Regia (walnut) seed oil, CAS No. 8024-09-7:

> Classification according to EC Regulation 1272/2008: This product does not require classification and labeling as hazardous according to CLP/GHS.

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