The Alchemy of Glass

Counterfeit, Imitation, and Transmutation in Ancient Glassmaking

MARCO BERETTA

Science History Publications/USA
a division of
Watson Publishing International LLC
Sagamore Beach
2009

CHAPTER 5

From Byzantine Glass to Early Modern Alchemy

"Le verre paroît être la véritable terre élémentaire"

Buffon, *Histoire naturelle* (1749)

GLASSMAKING CONTINUES IN BYZANTIUM

While the Roman Empire prospered, glass manufacturing spread steadily throughout its territories and, as evidenced in the episode of Emperor Tiberius' appreciation for the invention of unbreakable glass (see Chapter 2), the social status of glassmakers (*vitrearii*) was higher compared to that of other guilds of craftsmen. Unfortunately, we only possess a few literary and epigraphic hints as to who these glassmakers were and the degree of their specialization. An inscription by Iulius Alexander (Fig. 1), a glassmaker from Carthage operating in Lyon sometime in the second to third century CE, reveals a certain degree of

wealth.[1] We know that the *margaritarii*[2] who traded pearls and precious stones from the Eastern Provinces were so well represented in Rome that the *Officinae Margaritariorum* were active in the Forum. And an interesting undated inscription reports the existence of the glassmaker "C. Fufio zmaragdo margargaritario,"[3] revealing that the *margaritarii* also fabricated false emeralds. Emperor Constantine's donation of a table of gold and emerald (*tabulum de auro et smaragdo*) to the altar of Saint Peter also attests to the importance of this kind of profession:[4] we may wonder whether the *tabula smargdina*, the size of which could be hardly be made entirely of emerald, was fabricated with green glass instead, the product of the Roman tradition of manufacturing these kinds of artifacts.[5] The historical record also suggests that glass was used to imitate pearls and, more generally, *margaritae*, and we may presume that this profession did not disappear during the Byzantine Empire and later periods, given the appearance of the earliest statutes regulating glassmaking in Venice during the thirteenth century CE. These documents still referred to the guild of the *margaritari* in order to designate those glass-

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[1] "D(is) M(anibus)//et memoriae aeternae Iul//i Alexandri, natione Afri, civi//Carthaginesi omini optimo, opif//ici artis vitriae, qui vix(it) anos LXXV,//mensen V, dies XIII, sene ulla//lesione animi cum coniuge//sua virginia, cum qua vix//sit annis XXXXVIII, ex qua//creavit filio<s>III et filiam,//ex quibus his omnibus ne//potes vidite deos supest//ites sibi reliquit. Hunc//tumulum ponendum cu//raverunt Numonia Ba//llia, uxor et Iulius Al//exius, filius, et Iulius F//elix, filius, et Iulius Gal//lonius, filius, et Num[o]//nia Belliosa, filia; it[em]//nepos eius Iulius An[ct]//us, Iulius Felix, Iuliu[s Alex]//sander, Iulius Galon[ius Iuli]//us Leontius, Iulius Gall[onius?]//Iulius Eonius p(ro) p(arte) c(u)r(averunt) et sub asc(ia)//dedicav(erunt)." *Corpus Inscriptionum Latinarum*, XIII, 2000.

[2] An epigraph was found in Rome in 1907 bearing the following inscription dating from the first century CE: "Euhodus ma[rgari]/[t]arius de Vela[bro] / sibi et Tampiae L(uci) l(ibertae) / Stratonice et liber[is?]."

[3] Achille Deville, *Histoire de l'art de la verrerie dans l'Antiquité* (Paris: Morel, 1873), p. 61. On recently-discovered inscriptions see Pavlos Triantafyllidis, "Glassmakers of Late Antiquity in Greece: Philological References and New Archaeological Evidence," *Journal of Glass Studies*, (2007), *49*:262–264.

[4] Francesca Dell'Acqua, *Illuminando colorat. La vetrata tra l'età tardo imperiale e l'alto Medioevo: le fonti, l'archeologia* (Spoleto: Centro Italiano di Studi sull'alto Medioevo, 2003), p. 119.

[5] On the *tabula*, see the still-useful synthetic reconstruction given in Eric J. Holmyard, *Alchemy* (Harmondosworth: Penguin Books, 1957), pp. 97–100.

makers who specialised in the fabrication of glass enamels and pearls.[6] It is unclear, however, if the *gemmarii*, about whom only one inscription seems to have survived,[7] were specialised in the fabrication of gems or simply in their trade.

Glassmaking as a specialist profession seems to have reached its peak in 337, when the Emperor Constantine promulgated an Edict commanding that the glassmakers should be exempted "from all public services, on condition that they devote[d] their time to learning their crafts. By these means they may desire all the more to become more proficient themselves and to train themselves."[8] The list of this edict's beneficiaries included, among others, the architects, the physicians and, in relation to glassmaking, the *laquerarii*, the *diatretarii*, the mosaicists, thus demonstrating that new specialisations were emerging within the art form. It is an interesting coincidence that when the edict was written, the founding of the *Nova Roma Constantinopolitana*, Byzantium, was still a recent event. Its foundation marked both the drift of Roman power to the East, and the birth of a new era for the Christian religion.

FIG. 1. Copy of the glassmaker Iulius Alexander's inscription. Rome, Museo della Civiltà Romana.

Even in the intermediate phase that links two such distant epochs as Late Antiquity and the Middle Ages, glass remained a material of great importance not only for daily life and the development of illumination

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[6] Glassmakers migrated from Ravenna to Torcello at the end of the sixth century. On the *margaritari* during the Middle Ages in Venice see Luigi Zecchin, *Vetro e vetrai di Murano. Studi sulla storia della vetro*, vol. 2 (Venice: l'Arsenale Editrice, 1989), p. 250 where he refers to statute entitled *Mariegola dei cristalleri, margariteri, paternostrer.*

[7] "M. Lollius Alexander Gemmarius." Cit. in Achille Deville, *Histoire de l'art de la verrerie dans l'Antiquité.* Cit., p. 61.

[8] Codex Theodosiamun, XIII, 4, 2.

for architectural spaces, but also for scientific purposes in optics and alchemy. It is necessary to distinguish two traditions that arose during Late Antiquity and which were destined to have separate trajectories and developments. While the Latin West witnessed a rapid decline of scientific knowledge, in Alexandria and, above all, in Constantinople and Syria, the Greek scientific tradition continued to be developed by a series of naturalists who kept scientific investigation distinct from Christian orthodoxy. It is therefore not surprising that while in the first century CE, many Latin authors still explicitly refereed to alchemical authors, from the third century CE onwards the pursuit of alchemical research remained confined to the Greek and then the Byzantine tradition. More interesting is the fact that glassmaking progressively migrated from the Roman centers of production to the Southeastern capital and other associated cities. Alongside several Syrian centers and the Alexandrine area, Constantinople represented a cultural site capable of assuring favourable conditions for scientific and technical research, however briefly. The widespread opinion that the omnipresence of religion in Byzantine culture made scientific endeavours suspect and sterile[9] is due both to the scarcity of studies of a tradition which has often remained in manuscript form, and to the prominent role played by the occult sciences which, until recently, have been identified as revealing sign of a lack of interest in the "positive" natural sciences.[10]

From the first half of the fourth to the end of the sixth century CE, a remarkable number of scholars, such as Zosimus, Proclus, Anthemius and Alexander of Tralles, Euthochius, Philoponos, and Aetios of Amida, distinguished themselves in developing the works of Pseudo-Democritus, Aristotle, Archimedes, Apollonius and Galen in original ways.[11] Despite the fact that several Byzantine scientists kept the Greek

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[9] Norman H. Baynes, *The Byzantine Empire* (London: Oxford UP, 1949), p. 23 and ff.

[10] An extremely useful reassessment of this historiographical image is published in the recent collection edited by Paul Magdalino and Maria Mavroudi, *The Occult Sciences in Byzantium* (Geneva: La Pomme d'Or, 2006).

[11] An adequate historical reconstruction of Byzantine science is still a *desideratum*. Useful but generic and outdated information can be drawn from George Sarton, *Introduction to the History of Science* (Baltimore: Carnegie Institution of Washington, 1927), vol. 1, pp. 414–442; Aldo Mieli, *La science arabe et son rôle dans l'évolution scientifique mondiale* (Leyden: Brill, 1938), pp. 39–47. Although mostly devoted to a later period, on the history of medicine see *Symposium on Byzantine Medicine.*

scientific tradition alive during the preceding centuries, especially in mathematics, it was only during this brief period of rebirth lasting little more than a century that significant results were achieved in many scientific and technical fields. In this favourable context, there is evidence of an active and important community of glassmakers in Constantinople.[12] Unfortunately, apart from the massive archaeological remains, our knowledge of Byzantine glass production and of its uses is confined to exceedingly few literary sources, most of which are late and Medieval. However, the spectacular evidence of a flourishing glass industry during the early centuries (fourth-sixth centuries CE) of the Byzantine Empire are undoubtedly the monumental mosaics which adorned the newly-conceived basilicas and mausoleums.

The construction of the *Hagia Sophia*, the most important architectural building of Late Antiquity, during the reign of the Emperor Justinian (Fig. 2) provides us with useful information on the changing importance of glass in the Byzantine cultural milieu. Anthemius of Tralles, one of the basilica's architects, was a mathematician and engineer who died in 534. He wrote an important treatise on burning mirrors in which he demonstrated the plausibility of the Archimedean project of burning ships from a distance through flat glass mirrors.[13] We have already emphasized that Theophrastus (*De Igne*) claimed the existence of glass mirrors even though he did not clearly explain their use. Aside from the material used for the production of these instruments, this kind of literature is important because it combines the principles of an abstract science—geometry—with practical techniques used for building these instruments—glassmaking. In fact, between the Byzan-

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Dumbarton Oaks Papers 38, John Scaraborough ed. (Washington: Dumbarton Oaks Research Library and Collection, 1985).

[12] Joseph Philippe, *Le monde Byzantin dans l'histoire de la verrerie. (Ve–XVIe siècle)* (Bologna: Editrice Patron, 1970). Regrettably Philippe's classical work does not take scientific and technological literary sources into consideration and mostly focuses on archaeological findings.

[13] Roshdi Rashed (ed. and transl.), *Les Catoptriciens Grecs. I, Les miroirs ardents. Textes établis, traduits et commentés par Roshdi Rashed* (Paris: Les Belles Lettres, 2000), pp. 317–319. On Anthemius see also Thomas Heath, *A History of Greek Mathematics* (Oxford: Clarendon Press, 1921), vol. 2, pp. 200–203 and pp. 541–543 and G. L. Huxley, *Anthemius of Tralles. A Study in Later Greek Geometry* (Cambridge Mass.: Eaton Press, 1959).

FIG. 2. Portrait of Justinian in glass mosaic in the Basilica of San Vitale in Ravenna (sixth century CE).

tine naturalists and their Arab translators and interpreters, catoptrics (the study of light reflection) developed as a mixed science: a combination of theory (*theoria*) and practise (*techne*). It is for this reason that one finds spherical and helixoidal mirrors alongside geometrical demonstrations of the reflection of luminous rays on parabolas, with several references to the type of instruments used and the material with which they were made. It is therefore not surprising that Anthemius' work on mirrors was one of the Arabs' main sources for developing ancient catoptrics in new ways. As has recently been shown,[14] the first geomet-

[14] Roshdi Rashed, "A Pioneer in Anaclastic. Ibn Sahl on burning mirrors and lenses," *Isis*, (1990), *81*:464–491.

rical studies on the optical properties of lenses belong to this specific tradition, a point that emphasizes how Byzantine scientists tried to make a more advanced synthesis between the technical and geometrical traditions than their predecessors.

Besides his works on geometrical optics, Anthemius is above all known for his employment by the Emperor Justinian to rebuild the basilica of the *Hagia Sophia*. In this project, Anthemius collaborated with another mathematician and engineer, Isidorus of Miletus, who according to Sarton was at that time "the centre of a school of mathematicians who were especially interested in Archimedean and Apollonian geometry."[15] As it has been rightly pointed out, Anthemius and Isidorus "were not just master-builders who knew from experience what could be done, but people able to bring a fresh theoretic insight to new problems. What else we know of Anthemius and Isidorus suggests that they may have been primarily academics."[16]

Praised by contemporaries and throughout history as the greatest achievement of Byzantine architecture, the basilica of the *Hagia Sophia* defied the conventions of its time in both its size and interior decorations.[17] In this project, glass occupied a central role. In the absence of direct sources, it is not possible to clarify the reasons that led to Anthemius' employment in the basilica's reconstruction. But one can formulate several hypotheses. For example, it is important that in the chapter devoted to the burning mirrors in the *Suda*, glass is confused with an element, *élektron*, described as a combination of glass and gold that completely covered "a table in Sancta Sophia."[18] Similarly, an

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[15] George Sarton, *Introduction to the History of Science,* cit., vol. 1, p. 415.

[16] Rowland J. Mainstone, *Hagia Sophia. Architecture, Structure and Liturgy of Justinian's Great Church*, 1st ed. 1988 (London: Thames and Hudson, 2001), p. 137. On Anthemius' and Isidorus' academic and scientific background see G. Downey, "Byzantine architects, their training and methods," *Byzantion*, (1946–48), *18*:99–118.

[17] The literature on the Hagia Sophia is exceedingly rich. An outstanding contribution which focuses primarily on technical and architectural features is that of Rowland J. Mainstone, *Hagia Sophia.* cit., 2001. See also W.R. Lethaby and Harold Swainson, *The Church of Sancta Sophia Constantinople. A Study of Byzantine Building* (London: Macmillan & Co. 1894).

[18] Trowbridge, cit., p. 31. A reference to a mirror made in *élektron* has been found in an alchemical manuscript in Syriac attributed to Zosimos (Cambridge, Ms. 6,29). The manuscript has been recently edited and translated in Alberto

anonymous author speaks of covering the walls with a substance called *hyalinos* that was probably "gold colored glass mosaic."[19] Paul the Silentiary, in his poem dedicated to the basilica, adds: "Thus rises on high the deep-bosomed vault, borne above triple voids below; and through five fold openings, pierced in its back, filled with thin plates of glass comes the morning light scattering sparkling rays."[20] Procopius provides us with a more expressive image of the first visitors to the Basilica's spectacular experience:

> So the church has become a spectacle of great beauty, overwhelming to those who see it and altogether incredible to those who only hear of it. For it soars to a height to match the sky and . . . looks down upon the rest of the city . . . Its breath and length have been so fittingly proportioned that it may rightly be said to be both very long and unusually broad. And it exults in an indescribable beauty. For it subtly combines mass with harmony of proportions, having neither excess nor deficiency, inasmuch as it is both more pompous than the other buildings we are accustomed to and much more decorous than those which are huge beyond measure and abounds exceedingly in sunlight and gleaming reflections. Indeed one might say that its interior is lit not by the sun from without but by a radiance generated within, such is the abundance of light that bathes this shrine all round.[21]

The combination of grandiose wall mosaics in glass and large and numerous windows to let in natural light leads us to speculate that An-

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Camplani, "Procedimenti magico-alchemici e discorso filosofico ermetico," in G. Lanata ed., *Il Tardoantico alle soglie del Duemilla. Diritto Religione Società (Atti del V colloquio Nazionale dell'Associazione di Studi Tardoantichi)* (Pisa-Roma: ETS, 2000), pp. 73–98.

[19] Trowbridge, cit., p. 45.

[20] Cited in W.R. Lethaby & Harold Swainson, *The Church of Sancta Sophia,* cit., p. 40. In addition, Paul the Silentiary informs us that the basilica was also illuminated at night with glass lamps.

[21] Procopius, *Buildings [De Aedificiis]*, Book I, 1, 27–30, Trans. By H.B. Dewing, Loeb Classical Library, (Cambridge Mass.-London: Harvard UP–Heinemann, 2002), pp. 13–17. In other passages of his work (Book I,3; I, 4; I,5, I,11), Procopius emphasized the contrast between the darkness of old churches and buildings with the new light brought about in Byzantine architectural spaces by Justinian and his master-builders.

themius' theoretical competency regarding the reflective property of mirrors found practical application in the basilica, which so aroused the marvel of his contemporaries. In fact, it is difficult to imagine that such a vast use of mosaic *tesserae* in glass with such vivid and shining colors could have been achieved without both specialised chemical knowledge of the properties of minerals, and a profound optical study of the most effective means of admitting light to reflect on the great mosaics that transmitted an impressive representation of colored forms to the faithful.[22] The metaphysics of light which permeated the Christian religion[23] combined with the Byzantine scientists' inheritance of the Greek optical and philosophical traditions, perhaps found in this grandiose architectural creation one of its few expressions in which the names of the makers have survived.

The earliest glass mosaics of *Hagia Sophia* are no longer in place, but an example of the extraordinary skill of Byzantine glassmakers is evident in the beautiful vaults and walls of the Mausoleum of Galla Placidia (fifth century CE) in Ravenna. In fact the churches, baptisteries (Fig. 3) and the basilicas built in Ravenna and in Classe between the fifth and the sixth centuries CE are all adorned with wall and vault glass mosaics which, in terms of both the quantity and the quality of their production, offer a unequalled example of glass industry in Late Antiquity. Regrettably, however, we do not have any texts providing us with information on the provenance of these glassmakers, on the techniques

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[22] A recent investigation on the mosaics of Hagia Sophia by Liz James seems to reach the same conclusion: "Light striking a mosaic acts as a dynamic force, a force which has to be carefully and deliberately employed by the mosaicist. The Byzantines exploited this to the full, combining geodesy, the art of measuring volume and surface, with optics . . . It seems impossible to believe that mosaicists were not aware of these effects, that light was not deliberately used to create space and colour . . .". Liz James, "What Colours were Byzantine Mosaics," in *Medieval Mosaics. Light, Color, Materials*, Eve Borsook, Fiorella Gioffredi Superbi, Giovanni Pagliarulo eds. (Florence: The Harvard University Center for Italian Renaissance Studies at Villa I Tatti, 2000), p. 43.

[23] On this topic see Graziella Federici Vescovini, "Luce," in *Enciclopedia dell'Arte Medievale*, (Rome: Treccani, 1997), vol. 8, pp. 25–35 (with updated bibliography). The same author has investigated in depth the relation between the metaphysics of light, Medieval optics and *Perspectiva* in her study *Studi sulla prospettiva medievale*, Reprint of 1965 edition, (Torino: G. Giappichelli, 1987).

FIG. 3. Glass mosaic of the dome of the Arian baptistery in Ravenna depicting the baptism of Christ by Saint John the Baptist (right), and a pagan god on the left. First half of the fifth century CE.

they used to color the *tesserae*, on their division of labour, or on the furnaces and other tools they used to perform their work.

In addition to church decoration, Byzantine glassmakers developed new techniques combining glassmaking and metallurgical knowledge. A typical example of this is represented by the technique of gold leaf, described in some detail by Theophilus (Roger of Helmarshausen?) in his treatise *De diversis artibus* (first half of the twelfth century CE). As a detailed recipe it is worth quoting at length:

> The Greeks[24] also make from these blue stones precious goblets for drinking, embellishing them with gold in this way.

[24] By 'the Greeks', Theophilus referred to the Byzantines.

> Taking gold leaf [. . .] they fashion from it the likeness of men or birds, or animals, or foliage, and apply them to the goblet with water in whatever place they choose. This leaf ought to be somewhat thicker than usual. Then they take very clear glass, like crystal, which they make themselves, and which soon melts when it feels the heat of the fire, and they carefully grind it on a porphyry stone with water and lay very thinly over the whole leaf with a paintbrush. When it is dry, they put in the kiln (of which we shall speak later) where the painted glass for windows is fired, and light a fire underneath of beechwood thoroughly dried in smoke. When they see the fire penetrate the goblet so far that it finally shows a slight red colour, they immediately withdraw the wood and block up the kiln until it cools by itself. This gold will never come off.[25]

In his *De coloribus et artibus Romanorum* (ca. eleventh century CE), Eraclius described another technique adopted by the Romans to produce gold glass by which the "gold-leaf [was] carefully inclosed between the double glass."[26] Theophilus (II, 15) attributed the so-called sandwich technique to Byzantine glassmakers who exclusively used it in their mosaics. By inserting gold leaf between two strata of transparent or colored glass, gold appeared even more luminescent (Fig. 4). Moreover, this technique gave the impression that glass was infused with gold the whole way through.

Although its origins are problematic, the Pala d'oro of the Basilica di San Marco in Venice is also a highly significant example of the Byzantine re-interpretation of ancient glassmaking techniques. While the present structure of the Pala, dating to 1347, was the result of the collaboration of Venetian and Byzantine artists (Fig. 5), its entire nucleus was made four centuries earlier in Constantinople.[27] Made of gold and silver, the Pala was adorned with enamel and thousands of precious stones which an inventory in 1796 enumerated as 1300 pearls, 300 sap-

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[25] Theophilus, *The Various Arts. De Diversis Artibus*. Edited and annotated by C. R. Dodwell (Oxford: Clarendon Press, 1986) [book II, 13] p. 45.

[26] Published in Mary P. Merrifield (ed.), *Medieval and Renaissance Treatises on the Arts of Painting. Original Texts with English Translations*, 2 vols. (London: John Murray, 1849), vol. 1, p. 188.

[27] On the Pala see Sergio Bettini, "Venezia, la Pala d'Oro e Costantinopoli," in *Il Tesoro di San Marco* (Milano: Olivetti, 1986), pp. 43–72.

FIG. 4. Mary, between Peter and Paul in a gold glass medallion. Fourth Century CE. Stuttgart. Ernesto Wolf Collection.

phires, 300 emeralds, 90 amethysts, 15 rubies, 4 topaz and other rare stones and minerals (Fig. 6). During recent restoration work, it was discovered that many of these stones were in fact made of glass, and although it was suspected that the original stones were substituted in various epochs with their imitations, in light of what we have argued in the previous chapters one may wonder if it is not more likely that many of the precious stones were in fact made of glass from the very beginning. After all, in the case of the Evangelarius of Ariberto (Fig. 7), glass was indeed used to create artificial precious stones. Interestingly for our purposes, the systematic use of these decorative techniques coincides with both significant progress in glass production and the evolution of alchemy as an independent discipline.

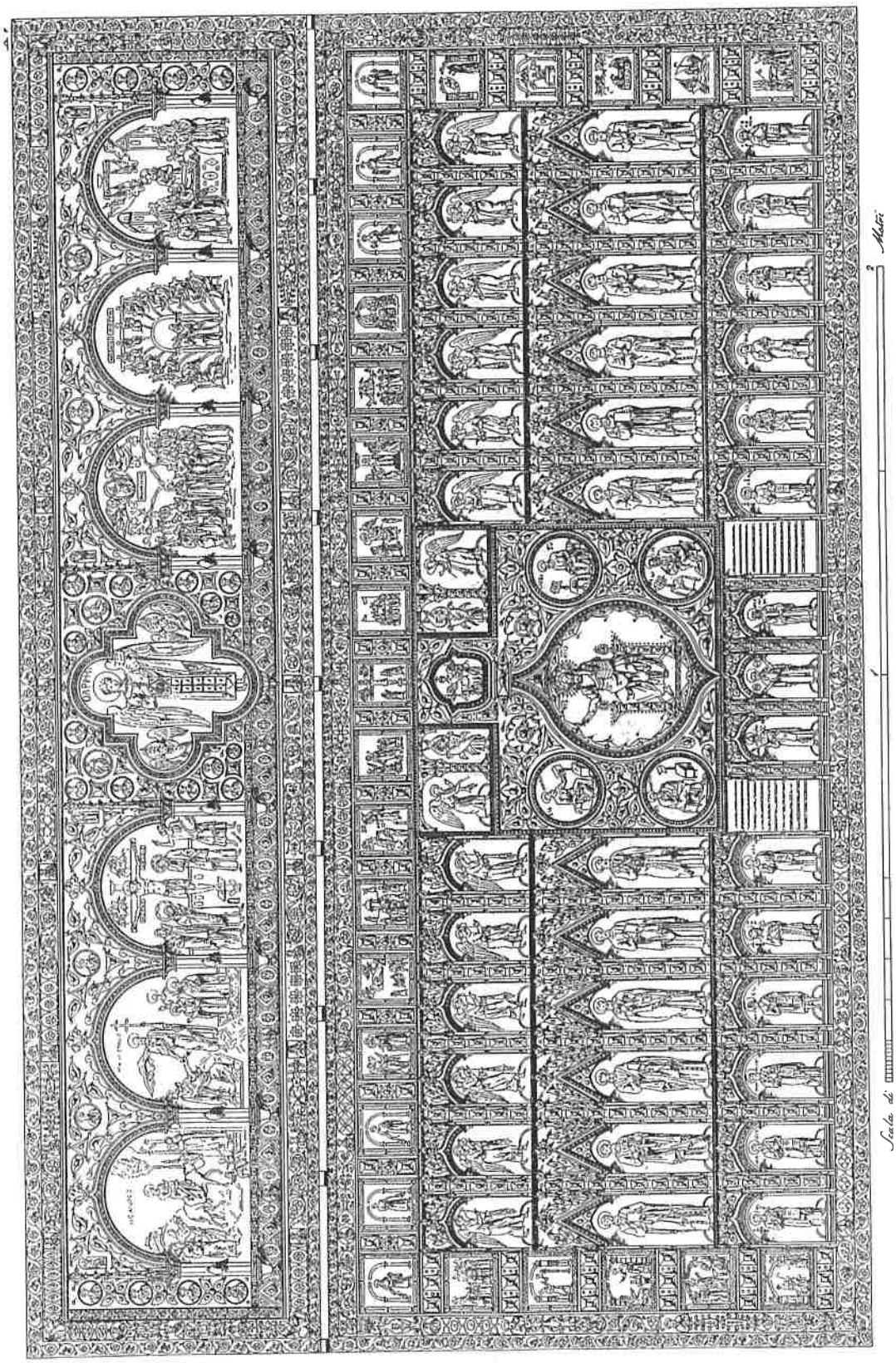

FIG. 5. Engraving by Dionisio Moretti of the Pala d'Oro taken from Antonio Quadri, *La piazza di San Marco in Venezia*, printed in Venezia in 1831.

FIG. 6. Enamelled Christ in his throne adorned with precious stones (or glass stones?). Tesoro di San Marco Venice. Photo by Mario Carrieri.

ALCHEMY AND BYZANTINE CULTURE

Byzantine science has until recently been a neglected chapter of the history of ancient science.[28]Byzantine culture has been credited for the

[28] Maria Mavroudi, "Occult Science and Society in Byzantium: Considerations for Future Research," in *The Occult Sciences in Byzantium*, cit.

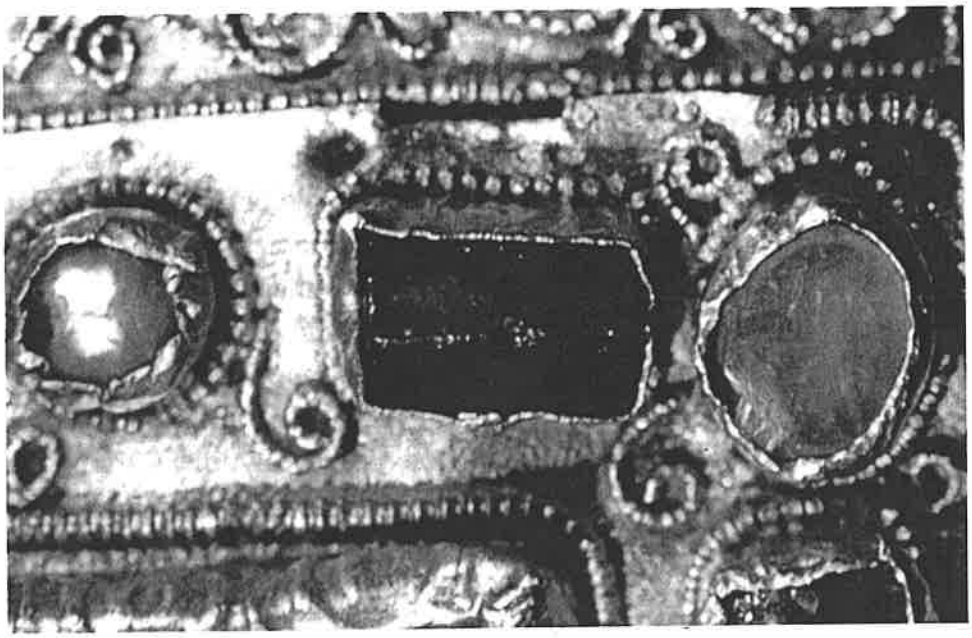

FIG. 7. A glass emerald between two pearls. Detail of the *Evangelarius* of Ariberto (eleventh century CE). Tesoro del Duomo di Milano.

preservation of what is often characterized as an arbitrary selection of Greek sources and their transmission to the Arabic civilization, but the originality of its own scientific tradition has not been appreciated. The case of alchemy shows, by contrast, that Byzantine culture played a crucial role in directing the heritage of the Greco-Egyptian tradition onto a new path, as epitomized in the writings of Zosimos of Panopolis.[29] The corpus of ancient alchemical writings was collected probably for the first time in Constantinople between the seventh and the beginning of the eleventh century, when the *Codex Marcianus Gr. 299* was compiled.[30] This manuscript, preserved in the Biblioteca Marciana in Venice, is the primary source of most of the known ancient alchemical texts, and while

[29] On this see Michèle Mertens, "Graeco-Egyptian Alchemy in Byzantium," in *The Occult Sciences in Byzantium*, cit., pp. 205–230.

[30] This is the most important ancient collection that has transmitted the main corpus of Greek and Byzantine alchemical writings. On this codex see Henri Dominque Saffrey, "Historique et description du manuscrit alchimique de Venise *Marcianus Graecus 299*," in *Alchimie. Art, histoire et mythes*, cit., pp. 1–10 and the forthcoming contribution by Antonio Rigo and Birgitte Mondrian, "L'histoire d'un manuscript alchimique: le *Marc. gr. 299* de Byzance (XIème s.) à M. Berthelot."

it includes the writings of Pseudo-Democritus and Zosimus, among others, it also presents writings by Byzantine authors such as Stephanos of Alexandria (first half of the seventh century CE)[31] and, in the table of contents, reports of lost works attributed to authors bearing the names of the Byzantine Emperors Justinian and Heraclius.[32] These titles, the text of which are lost, show that alchemy attained an unprecedented height of cultural and social status in Byzantium. The remarkable strength and prestige of the Byzantine alchemical tradition is further evidenced in the works by Michael Psellos (eleventh century CE), the most influential intellectual of the period, on the making of gold[33] and on the virtues of precious stones.[34] While these works do not contain anything particularly original, they demonstrate that alchemy was an integral part of high Byzantine cultural circles, and it is highly possible that, like astrology, alchemy too was included in higher education.

Mertens notes that the original Byzantine contribution to the alchemical corpus "were several practical recipes" dealing, "among other things, with the practice of silversmiths and goldsmiths, the tempering and dyeing of metals, glass-making, the coloring of precious stones, the manufacture of pearls and the making of moulds."[35] It is therefore probable that the prosperous glass industry and its prominent role in the architectural decoration of Byzantine churches and basilicas was a source of inspiration to the alchemists in their search for the transmutation of matter. This hypothesis finds confirmation in a work by Stephanos of Alexandria[36] included also in another manuscript, the *Parisinus Ms.*

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[31] Maria Papathanassiou, "Stephanos of Alexandria: A Famous Byzantine Scholar, Alchemist and Astrologer," in *The Occult Sciences in Byzantium*, cit., pp. 163–204.

[32] Apart from a few fragments these works have been lost or, as suggested by Saffrey, deliberately omitted.

[33] Michael Psellos, Letter on *Chrysopoeia*, in Joseph Bidez, *Catalogue des manuscrits alchimiques grecs*, vol. 6, (Bruxelles : M. Lamertin, 1928), pp. 1–47. Interestingly, in the manuscript, the letter was followed (Parisinus Ms 2327 at the Bibliothèque nationales in Paris) by a recipe on the fabrication of glass. On Psellos' alchemy see Gianna Katsiampoura, "Transmutation of Matter in Byzantium: The Case of Michael Psellos, the Alchemist," *Science and Education*, (2008), *17*:663–668.

[34] Pierpaolo Galigani, *Il De lapidum virtutibus di Michele Psello. Introduzione, testo critico, traduzione e commento* (Florence: CLUFS, 1980).

[35] Michèle Mertens, "Graeco-Egyptian Alchemy in Byzantium," in *The Occult Sciences in Byzantium*, cit., p. 225.

[36] Stephanos of Alexandria moved to Constantinople as early as 617 CE.

2327,[37] where the author describes the artificial fabrication of precious stones by means of colored glass and enamels.[38]

Many of these recipes probably derived from the Greco-Egyptian tradition, and without textual evidence it is impossible to determine what exactly was added during the Byzantine period. However, it is interesting to point out that once again, the progress of glassmaking went hand in hand with the development of alchemy. The earliest explicit definitions of the latter discipline as a holy art during the fifth century CE coincided with widespread experimentation with new glass techniques. It is therefore not surprising that the definition of transmutation set forth by Aeneas of Gaza, mentioned at the end of the previous chapter, took glassmaking as its point of departure.

The survival of the *Marcianus Graecus* ensured a future for the Greek alchemical tradition, and its acquisition by Cardinal Bessarion probably favoured its study after 1468, when it was donated to the Biblioteca Marciana in Venice.[39] However, the Western and Latin cultures had already raised an interest in alchemy and its connection to glass at an earlier stage.

THE LATIN TRADITION FROM THE *mappae clavicuale* TO THE *sedacina*

Recipes on glass making and the fabrication of precious stones circulated in Latin texts from the fourth and fifth century onwards.[40] Their origin is unclear. It is difficult, however, to reduce them to a compilation of exclusively Latin sources, principally of Pliny's mineralogical books.[41]

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[37] Bilbiothèque Nationale–Paris. The index and examination of its contents are given in Marcellin Berthelot, *Le origines de l'alchimie*, cit., pp. 335–347.

[38] *Ibid.*, p. 278.

[39] On the fortune of Corpus during the Renaissance see Sylvain Matton, "L'influence de l'humanisme sur la tradition alchimique" *Micrologus*, (1995), *3*:279–345.

[40] On the Latin tradition of glassmaking and its relation to alchemy, see Wilhelm Ganzenmüller, "Die Anschauungen vom Wesen des Glases vom Mittelalter bis zum Beginn des 19. Jahrhunderts, " in Id., *Beiträge zur Geschichte der Technologie und der Alchemie* (Weinheim: Verlag Chemie, 1956), pp. 128–155 as well as the subsequent articles.

[41] For a still-useful overview of this literature see Lynn Thorndike, *A History of Magic and Experimental Science*, vol. 1 (New York: The MacMillan Company, 1929), pp. 760–773.

Despite the meagre documentation of glassmaking in Late Antiquity, it is now accepted that the most innovative techniques introduced after the fourth century CE were the work of Byzantine glassmakers and that, when needed, their expertise was exported to Western cities, as was the case in Ravenna. We cannot therefore exclude the possibility that the literary interest in glass shown by Byzantine authors also spread to the West, and that key texts were translated into Latin. It should be noted that in 405, Ravenna became the Byzantine capital of the Western Empire, and that Byzantine culture exerted a considerable influence there until the middle of the eighth century, when the city fell to the Lombards. Interestingly, it was in this critical moment of Ravenna's history that a new glass center was founded in Torcello, the island next to Venice. As Philippe points out,[42] during its Byzantine period Ravenna communicated with the North through Aquileia, a Roman city that had been an important glass center as early as the third century CE. The shortest way to reach Aquileia from Ravenna was to pass through the Venetian sea. Thus, the foundation of a glass center in Torcello after the fall of Ravenna cannot come as a surprise, and illustrates the fascinating migration of glassmaking from Constantinople to Venice through Ravenna, as well as its progressive translation from the Greek culture to the Latin one. This may also explain why many early Latin recipe books contain technical terms with Greek roots.

The first and most important collection of such texts is the so called *Mappae Clavicula*: a collection of chemical and alchemical recipes, the original nucleus of which dates to the fourth century CE and was certainly Greek. This was translated into Latin about one century later.[43] This older corpus included some two hundred recipes, a significant part of which were devoted to the fabrication of precious stones through the use of glass as well as one, probably derived from Pliny's account, giving instruction on the manufacture of unbreakable glass.

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[42] Philippe, *Le monde Byzantin dans l'histoire de la verrerie*, cit. pp. 85 and ff.

[43] Robert Halleux and Paul Meyvaert, "Les origines de la *Mappae Clavicula*," *Archives d'histoire doctrinale et littéraire du Moyen-Age*, (1987), *54*:7–58; The most up-to-date essay is Francesca Tolaini, "*De tinctio omnium musivorum*. Technical Recipes for Glass in the so-called *Mappae clavicula*," in *When Glass Matters*, Marco Beretta (ed.) (Florence: Olschki, 2004), pp. 195–219. See also Cyril Stanley Smith and John G. Hawthorne, *Mappae Clavicula. A Little Key to the World of Medieval Techniques* (Philadelphia: The American Philosophical Society, 1974).

Around the end of the sixth century, Isidorus of Seville included a long digression on glass and precious stones in Book XVI of his *Etymologiae*, which took most of its information from Pliny's *Naturalis historia* but already hinted at an independent contemporary tradition of ideas and techniques related to glassmaking. So, after having pointed out that glass was "colored in many ways so that it [might] imitate hyacinth-stones, sapphires, green stones, and onyx, and the color of other gems" he reported that obsidian was also used "to make gems out of it."[44] About one century later, Rabanus Maurus also dedicated a chapter of the sixteenth book of his *De Universo* to glassmaking. Indeed, during the eight and ninth centuries, glassmaking seemed to experience something of a renaissance. A collection of recipes entitled *Compositiones ad tingenda et musiva*[45] (ninth century CE) included several recipes from the *Mappae* with a few new additions. Eraclius' *De coloribus et artibus romanorum* (ca. eleventh century CE) contained recipes devoted to the fabrication of gems and precious stones with glass. One of them alluded to the alchemical procedures that we have invoked in earlier chapters. The author in fact wrote:

> You will thus be able to make beautiful shining gems of every sort with Roman glass. Hollow out some clay for yourself as a mould for the stone; and put into it some glass broken into small pieces. You may easily prepare this by this artifice. Let a certain reed be skilfully turned round and round, and when it [the clay] begins to harden, and the rod sticks tight, then fix it on the rod on both sides, and let the rod be held by the glass placed round it; and then put the clay, guarded by a hollow iron, into the fire, and when the glass is thoroughly liquefied, press in into the hollow with a bright iron, so that you may have no bubble or flaw in it.[46]

The reproduction of the gems was made possible by the addition of colors, and Eraclius' treatise contains several recipes devoted to them. The lack of reference either to the quantities of the ingredients em-

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[44] Isidore of Seville, *Etymologiae*, XVI, 16, 4–5 English translation *The Etymologies of Isidore of Seville* (Cambridge: Cambridge UP, 2008), p. 328.

[45] *Compositiones ad tingendo musiva*. Hjalmar Hedefors (ed.) (Uppsala: Almqvist & Wiksell, 1932).

[46] Marriefield, *Medieval and Renaissance Treatises*, cit., vol. 1, p. 196.

ployed or to the design of the furnace(s) makes it extremely difficult to translate Eraclius' recipes into modern terms. To be sure, his attitude was clearly different from the earlier compilers, and at the beginning of his work he proudly proclaimed that he presented nothing that he had not first tried himself.

In addition to the anthologies of recipes, it is worth mentioning an illustration of a glassblowing scene which adorned a manuscript dating to 1023, representing the chapter of Book XVII of Rabanus Maurus' *De Universo* devoted to glass (Fig. 8). In comparison to the Roman iconographic and textual sources on the technical procedures of glassmaking, in this picture the furnace seems to have changed radically as it now shows three fusion chambers instead of one, thus underlining a considerable increase in size. Additionally, at the top of the furnace another chamber was constructed for annealing. The date of the original illustration (of which this is a later copy) is uncertain, but it nevertheless reveals that after the Carolingian revival of glassmaking, significant technical changes were introduced.

Although other literary sources hint at glassmaking during the period between the Carolingian epoch and the end of the eleventh century,[47] it seems that the Latin West, unlike the Byzantine tradition, was less inventive in developing this art and in introducing significant innovations. This difficulty was no doubt also due to the shortage of mineral alkali that ceased circulation after the fall of the Empire. From the seventh and eighth century onwards, glassmakers from the West could no longer rely on the trade of *nitrum* (soda) coming from Egypt and were forced to obtain potash from vegetable ashes: a costly procedure that yielded an ingredient of poorer quality.

At the beginning of the twelfth century, however, the situation changed rapidly. The use of stained glass, introduced by the Abbé Suger in decorating the windows of the cathedral of Saint Dénis, opened a new chapter for glassmaking throughout Europe. On this topic Suger remarked:

> Now, because [these windows] are very valuable on account of their wonderful execution and the profuse expenditure of painted glass and sapphire glass, we appointed an official master craftsman

[47] A systematic survey of these sources is given in Francesca Dell'Acqua, *Illuminando colorat*, cit., pp. 99–169.

FIG. 8. Rabanus Maurus, *De universo*. Chapter 10 *De vitro*. Montecassino, Biblioteca ms. Casin. 132, l. 429.

> for their production and repair, and also a skilled goldsmith for the gold and silver ornaments . . .[48]

[48] *Abbot Suger on the Abbey Church of St.-Denis and its Arts Treasures*, Edited, translated and annotated by Erwin Panofsky, 2nd edition (Princeton: Princeton UP, 1979), p. 77.

As stained glass became an important element of the practical and metaphysical aspects of the new Church architecture, it was not surprising that the craftsmen who were working on this task were highly regarded, and worked hand in hand with goldsmiths. It is also worth noting the common reference to sapphire glass, which evoked the fabrication of gems and precious stones. This was consistent with the Abbey's treasure, which contained several vessels made of rock crystal and gold adorned with precious stones.

At about at the same time that Suger was engaged in building his abbey, Theophilus wrote the first manual of medieval metallurgy, *De diversis artibus*, which for the first time described techniques and experiments that were not directly tied to either the Roman or Byzantine traditions. The second book of this work was devoted to glass, and Theophilus declared in the preface that all the procedures described therein had been examined individually, "with careful trial and proved them all with hand and eye."[49] The first chapter was devoted to a detailed description of glass furnaces and of the various phases of the process of production. In addition to the techniques of making vases, flasks, mosaics, and gold glass—which were known in antiquity and which, as we have already pointed out, were mostly attributed to the Byzantine glassmakers—Theophilus included careful examinations of the fabrication of glass for windows and stained glass in his textbook. Although the textbook is very practical and does not contain any direct reference to alchemical doctrines, Theophilus devoted one chapter to setting gems in painted glass, with instructions on how to "make the emeralds of green glass."[50] For centuries to come, *De diversis artibus* was an important and unique attempt to systematize existing knowledge on glassmaking. It would be necessary to wait for the progress achieved in Murano and Venice during the fourteenth century and the Early Renaissance to read more innovative recipes.

The cultural importance of glass during the late Middle Ages fostered renewed interest in its properties among philosophers of nature and alchemists. In the second half of the fourteenth century, Albertus Magnus connected glassmaking with alchemy, and in the third book of his lapidary he questioned the conclusion reached through some alchemical experiments by a "certain Gilgil, of Moorish Seville" by which

[49] Theophilus, *The various arts*, cit., p. 37.
[50] *Ibid.*, p. 57.

he pretended to demonstrate that ash "liquefied into glass." Albertus maintained, following Aristotle, that ash contained a certain degree of moisture and that in this specific case transmutation was not possible.[51] If the discussion connecting glassmaking to alchemy mentioned by Albertus was philosophical, the theory of matter set forth by the Catalan alchemist Sedacer at the end of the fourteenth century was the result of a full appreciation of the marvellous effects of glassmaking and, probably, of first-hand experience in this art. According to Sedacer, glass was "a transparent body, artificially brought to the nature of quintessence" and it could be transmuted into any other body: hence its name of "lapis convertibilis."[52] Sedacer was undoubtedly the most explicit Medieval author in terms of reducing the *opus magnum* to glass' natural ability to imitate any mineral.

Sedacer's emphasis on the central role of glass in alchemical transmutation has often been treated as a secondary and eccentric example of a tradition centered on the concept and practice of the *chrysopoeia*. However, although glassmaking was not as important for Medieval alchemy as it was for the Ancient and the Byzantine alchemists, it still played a significant role in directing reflections on the transmutation of matter. In her seminal study on Medieval glassmaking and on the work of Jean d'Outremeuse, Anne Françoise Canella has shown that between the second half of the fourteenth and the end of the fifteenth centuries, no less than twenty-five different works contained recipes on the fabrication of precious stones with glass.[53] With very few exceptions, these manuscripts put recipes into circulation that were rooted in a much older tradition.

GLASSMAKING GOES PUBLIC: THE ORIGINS AND ADVENT OF THE *Arte vetraria*

Glassmaking had always been a secret art. Both individual craftsmen and guilds of glassmakers systematically protected the secrets of their

[51] Albertus Magnus, *Book of minerals*, cit., pp. 163–164.

[52] "Corpus diaphanum artificialiter ad naturam quinte essencie redactum." Pascale Barthélemy (ed.), *La Sedacina ou l'Oeuvre au crible. L'alchimie de Guillaume Sedacer, carme catalan de la fin du XIVe siècle,* 2 vols. (Milan: Arché, 2002), vol. 2, p. 164.

[53] Anne Françoise Canella, *Gemmes, verre coloré, fausse pierres précieuses au Moyen Age* (Geneva: Droz, 2006), pp. 79–94.

knowledge. Although this practice had often little to do with the meaning attributed to secrecy by alchemists, the conditions by which glassmaking developed since antiquity often entailed the awareness of performing an art that was intimately interwoven with the most hidden mysteries of matter. It is indeed remarkable that, in spite of the growing importance of glass and the spread of recipe books during the Renaissance, no monographic study was published until Neri's treatise appeared at the beginning of the seventeenth century.

The greatest uncertainty surrounded the discovery of artificial *cristallo* and other precious stones in the first half of the fifteenth century, attributed to the Venetian Angelo Barovier. As we pointed out in previous chapters, Roman glassmakers managed to imitate crystal with unsurpassed skill, such that Barovier's achievements are not necessarily superior in manufacture to their ancient predecessors. Whether Barovier had access to manuscripts containing ancient recipes or he re-invented a method on his own is impossible to determine. Crystal glass in fact had been reinvented several times in its history, and continued to be reinvented after Barovier's time. This is not surprising because the vagueness of the recipes which circulated in manuscript form, and which can still be found in the archives of Venice and Murano, show that the secrecy in which the techniques of glassmaking were kept made it impossible to attribute the inventions for which craftsmen credited themselves in each epochs.[54] Furthermore, the so-called glass *à la façon de Venice* involved recipes which were Byzantine and, in a few cases, even Egyptian-Greek in origin. The appropriation of these recipes became one of the *leitmotivs* of Renaissance craftsmen, who saw in the production of glass luxury artefacts a means of exceptional revenue and reputation. Leonardo da Vinci himself gave a recipe for preparing ruby glass and melting pearls, but the contents of which do not allow us to understand the details of the procedure.[55] As a matter of fact, Leonardo also associated alchemy with glassmaking. In criticising the occult sciences in the *Quaderni di Anatomia*, he remarked:

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[54] *Ricette vetrarie del Rinascimento. Trascrizione di un manoscritto anonimo veneziano*, Cesare Moretti, Tullio Tonnato (eds.) (Venice: Marsilio, 2001); *Ricette vetrarie muranesi. Gaspare Brunoro e il manoscritto di Danzica*, Cesare Moretti, Carlo Stefano Salerno, Sabina Tommasi Ferroni (eds.) (Florence: Cardini Editore, 2004).

[55] *The Notebooks of Leonardo da Vinci. Arranged, Rendered into English and Introduced by Edward MacCurdy* (New York: Braziller, 1954), p. 1005 and pp. 1175–1176.

> But of all human discourses that must be considered as most foolish which affirms a belief in necromancy, which is the sister of alchemy, the producer of simple and natural things, but is so much the more worthy to blame than alchemy, because it never gives birth to anything whatever except to things like itself, that is to say lies; and this is not the case with alchemy, which works by the simple products of nature, but whose function cannot be exercised by nature herself, because there are in her no organic instruments with which she might be able to do *the work which man performs with his hands, by the use of which he has made glass.*[56] (Italics mine)

Fig 9. Sculpted portrait medallion of Vannoccio Biringuccio, made during the nineteenth century. Florence, Specola.

The first relatively comprehensive survey of glassmaking would be published only in 1540 by a friend of Leonardo's, Vannoccio Biringuccio (Fig. 9), in his metallurgical treatise entitled *De la pirotechnia.* The treatise was published posthumously and was, significantly, printed in Venice, where Biringuccio had studied the glass furnaces and techniques he encountered during his visit to Murano (Figs. 10–11). Biringuccio devoted one chapter to glass where, unlike the very practical instructions that characterized his treatments of minerals and metals, he introduced the subject with a theoretical digression. This was due to the inner nature of glass, to which Biringuccio compared that of stones, metals and minerals:

> Thus in this chapter I shall speak to you of glass, not as a proper semi-mineral, nor yet as a metal, but as a fusible material that is almost made mineral by art and by the power and virtue of fire, born from speculation of good alchemistic savants [*buoni ingegni alchimici*], through whose efforts it imitates the metals on the one hand and the transparency and splendour of gems on the other [. . .] Certainly, in this art surpasses Nature; for although she has pro-

[56] *Ibid.*, 81.

FIG 10. Glass furnace for melting and annealing, probably seen by Birnguccio during is visit to Murano. *De la Pirotechnica* (Venice, 1540) fol. 44.

> duced crystal and all the other kinds of gems that are much more beautiful of than this, no way has yet been found for working with these as is done with glass.[57]

Interestingly Biringuccio identified the glassmakers of Murano as an example of these "ingenious alchemists," who were able "to counterfeit emeralds, diamonds, rubies, and all other gems of any color whatsoever."[58]

Alchemy and glassmaking were notably central to the cultural milieu which favoured the publication of Biringuccio's treatise. Both Leonardo and Biringuccio worked in Florence, where Cosimo I and his

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[57] Vanoccio Biringuccio, *The Pirotechnia of Vannoccio Biringuccio*. Translated from the Italian with an introduction and notes by Cyril Stanley Smith & Martha Teach Gnudi (New York: American Institute of Mining and Metallurgical Engineers, 1959), pp. 126–127.

[58] *Ibid.*, p. 132. The association between alchemy and the counterfeit of precious stones was accomplished two decades later by Giovan Battista della Porta in his *Magia Naturalis sive De miraculis rerum naturalium libri IIII* (Rome: apud Matthiam Cancer, 1558), pp. 117–126.

FIG. 11. The same furnace as Fig 10, in a woodcut published by G. Agricola in 1556 in his *De re metallica* (Lib. XII).

son Francesco de' Medici showed a remarkable interest in alchemy and created the most conductive conditions to perform the art. While Cosimo I's alchemical interests initially centered on the manipulation of metals and vegetable substances, in a later period of his life he seemed to have a predilection for making experiments on the production of precious stones and, more generally, for connecting alchemy to glassmaking.[59] For this purpose, he had a chemical laboratory built in the Palazzo Vecchio.[60] This interest is further evidenced by the acquisition of several manuscript treatises on glass and on the fabrication of gems during the sixteenth century, which are now preserved at the National Library of Florence and have been edited by Maria Grazia Tagliavini.[61]

Cosimo's son and heir Prince Francesco also appreciated the importance of glass for the attainment of the Philosopher's Stone, and in 1574 he transferred the workshops and laboratories from the Palazzo Vecchio to new spacious quarters built by Bernardo Buontalenti in the Casino of San Marco. The Venetian ambassador Andrea Guissoni reported with admiration the activities of the laboratory where masters from Murano, employed by the Medici sovereigns, had invented a new method for the fusion of rock crystal.[62] Francesco himself also delighted in producing false precious stones of such quality that even jewellers were unable to recognise the difference; this was particularly true for a recipe he invented to imitate the emerald.[63] Michel de Montaigne com-

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[59] Maria Grazia Tagliavini, *Il gusto della meraviglia: bicchierografie tra arte e scienza nel XVI e XVII secolo,* PhD doctoral dissertation; 2 vols. (Pisa: Università di Pisa, 2005), vol. 1, p. 156.

[60] Alfredo Perifano, *L'Alchimie à la Cour de Côme Ier de Médicis: savoirs, culture et politique* (Paris : Honoré de Champion, 1997).

[61] Maria Grazia Tagliavini, *Il gusto della meraviglia,* cit., pp. 211–278. Although some of the manuscripts of the Medici collection, many of which came from Murano, are of a later date, the beginning of the interest in glassmaking is to be attributed to Cosimo I. For the collection see also Gabriella Pomaro, *I ricettari del fondo Palatino della Biblioteca Centrale di Firenze. Inventario* (Florence: Giunta Regionale Toscana and Editrice Bibliografica, 1991).

[62] "Ha ritrovato il modo di fondere il cristallo di montagna . . . e perciò ha salariato alcuni maestri dei nostri da Murano molto sufficienti." Cit. in Detlef Heikamp, *Studien zur mediceischen Glaskunst: Archivalien, Entwurfszeichnungen, Gläser und Scherben* (Florence: Kunsthistorisches Institut, 1986), p. 68.

[63] "Francesco si diletta anche di formar delle gioie false così simili alle vere, che alle volte i gioiellieri medesimi ne restano ingannati, e mi mostrò un vasetto fatto da lui di smeraldo in vero molto bello." Cit. in *ibid.*, p. 68.

firmed the Venetian ambassador's report during his visit in Florence: on November 22, 1580, he remarked:

> The same day we saw a palace of the duke, where he himself takes pleasure in working at counterfeiting oriental stones and cutting crystal; for he is a prince somewhat interested in alchemy and the mechanical arts . . .[64]

It was in this context that the skilful artist Agostino del Riccio compiled his treatise on the *Istoria delle pietre*, most of which was devoted to the examination of crystal and precious stones.[65]

While the experiments were performed in the laboratories of the Casino, the Prince's residence in the Palazzo Vecchio also underwent an important renovation, aiming to emphasize the central importance of alchemy and the chemical arts within the Medici Court. In his marvellous *Stanzino* commissioned from Giorgio Vasari and several younger painters under his direction, a complex visual narrative evoked the process of the *opus magnum* through sixty three scenes.[66] Apart from the famous painting by Johannes Stradanus of the alchemists' laboratory (Fig. 12), which illustrated the laboratory of the Casino of San Marco, other paintings were directly connected with the chemical arts: for example, the allegories of the four elements on the vault, at the center of which was a painting illustrating Prometheus taking a specimen of rock crystal from nature.[67] (Fig. 13) This central figure both emphasized the alchemical narrative of the *studiolo* as well as one of the Prince's main in-

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[64] Michel de Montaigne, *The Complete Works. Newly Translated by Donald M. Frame* (Standford: Standford University Press, 1958), p. 930.

[65] Agostino Del Riccio, *Istoria delle pietre*. Raniero Gnoli and Attilia Sironi (eds.) (Turin: Umberto Allemandi, 1996).

[66] On the stanzino see Marco Dezzi Bardeschi (ed.), *Lo Stanzino del Principe in Palazzo Vecchio. I concetti, le immagini, il desiderio* (Florence: Le Lettere, 1983); Luciano Berti, *Il Principe dello Studiolo. Francesco I dei Medici e la fine del Rinascimento fiorentino* (Pistoia: Maschietto, 2002) and the recent thorough study by Valentina Conticelli, *"Guardaroba di cose rare et preziose." Lo studio fiorentino di Francesco I De' Medici: arte, storia e significati* (Milan: Lumières Internationales, 2007).

[67] Prometheus was credited as the inventor of precious stones. For the alchemical narrative of the studiolo see the cited work by Valentina Conticelli.

[68] Detlef Heikamp, *Studien zur mediceischen Glaskunst*, cit.

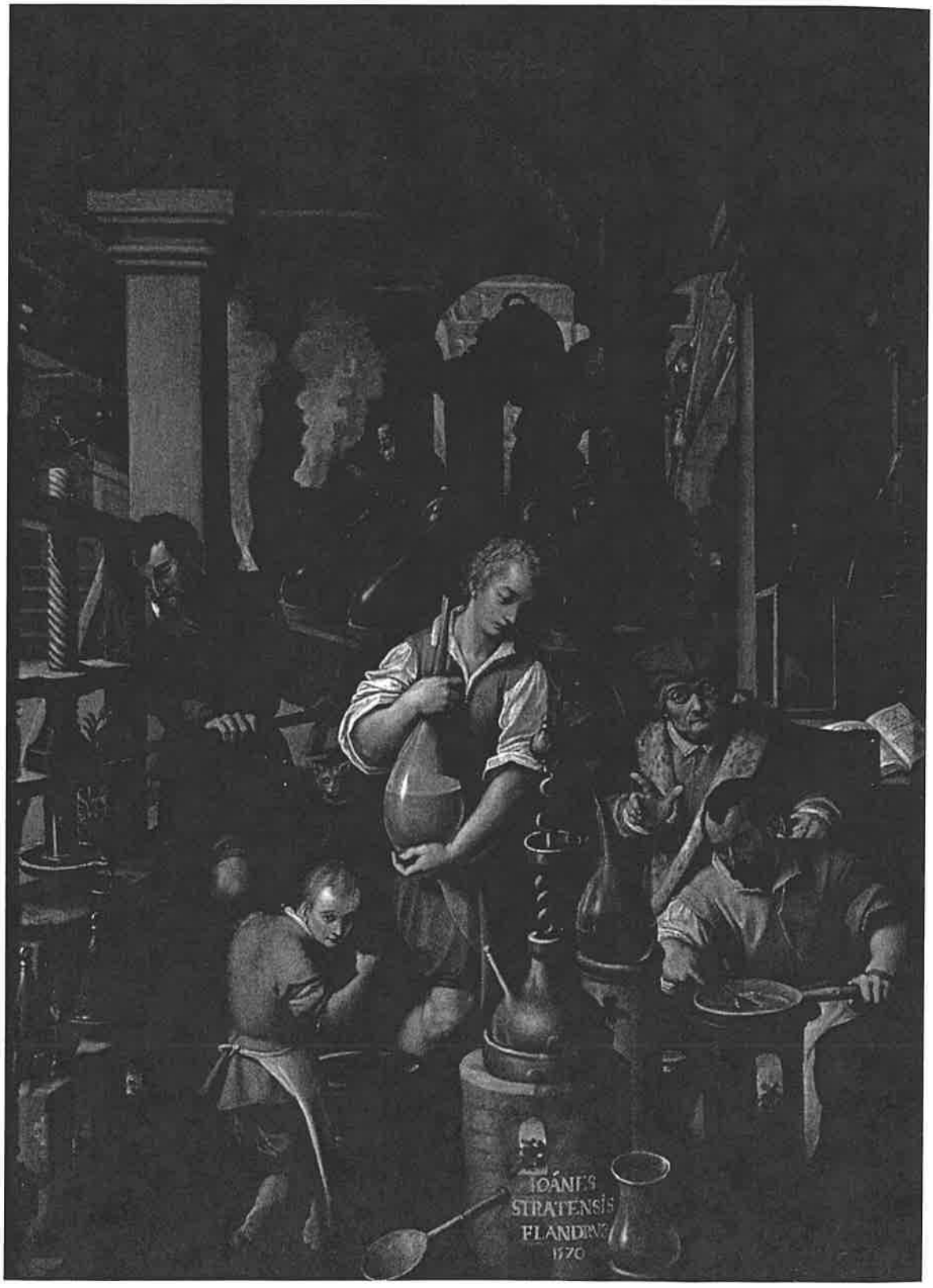

FIG. 12. Johannes Stradanus' painting of the alchemical laboratory at the Casino of San Marco, with Francesco de' Medici (on the right) guided by an experienced alchemist in his experiment. Palazzo

FIG. 13. The central fresco on the Stanzino vault, depicting Nature giving a piece of rock crystal to Prometheus. Palazzo Vecchio, Florence.

terests. The *studiolo* was additionally adorned with a painting of Vulcan's workshop (Fig. 14), the pharmaceutical foundry, the laboratory for the production of gunpowder, the gold mine, the goldsmiths' workshop (portraying Prince Francesco working with precious stones), the diamond mine, the textile workshop, the collection of amber and pearls, and two further images depicting the discovery of glass and the glass foundry (Figs. 15–16). The painting devoted to the discovery of glass illustrated Pliny's story, recounted above, while the glass foundry by Giovanni Maria Butteri showed Prince Francesco's visit to the workshop at the Casino, in which a large furnace is visible in the background. Significantly, Butteri's painting on glass was put next to Stradanus' *The alchemists*, thus insisting on a relationship between alchemy and glassmaking which had to be apparent to contemporary viewers.

The Medici rulers' special interest in the marvellous properties of glass remained constant throughout the century,[68] and nearly became an obsession for Prince Antonio de' Medici who, in 1597, moved his residence to the Casino of San Marco in order to better monitor and control all the phases of production of the alchemical work there.[69] Antonio kept a detailed record of his experiments, which were probably intended for publication, and of the apparatus he used (Fig. 17). Among the people employed in the Casino we find Antonio Neri: an expert alchemist who had travelled in Germany and in the Netherlands and was particularly well-versed in glassmaking, the secrets of which he learned during a visit to Murano.[70] In 1612, Neri published a work entitled *L'arte*

[69] Pier Francesco Covoni, *Don Antonio de' Medici al casino di San Marco* (Florence: Tip. Cooperativa, 1892). On Paracelsian chemistry in Florence see Paolo Galluzzi, "Motivi paracelsiani nella Toscana di Cosimo II e di Don Antonio dei Medici : alchimia, medicina chimica e riforma del sapere," in *Scienze, credenze occulte, livelli di cultura: Convegno internazionale di studi: Firenze, 26–30 giugno 1980* (Florence: Leo S. Olschki, 1982), pp. 31–62.

[70] On Antonio de' Medici, Antonio Neri, alchemy and glassmaking see the well-documented introduction by Ferdinando Abbri to Antonio Neri, *L'arte vetraria. Introduzione e cura di Ferdinando Abbri* (Florence: Giunti, 2001), pp. 5–23. Paul Engle has recently published the illustrations (with plenty of glassware) of an alchemical treatise which Neri was preparing in 1598–99; Paul Engle, "Depicting Alchemy: Illustrations from Antonio Neri's 1599 Manuscript," in Dedo von Kerssenbrock-Krosigk (ed.), *Glass of the Alchemists: Lead Crystal-Gold Ruby, 1650–1750* (Corning, N.Y.: Corning Museum of Glass, 2008), pp. 48–61.

FIG. 14. Vittorio Casini, *Vulcan's workshop*. Palazzo Vecchio, Florence.

FIG. 15. Giovanni Maria Butteri, *The discovery of glass or Aeneas in Italy*. The putto in the front is holding a piece of transparent glass. Palazzo Vecchio, Florence.

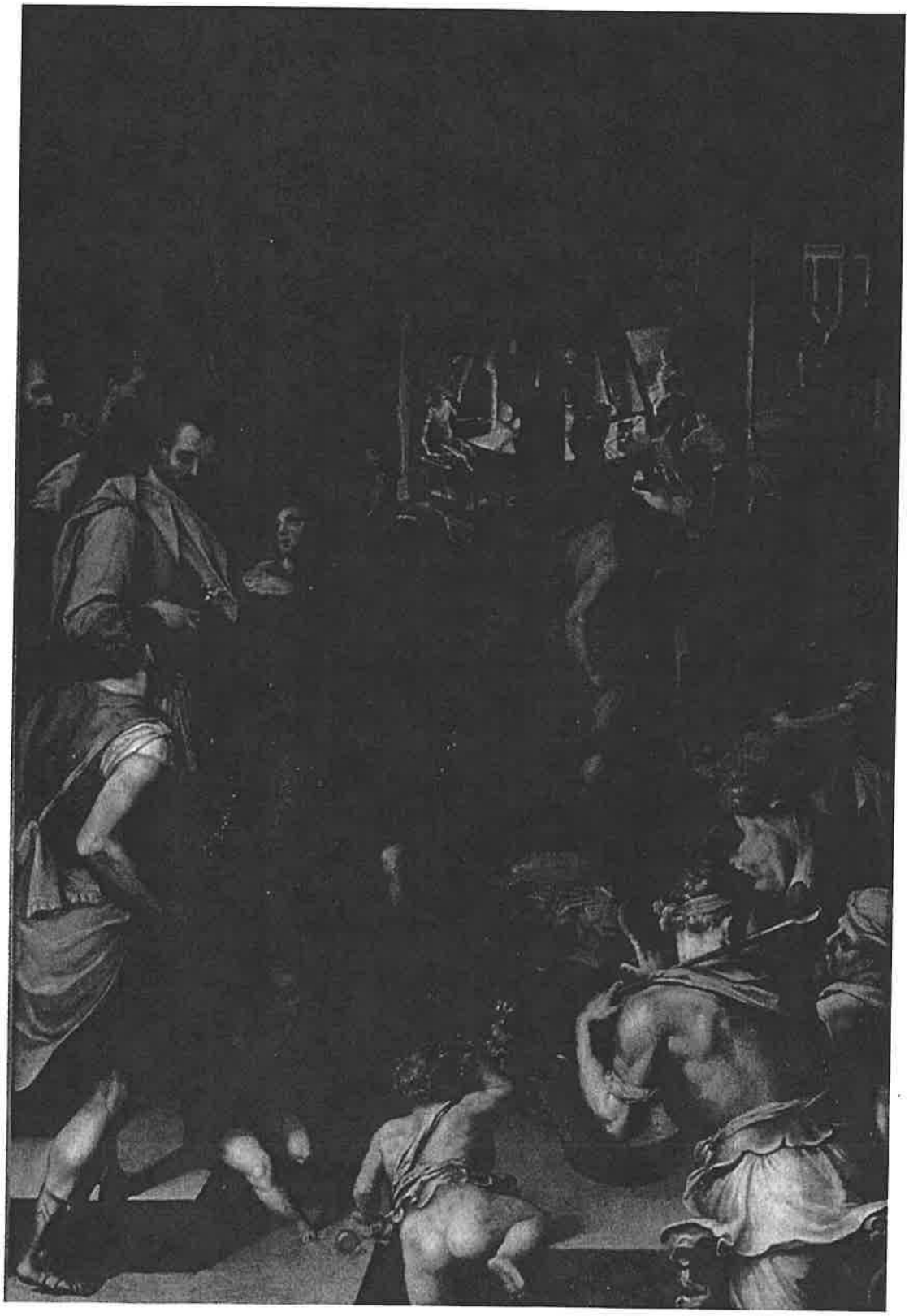

FIG. 16. Giovanni Maria Butteri, *The glass foundry at the Casino of San Marco*. Palazzo Vecchio, Florence.

FIG. 17. Printed frontispiece of the manuscript record of Antonio de' Medici's experiments. Florence, Biblioteca Nazionale Centrale di Firenze, Magl. XVI, 63/1.

vetraria (Fig. 18), in which he offered a synthesis of what he had learned during his travels and what he had proven with his experiments in the Casino. It was the first treatise on glassmaking to go to press and was published only two years after Galileo's revolutionary *Sidereus Nuncius*: the astronomical booklet through which the Florentine astronomer announced to the world the spectacular observations he was able to make through glass telescopic lenses.

Glass was poised to become the principal material of the Scientific Revolution, but the progress by which all this was made possible followed an obscure history which had little to do with the philosophy of nature promoted by the Galilean credo. And Neri's work was not in fact, as it is often credited, a technical textbook, but a revised and updated collection of recipes designed to connect glassmaking with alchemy. Like the recipes of ancient alchemists, Neri too provided his readers with instructions on how to color glass and make it transparent, but like his predecessors he omitted the quantities of the ingredients, the kinds of combustibles and the size or instruments of the furnaces. In glassmaking, everything had to be guessed at or experimented. Indeed, at the end of the third book, in a recipe devoted to the color of the pearls, Neri remarked that the only way to attain a good result was by following trials and experimentation. The search for standards and rules was seen as an impossible, if not useless, task.[71]

In the first book of the *Arte vetraria*, Neri mentioned a technique of manipulating rock crystal that he saw in Murano, which served to de-

[71] "Che in questo non si può dare regola poiché sta nella pratica, laquale si fa con l'esperimentare, quando il colore sta bene si facci lavorare subito perché facilmente si ismarisce questo colore, che così io l'ho praticato e sperimentato più volte." *L'arte vetraria,* cit., p. 79.

termine which kinds of gems could be transmuted by means of glass;[72] and in the fifth book he listed eighteen recipes, many of which were ancient as the art itself, for the fabrication of emerald, topaz, sapphire and other precious stones. A detailed reconstruction of the genealogy of Neri's recipes would undoubtedly illustrate the history of two millennia of glassmaking, thus revealing the strata of a tradition jealously preserved by the cultivators of the art.


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Con licenza de' Superiori.

FIG. 18. Frontispiece of Neri's *L'arte vetraria.*

The publication of Neri's work met with immediate success, but it soon became clear that glassmaking was too important an art to be left in the exclusive hands of the alchemists. Promoted by Robert Boyle and the Royal Society, the English edition of Neri's work produced by the physician Christopher Merret[73] was heavily annotated, and contained several illustrations explaining the function of different glass furnaces; so did the Latin (1668) and the German (1678) editions, which followed soon after. But despite the effort to make Neri's treatise a useful textbook for modern chemical technology, glassmaking remained associated with alchemy for a long time to come. In 1679, Johann Kunckel published an fully edited version on Neri's work,[74] with

[72] "Ogni pietra che con l'acciaiolo, o vero fucile, fa fuoco, e atta a vetrificare e a fare il vetro e cristallo e tutte quelle pietre che non fanno fuoco con acciaiolo, o fucile come sopra non vetrificano mai; il che serva per avviso per poter conoscere le pietre che possono trasmutarsi in vetro da quelle che non si possono trasmutare." Ibid., p. 38.

[73] *The Art of Glass, Wherein Are Shown the wayes to make and colour Glass, Pastes, Enamels, Lakes and other Curiosities* (London: Octavian Pulleyn, 1662).

[74] Johann von Kunckel, *Ars vitraria experimentalis, oder, Glasmacher-Kunst: lehrende, als in einem commentario über die sieben Bücher P. Anthonii Neri, und denen Anmerckungen Christophori Merretti (so aus den Ital und Latein, beyde mit Fleiss ins Hochdeutsche übersetzt) die allerkurtz bundigsten Manieren, das reineste Chrystall-Glas, alle gefärbte oder tingirte Gläser, künstliche Edelstein oder Flüsse zu machen: sampt einem II. Haupt-Thiel, so in mehr als 200 Experimenten bestehet, darinnen von*

the report of more than two hundred original experiments and a new recipe for gold-ruby glass: a combination of dissolved gold and tin in *aqua regia* (purple of Cassius) combined with glass which resulted in the most spectacular specimen of ruby glass.[75] As much as Kunckel credited himself with this invention, ruby glass was reported to have been manufactured by Pliny in antiquity, as well as by several subsequent authors who, with different degrees of confidence, vindicated the discovery of a method of coloring glass in such a way as to imitate the purple shade of the ruby.[76] Two most prominent chemists of the seventeenth century, Rudoph Glauber[77] and Johann Joachim Becher,[78] continued to see in this art a key to unveiling the mysteries of the transmutation of matter and, taking inspiration from Venetian glassmakers, tried several recipes by which they could imitate precious stones and crystal.

One century later, in the very first volume of his *Histoire naturelle* (1749), Comte Buffon, one of the protagonists of the French *Lumières*, gave glass a central role in his theory of the geological evolution of the Earth. Buffon set forth a hypothesis concerning the structure of our planet which revived opinions and ideas rooted in the history of glass. After having claimed that the Earth was made of glass,[79] Buffon concluded:

Glasmahlen, Vergulden und Brennen Türckische Pappier, [et]c. und viel andere ungemeine Sachen zu machen, gelegret werden: mit einem Anhange von denen Perlen und fast allen natürlichen Edelsteinen (Leipzig: Gedruckt bey Christoph Günthern, 1679).

[75] Dedo von Kerssenbrock-Krosigk, *Rubinglas des ausgehenden 17. und des 18. Jahrhunderts* (Mainz am Rhein: P. von Zabern, 2001); Anna-Elisabeth Theuerkauff-Liederwald, "Becher-Gläser, daran die Farben aus denen Metallen gezogen, von dem berühmten Kunckel verfertiget," *Journal of Glass Studies*, (2007), *49*:179–190; Dedo von Kerssenbrock-Krosigk, (ed.), *Glass of the alchemists: lead crystal-gold ruby, 1650–1750* (Corning, N.Y.: Corning Museum of Glass, 2008).

[76] For a survey of these claims, see Wilhem Ganzenmüller, "Beiträge zur Geschichte des Gold rubinglases," in Id., *Beiträge zur Geschichte der Technologie und der Alchemie* (Weinheim: Verlag Chemie, 1956), pp. 85–128.

[77] Werner Loibl, "Johann Rudolph Glauber und die 'gläsernen' Folgen," *Journal of Glass Studies*, (2007), *49*:81–101.

[78] Martin Mádl, "Johann Joachim Becher and the Beginnings of Baroque Glassmaking in Central Europe," in Dedo von Kerssenbrock-Krosigk, (ed.), *Glass of the alchemists*, cit., pp. 97–105.

[79] "Le feu a produit par la fonte des matières une croûte vitrifiée, et la base de toute la matière qui compose le globe terrestre est du verre, dont les sables ne sont que des fragmens ; les autres espèces de terre se sont formées du mélange de ce sable avec des sels fixes et de l'eau, et quand la croûte fut refroidie, les parties humides qui s'étoient élevées en forme de vapeurs, retombèrent et formèrent les mers." Buffon,

> Je conçois donc que la terre dans le premier état étoit un globe, ou plûtôt un sphéroïde de matière vitrifiée, de verre, si l'on veut, très-compacte, couvert d'une croûte légère et friable, formée par les scories de la matière en fusion, d'une véritable pierre ponce.[80]

From this it followed that nearly all known matter originated as glass, and could therefore be transmuted:

> Le verre paroît être la véritable terre élémentaire, et tous les mixtes un verre déguisé ; les métaux, les minéraux, les sels, etc. ne sont qu'une terre vitrescible.[81]

Buffon's theory elicited strong reactions. While the hypothesis on the epochs and evolution of the Earth caused immediate scandal and censorship, the original view on glass as the matrix of our planet was the object of scorn,[82] even if it was appreciated within a more restricted circle of savants. Probably inspired by Buffon's theory, the Baron d'Holbach translated Neri's treatise into French and added all the comments published by German chemists, many of whom were alchemists.[83] It was the most comprehensive edition of treatises on glassmaking ever published, and contained references both to the technical tradition and to the alchemical sources and beliefs which still made glass a material

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Histoire naturelle, (Paris: Imprimerie Royale, 1749), vol. 1, p. 195. I thank Thierry Hocquet for bringing this passage to my attention. This and the follwing citations from the electronic edition of Buffon's *Histoire naturelle* are taken from the Buffon website http://www.buffon.cnrs.fr/.

[80] *Ibid.*, p. 259.

[81] *Ibid.*, p. 261.

[82] Tomas Maurice Royou, *Le Monde de verre réduit en poudre, ou Analyse et réfutation des époques de la nature de M. le Comte de Buffon* (Paris: Couturier, 1780).

[83] Antonio Neri, *Art de la verrerie de Neri, Merret et Kunckel : auquel on a ajouté le Sol sine veste d'Orschall, l'Helioscopium videndi sine veste solem chymicum, le Sol non sine veste, le chapitre XI du Flora saturnizans de Henckel sur la vitrification des végétaux, un Mémoire sur la maniere de faire le saffre, le Secret des vraies porcelaines de la Chine & de Saxe : ouvrages ou l'on trouvera la maniere de faire le verre & le crystal d'y porter des couleurs, d'imiter les pierres prétieuses, de préparer & colorer les emaux, de faire la potasse, de peindre sur le verre, de préparer des vernis, de composer des couvertes pour les fayances & poteries, d'extraire la couleur pourpre de l'or, de contrefaire les rubis, de faire le saffre, de faire & peindre les porcelaines &c traduit de l'allemand par M. D.****. (Paris: Durand 1752).

which defied unequivocal classification. While chemistry was becoming an autonomous discipline and the criticism against the alchemical tradition grew ever more frequent, glassmaking remained a field in which even the most enlightened savants and philosophers felt free to defend theories and ideas which were nearly heresy for any professional chemist.

As late as 1778, under the auspices of the Académie Royale des Sciences de Paris, Fontanieu published a booklet entitled *L'art de faire les cristaux coloré imitans les pierres précieuses* (Paris: Imprimerie de Monsieur), where the ancient alchemical recipes on how to produce artificial emerald and other precious stones still found an attentive and qualified readership. Fontanieu's booklet was one of the last works to evoke a tradition which, as we have tried to show throughout this study, never completely disappeared, instead accompanying the history of alchemy from its first beginnings, reminding glassmakers of the achievements and ambitions of their predecessors.