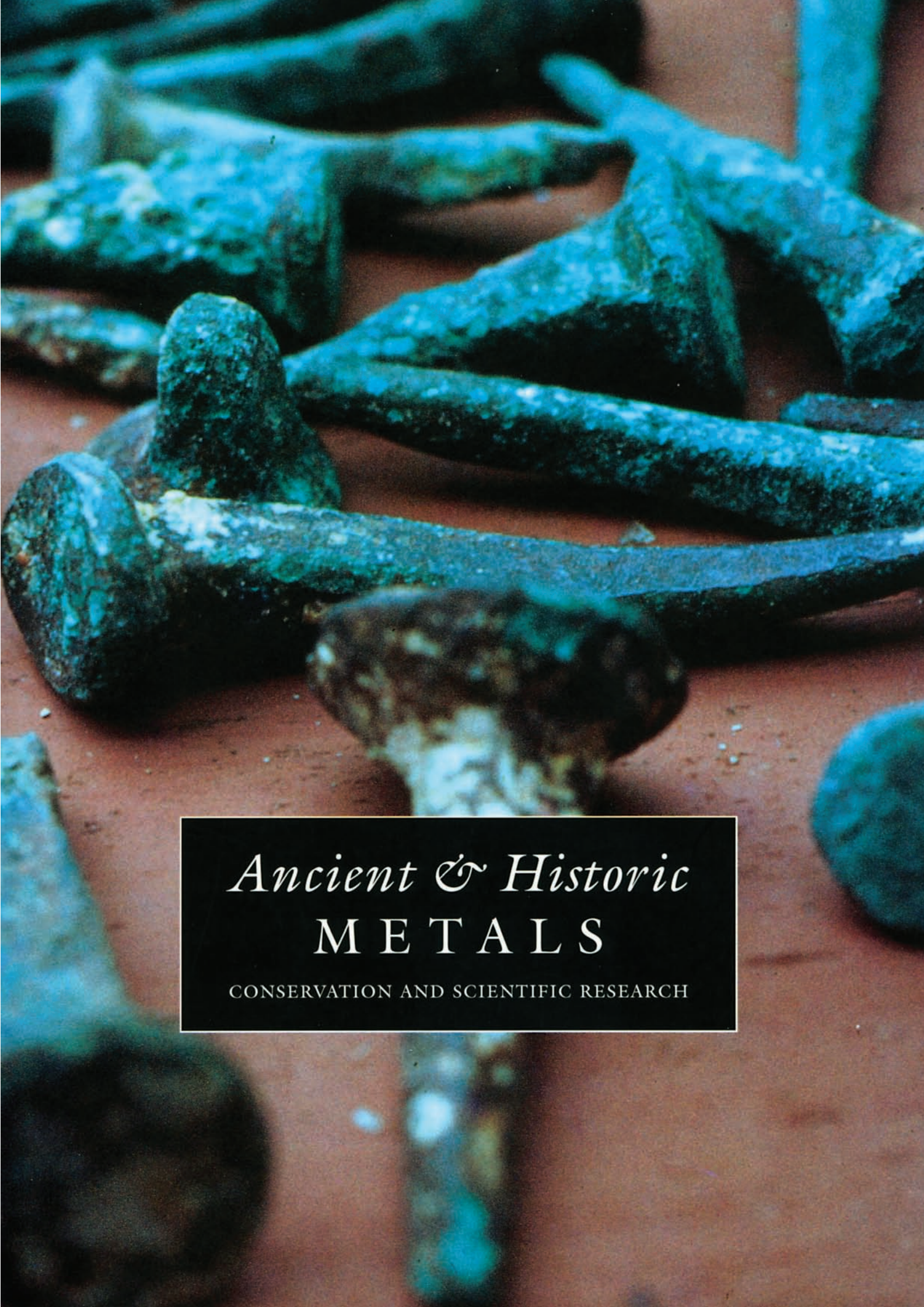

Ancient & Historic METALS

CONSERVATION AND SCIENTIFIC RESEARCH

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Proceedings of a Symposium
Organized by the J. Paul Getty Museum
and the Getty Conservation Institute
November 1991

Edited by
David A. Scott, Jerry Podany, Brian B. Considine

THE GETTY CONSERVATION INSTITUTE

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THE GETTY CONSERVATION INSTITUTE

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The Technology of Medieval Jewelry

JACK OGDEN

Despite the extensive research carried out on ancient goldsmithing technology over the last half century, the techniques of medieval goldsmiths have been largely ignored. The following is a preliminary examination of various technical aspects of medieval goldwork, including a comparison of medieval technology with that of Roman and earlier periods. In general, most techniques remained constant. One major exception, however, is the widespread use of drawn gold wire by about the ninth or tenth century C.E. This technique opened up new possibilities for decorative filigree methods which were used to advantage by medieval goldsmiths. Thus an understanding of technological developments is of primary importance for the stylistic study of medieval European gold jewelry.

Early Medieval Practices

Until about 1500 C.E., medieval jewelry techniques in Western Europe, particularly Britain, were related in a multitude of ways to the techniques of their Classical and Byzantine predecessors. Although the stylistic development of jewelry is not the principal concern here, it is important to note that material and technique do influence style to a considerable extent. For example, changes in the style of filigree work—of paramount importance in characterizing jewelry development in the medieval period—cannot be fully considered without understanding the various manufacturing options available to the goldsmith.

From the point of view of the jewelry historian, the distinction between ancient and medieval is based more on terminology than any real discontinuity. A Hellenistic goldsmith could pick up a medieval jewel and be familiar with most of its technology and the sequence of manufacture; the goldsmith might be surprised mainly by the novelty of design and the use of drawn wire. Even the workshops would have been comparable. Wall paintings of jewelers' workshops as seen in the houses of the Vetii at Pompeii, for example, differ little in their essentials from Renaissance or even

more recent depictions; the same types of tables, furnaces, anvils, and scales are present.

The medieval period has provided a range of representations of goldsmiths and jewelers at work. Some are religious paintings, such as Taddeo Gaddi's fourteenth-century *St. Elgius as a Goldsmith,* now in the Prado, Madrid. Others illustrate technical treatises, such as the mid-fifteenth-century manuscript of Pliny's *Natural History* preserved in the Victoria and Albert Museum, London (Whalley 1982). This latter manuscript, for example, has a rare depiction of a lapidary drilling precious stones with a pump drill. Representations of jewelers' shops are less common; however an engraving of a jeweler selling rings, plus some rather unorthodox gemmological tests, may be seen in a late-fifteenth-century work by Johannis de Cuba (Kunz [1917:facing 343] 1973). Representations of workshop scenes are far more prevalent from the sixteenth century onward.

Medieval documentary references to goldsmiths are quite common. The prime source is the German monk Theophilus, who compiled a comprehensive account of goldsmithing procedures in the first half of the twelfth century C.E. The third book of his *Treatise on Divers Arts* begins with details on how to construct a workshop and equip it with tables, seats, and forges, and then describes the individual tools and their use. Theophilus is now generally taken to be the pen name of Roger of Helmarshausen, a goldsmith-monk who actually left samples of his work, such as a book cover now in the Domschatz Trier (Ronig 1984:cat. no. 65; Hawthorne and Smith 1979:pl. 8). The identification of Theophilus with Roger of Helmarshausen and the dating of the treatise have been most recently discussed by Dodwell ([1961] 1986) and Hawthorne and Smith (1979).

Near-contemporaries of Theophilus include Jean de Garlande of about 1200, who briefly mentions goldsmiths. He writes that "the craft of these goldsmiths consists of hammering with little hammers on the anvil thin sheets of gold and silver and in setting precious stones in the bezels of rings for use by barons and noblewomen" (Cripps 1880:9). The Englishman Alexander Neckham (1157–1217) describes the necessary tools of a twelfth-century goldsmith (Neckham 1867). These include a forge with top chimney; bellows worked with one hand evenly and with light pressure; an anvil; forceps to hold metal during beating; a hammer for shaping gold; very sharp chisels and another chisel (possibly) for cutting stones, a touchstone to test metal; a whetstone to sharpen iron tools; a hare's foot (*pedem leporarium*) to smooth, polish, and clean gold; a leather bag around the waist to collect grains of metal "lest they vanish away"; a toothed saw (*serram dentatum*); and a file for gold (*limam aurifrigium*). It is interesting that there is no mention of wiredrawing equipment. A hare's foot seems an unlikely implement to use for polishing gold, but perhaps it was really used to clean the bench. Earlier this century Maryon advocated the use of the same implement: "The bench is swept several times a day with a hare's foot, which forms a convenient little brush to which the gold will not adhere" (1971:1).

Theophilus describes how different tools were made and shows that goldsmiths made their own equipment. This was true in antiquity and right up to modern times in many parts of the world. A regulation of the year 1513 states that goldsmiths should not work copper or brass apart from making their tools of the trade (Prideaux

1896–97:39). On this basis, many of the more complex or sophisticated implements, such as elaborate wiredrawing equipment or rolling mills, would be out of the question for small craftshops. The large, fully staffed, and impressively equipped workshops seen in Renaissance and later engravings could hardly have existed earlier outside of royal patronage or the main urban centers.

It was a common practice for goldsmiths to bequeath their tools to their sons, friends, or fellow goldsmiths. Sometimes wills list the tools in some detail. For example, the will of John Colan, a goldsmith of York who died in 1490, contains a comprehensive list of the goldsmith's equipment (Cripps 1914). It enumerates several varieties of hammers, stamps, swages, stakes, files, tongs, wiredrawing implements, a gold balance, and more. But one must not forget a vital truth about any craft: Tools are worthless unless manipulated by someone with skill and experience. As Biringuccio said at the end of his discussion of goldwork, "Having told you the general facts concerning the art of working gold and silver I think I have said enough about it. All the rest that is necessary depends entirely on ingenuity and practice" (Smith and Gnudi 1943).

Much documentary evidence for the medieval jeweler's trade derives from regulations defining their working practices and the limitations on the material they could use. Fraud by means of debased gold, plated base metals, filled hollow-sheet objects, and imitation stones were potential problems for the jewelry-buying public throughout history. Neckham said that the goldsmith should be able to "discern well the pure gold from the latten [brass] and copper lest he buy latten for pure gold" (1867).

Medieval English regulations stipulated that jewelers had to work in certain main streets, not in "lanes or alleys"; only very seldom was work in private houses allowed. Similar restrictions are laid down in the tenth century *Book of the Prefect* from Constantinople (Hendy 1985), and similar rules might well have been widespread. Goldsmiths should be visible, but the actual secrets of the craft should not be divulged (Prideaux 1896–97:doc. no. 44; 150). There are references to goldsmiths being punished because they allowed strangers to "see the privities of the trade" (Prideaux 1896–7:15–16; 22). In the early sixteenth century we are told that no goldsmith could work at night by candlelight or on Sundays.

There was clearly rivalry between goldsmiths. One was punished because he told a customer that a competitor's work was overpriced; another was castigated because he alleged that a rival did not known how to make a cup (Prideaux 1896–97:15–16). Successful goldsmiths could certainly become rich, and this meant they could also amass some gold and silver as stock in trade, rather than just working their patrons' materials.

It has been assumed that a master goldsmith would be skilled in all aspects of the trade (Lightbown 1978:84), but Biringuccio points out that such wide mastery was rare, and that in practice "one has his profession in engraving, another in the hammer, and another in mounting or setting jewels, and in making a ring well" (Smith and Gnudi 1943). There is little evidence for medieval specialization apart from mention of gold beaters in thirteenth-century Paris and enamelers, seal cutters, and burnishers in fourteenth-century London; the burnishers included women (Prideaux 1896–97:8).

In the sixteenth century, however, there is more evidence for specialization. Cellini lists several of his contemporaries and gives their specializations (Ashbee 1967:1–6). Gold wiredrawers are mentioned in 1512 (Prideaux 1896–97:38). In general, the specialized manufacture of components for the jewelry industry is a relatively recent innovation. The 1884 *Fifteenth Annual Report of the Royal Mint* of London states, "A new industry, moreover, is springing up for the supply of rolled or drawn metals to jewelers and dentists."

By the early fourteenth century some distinction is made between wholesale and retail goldsmiths in Paris, and some English regulations appear to distinguish between a goldsmith selling to a merchant and selling to a member of the public. The cost of gold jewelry depended on the materials and labor costs, and these would usually be calculated and listed separately. This is an ancient practice. Plautus, in his play *Menaechmi,* written in about 190 B.C.E., has a dialogue between Menaechmus and a maid. The maid wants a pair of earrings as a gift, and Menaechmus says "sure, you provide the gold, I'll pay for the workmanship." The distinction continued through the medieval period and into the Renaissance. French documentary references to medieval jewelers often mention both the material cost and *la façon.* This is the same as the "fashion" we find in medieval and Renaissance English documents. Shakespeare reworked *Menaechmi* for his play *A Comedy of Errors.* In Shakespeare's version, the plot involved the manufacture of a gold chain, the invoice for which lists everything including the "fashion." Stubbes, writing in the 1580s, gives much of the same information in his description of goldsmiths' tricks: "If you buy a chain of gold, a ring, or any kind of plate, besides it you shall pay almost half more than is worth (for they will persuade you that the workmanship of it comes to so much, the fashion to so much, and I cannot tell what)" (Stubbes 1583). This might seem to imply that workmanship and "fashion" were distinct, but all other indications are that they were one and the same.

Medieval French regulations actually stipulated that workmanship and materials costs should be distinguished on invoices and receipts (Cripps 1880:32–34). Stubbes indicates that the workmanship would be about 50 percent of the cost of the materials. We can obtain some idea of medieval equivalents. For example, a gold ring made for the Duke of Orleans in the mid-fifteenth century cost 14 pounds for the materials and 13 shillings for the manufacture; this means that the goldsmith received less than one-twentieth of the value of the materials he was working. Though low by modern jewelers' standards and even by Stubbes's margin, this is far higher than the goldsmiths' profit margins defined in the maximum-price edict of Diocletian a millennia earlier (Ogden n.d.). On the other hand, other medieval documents show that manufacturing costs could easily be up to Stubbes's level of 50 percent or more of the materials cost. Presumably, fees depended on the nature of the materials, the complexity of work, and the prestige of the individual goldsmith.

Composition

Analyses of Anglo-Saxon and other Dark Age metalwork of the seventh century show that after about 625 C.E. coinage and jewelry alloys were sometimes debased to an

extraordinary degree; an alloy containing less than 10% gold is not unusual (Hawkes et al. 1966). There is little published information on the composition of Western European goldwork after this date. Farther east, analysis of Byzantine jewelry shows that a high purity of around 91–92% (perhaps intended to be 22 carats) lasted through the late tenth century, at least. In addition, several gold objects from the tenth to twelfth centuries were found to contain about 80% gold—possibly relating to the gold hyperperon coin of that purity, which was introduced in 1092 and survived almost through the twelfth century (Oddy and la Niece 1986).

In early medieval Western Europe, a wide range of gold purities were used. The goldsmith would refine or debase the gold depending on a variety of factors; at one end of the scale were official purity requirements, at the other the whim or dishonesty of the goldsmith. Goldsmiths would have generally refined their own gold as and when needed. Medieval and early Renaissance sources such as the "Mappae Clavicula" and Theophilus (Smith and Hawthorne 1974), Cellini (Ashbee 1967), Pegolotti (1936), and Biringuccio (Smith and Gnudi 1943) all describe the refining of gold. However, a statute of 1488 says that "finers [refiners] and parters dwell abroad in every part of the realm," which suggests that there were specialist refiners—perhaps mainly for silver—by the end of the medieval period (Cripps 1914).

Some tenth- to twelfth-century Western European goldwork certainly has the color of quite high purity gold, and gold is often referred to in contemporaneous documents as being of high purity. For example, objects are sometimes described as made of *aurum purissimum* (Lehmann-Brockhaus 1938). One may also find Western medieval and even Renaissance use of the Byzantine Greek term *obrysus* and its variants (e.g., *obrizé*) as a description of pure gold. The tenth-century *Alfric's Vocabulary* defines *obrizum aurum* as "real gold."

On the other hand, debasement was acceptable. The "Mappae Clavicula," for example, describes an alloy suitable for making male figures that consisted of 67% gold and 33% silver (Smith and Hawthorne 1974). Female figures were apparently better suited to an alloy of just 20% gold with 80% silver. Even the purer of these two alloys has a high enough silver content to be described as electrum. Other recipes for electrum have survived (Gay [1887] 1928). In general, medieval texts clearly distinguish between gold, electrum, and silver, but one reference to "purest electrum" (*electrum purissimum*) might suggest that not all recordkeepers had a deep understanding of the nature of the alloy (Lehmann-Brockhaus 1938:no. 2551). Analysis of one English gold ring of twelfth century date showed that it was of 60% gold, 30% silver, and 10% copper—a precise ratio that might not be coincidental (John Cherry, personal communication, 1991).

The "Mappae Clavicula" also describes a red alloy with about 57% gold, 29% silver and 14% copper (Smith and Hawthorne 1974:ch. 54). Red gold, or gold alloyed with copper, is quite frequently mentioned in medieval European literature (Kuhn and Reidy 1963) and several extant early medieval ornaments are of distinctly reddish color. In the twelfth century Theophilus describes Arabian gold as having an exceptional red color, and says that workmen imitated its appearance by alloying a fifth-part copper to pale gold (Hawthorne and Smith 1979:ch. 47). Theophilus appears not to have realized that the natural alloy contains copper, and he notes that

the presence of copper was a sign of the spurious alloy. On the basis of the admittedly small number of medieval English gold rings studied, the copper content seems to exceed the silver content far more frequently than it does in ancient goldwork. Possibly the red Arabian gold was derived from Crusader gold coins, some of which contain almost 15% copper. On the other hand, the exploitation of Arabian mines is also certain. Al-Hamdani reveals that Arabian mines were exploited in the tenth century (Dunlop 1957), and European corroboration includes the "Song of Roland" which refers to "ten mule loads of gold dug from Arabian mines."

The medieval jeweler generally obtained raw materials from a patron or with money provided by the patron; only rarely did a goldsmith amass enough capital to hold his own stock of precious metal. Gold sources usually included damaged or unfashionable objects returned for remaking. Medieval texts refer to goldsmiths purchasing gold jewelry for resale or reworking. An English charter of 1327 described goldsmiths "who keep shops in obscure streets, and do buy vessels of gold and silver secretly without enquiring whether such vessels were stolen or come lawfully by, and immediately melting it down, make it into plate, and sell it to merchants trading beyond the sea" (Jackson 1905:35). There were less conventional ways in which even the crown could obtain gold. In the fourteenth century "the gold from which the nobles of Edward III were coined was said to have been produced by occult sciences" (Freemantle 1870).

Coinage has long been a major source of gold for goldsmiths. There is documentary proof of this in Byzantine and early medieval times, if not earlier. Even in the nineteenth century, the annual report of the Royal Mint of London noted that "working jewelers are in the habit of making use of large quantities of sovereigns [a British gold coin of 22 carat gold] in the business of their trade, owing to the convenience of being able to obtain by this means gold of a known standard" (Freemantle 1870:24). There appears to have been no British law prohibiting the melting down of gold coinage to make jewelry prior to 1920.

Even if coinage was a main source of gold, the goldsmiths of medieval Europe could still have had to contend with widely differing purities. In the early fourteenth century, for example, Pegolotti of the great Florentine banking house of the Bardi, which had offices across Europe from London to Constantinople, produced a merchants' handbook giving prices and trade details of many countries (Pegolotti 1936). The author lists no fewer than thirty-nine different gold coins that a fourteenth-century merchant might encounter (Pegolotti 1936:287–89). He lists their purity in carats, ranging from debased Tripoli coins of just 11 carats (45.8% gold) up to high purities such as French coins of 23.75 carats. (This is perhaps the earliest recorded European use of the term carats as applied to purity rather than weight.) The Troy ounce was divided, like the Byzantine solidus before it, into 24 carats, which was thus equated with pure gold; 18 carat is 75% gold, and so on. The carat standard of gold makes no distinction between the possible alloying materials. In ancient and medieval times these were typically silver and, to a lesser extent, copper. Today all manner of metals are added, some of which cause problems for goldsmiths.

Other coins listed by Pegolotti include Saracen bezants at 15 carats and *Bisanti vecchi d'oro d' Allessandrie* at 23 carats. Recent analyses have indeed shown that

Islamic and Crusader bezants had a wide range of purities (Gordus and Metcalf 1980). In many ways, little has changed. The 1884 report of the Royal Mint published a list of the various purities of gold coinage issued by contemporary European mints (Royal Mint 1884) revealing variation even within countries—for example, the Austro-Hungarian 8 florin piece was 90% gold, the ducat of the same country was 98.5% gold.

It is hardly surprising that by the thirteenth century some of the authorities in Western Europe had seen the need to control the quality of gold worked and sold by goldsmiths. Such regulations could best be enforced through the goldsmith guilds that had existed in England at least since the twelfth century. In England the "Close Roll 22" of Henry III in 1238 concerning *de auro fabricando civitate Londiniarum* ruled that no one should use gold under a certain purity (defined by price) and that all work was to be carried out in the public street, "not in secret." The same ordinance includes provisions about counterfeit and precious stones plus a ban on the gilding of copper and other base metals. In France, a regulation of 1268 states that "no goldsmith may work in Paris, unless it be of the touch of Paris or better: which touch surpasses all the gold of every part worked on the earth." The "touch of Paris" was actually only 19.2 carats pure, that is, 80% gold. Perhaps the origin of this 80% standard is related to hyperperon coinage of similar purity, as well as goldwork from medieval Constantinople. The French regulations, like the English, include a ban on working at night (except on commissions for Royalty or the Bishop of Paris) and rule against the use of glass-imitation stones and doublets (Boileau 1837:38–39). The "touch of Paris" was also the minimum standard for gold jewelry and other wares allowed in a 1300 English statute of Edward I (Jackson 1905:7–8). According to the same source, goldsmiths were allowed to complete any work in hand made from poorer-quality gold, but if in future they purchased such objects, they had to be melted down and refined, not resold. Later the same century regulations of Edward III in England and John II in France reiterate that no goldsmith could work "gold worse than the touche of Paris" (Prideaux 1896–7:doc. no. 43; Cripps 1914).

A series of analyses of seventeen gold rings from thirteenth- and fourteenth-century Britain shows a wide variation in purity, from about 64 to 96% gold. There are, however, definite clusters at around 80 and 90% gold (both ± 2.5%; John Cherry, personal communication, 1991). Clearly this could be a fertile area for research.

Gold standards were by no means uniform or necessarily followed. One English document of 1339, refers to "parti-gold" (debased gold). Apparently, various debased alloys were also allowed in certain regions of France. For example the Montpellier goldsmiths were evidently allowed to work 14 carat (58.3%) gold (Cripps 1914:22), and in Put-en-Velay, both 14 and 16 carat gold are found (Cripps 1880:16). It appears that itinerant dealers were still selling debased and unmarked goldwork all over France in the late fifteenth century (Cripps 1880:19). A Scottish statute of 1457 gives 20 carat (83.33%) gold as the minimum gold standard for coins (Cripps 1914:161).

The jewelry standard was thus far lower than the contemporary English and French coinage standard of 23 carats, 3.5 grains (99.5%) that survived through the remainder of the medieval period. This is the defined purity of the gold trial piece

made as an assay standard in 1477 (during the reign of Edward IV) and described as being of 23 carats 3.5 grains of "perfect fine gold" (Ruding 1812). Chemical analysis of this same trial plate carried out in the nineteenth century showed it to be 99.35% gold, 0.5% silver, and 0.14% copper (Royal Mint 1874).

The minimum gold purity for jewelry was lowered in 1477 when a new regulation stated that "no goldsmith . . . shall work, sell or, set to sale any manner of base gold under the fineness of eighteen carats"; that is, 75% gold (Jackson 1905:12–13). Nevertheless, later in the century an Act of Parliament of Richard II made every goldsmith put his mark on his wares "because gold and silver, which is wrought by goldsmiths in England is often times less fine than it ought to be, because the goldsmiths are their own judges" (Jackson 1905:8–9). Too few analyses have been carried out so far to tell whether the new official 18 carat standard is reflected in the composition of late fifteenth-century gold jewelry from Britain. However, it should be noted that Middleham jewel (Fig. 1) is composed of an alloy with about 75% gold, although there is also [deliberate] gold enrichment up to about 86% in certain areas of the surface (John Cherry, personal communication, 1991). This can be seen in the darker color of the Trinity figures, compared to that of the design on either side. The next change in the gold standard—up to 22 carat (91.7%)—was not introduced in England, Scotland, or in France until the mid-sixteenth century.

The English statute of 1300 had included legislation to ensure compliance with the rules regarding gold purity: "Wardens of the crafts shall go from shop to shop among the goldsmiths to essay if their gold be of [that] touch" (Jackson 1905:7–8). "If gold found in the hands of a goldsmith or dealer is not worth the assay, in buckles, rings or other articles . . . these should be broken, and the man loose his work and rectify his gold" (Prideaux 1896–97:doc. no. 44). The purity of the gold was ascertained by "fire or touch," that is by fire assay or by touchstone. The latter was

FIGURE 1. *The so-called Middleham jewel, a magnificent late fifteenth-century English gold pendant set with a sapphire, found near Middleham Castle in Yorkshire in 1985. The front of the pendant is engraved with a depiction of the Trinity, the back with the Nativity.*

the simplest and "good stones and good needles for to touch be always there ready . . . to make assay of gold of the carat between the merchants and the said master" (Combe 1806). If the gold was not up to standard, it should be "new molten and reforged until it be put to point." Similar rules also applied to stones. Real stones could not be set in base metal, while false (i.e., glass) stones found set in gold were to be broken up and "ground in a mortar" (Prideaux 1896–97:doc no. 44). Notes in the records of the Worshipful Company of Goldsmiths refer to goldsmiths who produced substandard goldwork; this must have been a perennial problem.

We can imagine that similar regulations—in particular restrictions on the manufacture and sale of substandard gold objects—would be enforced as universally as local circumstances allowed. The tenth-century *Book of the Prefect,* dealing with bankers and precious-metal merchants in Constantinople, ruled that those who debased bullion and worked and sold it would have their hand cut off (Hendy 1985:251–53). This set of regulations from Constantinople also contains similar limitations as to places and times of work as found in the later English and French regulations. Possibly the Western regulations derived from the East.

The purity standards were, of course, minimum levels and quite possibly some goldsmiths might have preferred to use gold of higher purity. Certain types of work might have demanded certain purity levels. In the early sixteenth century Cellini notes that gold under 22.5 carats was too hard for fine work and dangerous to solder, while gold over 23 carats was a bit too soft (Ashbee 1967). In recent times jewelers have considered 22 carat gold ideal for fine work. Cellini's ideal was between about 92.5 and 96% pure; this is a fairly precise demand, but within the level of accuracy possible with experienced use of the touchstone. A common purity range for much Hellenistic, Roman, and Byzantine goldwork is 92.5–96%. Some medieval Byzantine goldwork seems to vary in composition depending on function. For example the ninth-century Byzantine gold cross in Tournai is made of sheet gold which is between 90 and 92% gold, whereas the bordering beaded wire, more prone to wear, has a slightly higher silver content (de Cuyper et al. 1987). Biringuccio in his *Pirotechnia,* book 5, chapter 2, noted that silver added to gold will harden it, but in general he seems to have had a cavalier approach to debasement. He notes that if you were a goldsmith you might debase gold with silver if you "begrudge the expense of having it fine, or if you find that you do not have enough, or if you do not care about such fineness" (Smith and Gnudi 1943).

Technology

Sheet Gold

Goldwork was characteristically manufactured from hammered sheet gold and rarely by casting. Hammering has thus always been one of the trademarks of the goldsmith and the most commonly illustrated and described of the goldworker's skills. Changes in the process include the introduction of the hafted hammer for metalwork in the first millennium B.C.E. (Ogden 1982:34). This can probably be linked to the recent research by Nicolini and Bouchet (1990), who used the scanning electron microscope

to distinguish between "primitive" or "vertical" hammering of ancient gold and the "progressive" hammering that they contend gradually replaced it.

The greatest potential change in the manufacture of gold sheet came after the period considered here, with the invention of the rolling mill, which rolls the metal between two iron or steel rollers. The invention is accredited to Leonardo da Vinci, who provided a sketch for one (Uccelli 1948). There is no evidence for rolling mills prior to the Renaissance, and these devices were probably rare in ordinary jewelry workshops for several centuries afterward. The earliest apparent documentary reference to rolling sheet gold dates from the seventeenth century (Singer et al. 1957:342). The eighteenth-century *Encyclopédie* of Diderot shows a simple hand-rolling machine for use by jewelers (Diderot and d'Alembert 1751–57:pl.6:25), but his and other contemporaneous workshop scenes are still filled with workers hammering out gold and silver sheet.

The various methods of raising and shaping sheet gold have been described in detail elsewhere; the medieval smith had no major new process at his disposal. Numerous tools, including dies and punches, have survived from the Viking and later worlds. Cellini describes the casting of copper-alloy dies and formers and the use of simple tools of wood and bronze for working sheet gold (Ashbee 1967).

Hollow sheet gold often needs to be filled to provide support and weight. Sulfur was typically used in late Hellenistic, Roman, and early Byzantine gold jewelry but does not appear to have survived into medieval times in Europe, although it is possibly present in some medieval Islamic goldwork. The suitability of the melting temperature and flow properties of sulfur are noted by Biringuccio. Pitch or a pitch-like substance was also used as a filler in early Islamic jewelry (Ogden 1987) but has not been recorded so far in medieval European goldwork. However, pitch or resin might well be expected since pitch is still a common filling material in flimsy modern sheet silver objects. From around the twelfth century onward, filled hollow sheet-gold jewelry was often forbidden in Western European statutes; thus filled hollow work became far rarer than it was in Byzantine or earlier times.

Cutting

Sheet gold was normally cut with chisels, as in antiquity, or with small shears or scissors. The use of scissors or small shears for goldwork in antiquity is generally doubted, and the presence of the tool marks from such implements on purported ancient goldwork is usually taken as a warning sign. However, fine cutting implements of this type came into common use during the course of the early medieval period. Theophilus describes the use of both scissors and shears for cutting metal in his chapters 23, 52, and 76 (Hawthorne and Smith 1979); and a fifteenth-century Greek manuscript, derived from earlier texts, refers to the use of small scissors to cut small pieces of solder (Berthelot 1888:no. 39) Shears are shown being used by a metalworker in an illustration from a mid-fifteenth century manuscript of Pliny's *Natural History* (Whalley 1982).

The fine almost lacelike pierced work of the late Roman and early Byzantine periods does not survive long into the medieval period. Some cruder pierced goldwork may be found, such as that around the side of the Alfred jewel and on several elements of the Egbert Shrine in Trier (Westermann-Angerhausen 1973:figs. 60–64, 66–69, etc.). Theophilus describes a type of pierced work using a chisel and small files which he terms *opus interrasile*. This term, found only in Theophilus, has also been used by modern historians to describe the finer Roman and Byzantine varieties of pierced goldwork. This terminology has its critics, however (Ogden and Schmidt 1990).

Files are mentioned by Theophilus many times, in relation both to their manufacture and use. His near-contemporary Alexander Neckham includes them in his list of essential goldsmith's tools. Files were used in the manufacture of tools and also in some shaping and fitting operations, though perhaps more commonly for silver rather than gold. By their very nature, files remove metal, and thus are to be avoided where possible when working gold. The use of files on goldwork in antiquity is usually doubted, while sure indications of the employment of such a tool is often taken as an indication of a post-ancient origin. In his chapter 26, Theophilus describes the use of a file to smooth the surfaces and edges of a silver chalice (Hawthorne and Smith 1979) and for similar purposes on other silver components, including niello work and openwork. Theophilus's "very small files—square, round, half-round, three-cornered, and flat and thin" do sound like the files found in modern jewelers' workshops (Hawthorne and Smith 1979:94). Cellini describes numerous small files and engravings of jewelers' workshops of the sixteenth century and later can show an assortment of such tools (Ashbee 1967).

The only saw mentioned by Theophilus is an iron saw, fed with sharp sand, used to cut rock crystal. The twelfth-century "Mappae Clavicula" manuscript similarly mentions a copper saw fed with saliva and emery powder for cutting gemstones (Smith and Hawthorne 1974:ch. 191a). In neither of these cases would a toothed saw be implied. Saws with teeth, probably used mainly for cutting wood, were thought by the Romans to have been invented by Daedalus but actually date back to the early Bronze Age in the Near East. For example, copper saws have survived from the First Dynasty of ancient Egypt (Lucas and Harris 1962:449). The use of a toothed saw for cutting gold is highly unlikely in medieval times, as it would result in lost metal and almost certainly would be too coarse for fine work. Nevertheless, Alexander Neckham, writing in the twelfth century, does include a toothed saw (*serram dentatam*) among the equipment to be found in a goldsmith's workshop (Neckham 1867). The jeweler's saw used by craftsmen today would no doubt have been appreciated by medieval goldsmiths, but it is hard to imagine that fine, handmade iron-piercing saws would have been worth the time and effort prior to their mass production and resulting affordability. They were difficult to make by hand and, like their modern mass-produced counterparts, all too vulnerable to fracture. Until good evidence exists to the contrary, the presence of characteristic parallel-sided, fine saw marks on gold or silver work purported to date from the Renaissance or earlier times should be viewed with great caution.

Wire

The early medieval period saw the introduction of wiredrawing—an innovation that was to have a widespread effect on both the construction and design of jewelry. Prior to this period, gold wire was generally formed by hammering—a process better suited to relatively large-diameter wires such as earring hooks—or by twisting narrow gold strips and then rolling the twisted wires to compact them. Wires of this general type have characteristic spiral seam lines, so to speak, along the wire, the number and spacing of which largely depend on the ratio of width to thickness of the original strip. The resulting wires have been classified under various names, including "strip twisted" and "block twisted," but I prefer to use the generic term *strip twisted* for all such wires. The various ancient technologies for making such twisted wires and their chronology have been dealt with at length by several authorities and will not be discussed here (Oddy 1977; Ogden 1991). Suffice it to say that the majority of wires in gold jewelry made prior to early medieval times show the characteristic spiral seam lines resulting from their twisted construction.

In wiredrawing, a rod or metal strip is pulled through consecutively smaller holes in an iron of steel drawplate; thus, it is literally drawn out in longer and thinner wires. Simple hand drawing, with strong forceps or tongs and a drawplate mounted on a sturdy piece of wood, is seldom practical for wires over about 2 mm in diameter. More complex drawing machines—termed *draw benches*—provided greater leverage and strength and allowed long lengths of wire to be made in a great variety of diameters.

The use of drawing for the production of Roman and pre-Roman gold wires has not been demonstrated despite the microscopic examination of thousands of ancient ornaments. On the basis of current knowledge, it is possible to conclude that gold wiredrawing probably first appeared in the Western world in about the seventh or eighth century C.E. Pre-seventh-century examples of drawn gold wire from Europe or the Mediterranean world have not yet been identified with certainty (Ogden 1991). The use of certain drawn wire on Korean gold earrings of the fifth to seventh centuries C.E. might suggest that the origins of wiredrawing lie in the East (Ogden 1991)

Duczko's study of Viking filigree work has demonstrated the general adoption of wiredrawing by the ninth century C.E. (1985). More recently Whitfield (1990) studied the various surviving drawplates and examined many examples of northern European filigree work. She concludes that wiredrawing was used in Northern Europe by around 800 C.E. According to Craddock (Youngs 1989), Celtic gold wires of the sixth to ninth centuries were made by twisting. Duczko's work on Viking jewelry has not found drawn wire dating from before the ninth century. On the other hand, it would be surprising to find that the braided silver wires on the eighth-century Derrynaflan paten were not drawn. The braided Trichinopoly work (named after the town in India where this type of braided chain was a traditional craft) of the ninth-century Trewhiddle silver scourge is certainly drawn (Fig. 2).

A well-known lunate earring type that straddles the Byzantine and early Islamic world, and which can be dated fairly accurately to the tenth century C.E., sometimes

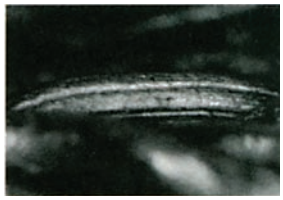

FIGURE 2. *Detail of drawn silver wire from the scourge in the Trewhiddle hoard. Anglo-Saxon, 870 C.E. British Museum, MLA 80.4-10.4.*

FIGURE 3. *A gold lunate earring exemplifying a well-known Byzanto-Islamic earring type dating from the tenth century C.E. This earring incorporates drawn round wire and spiral-beaded wire. The loops originally bore pearls.*

includes drawn wire (Fig. 3). Drawn and strip-twisted gold wires have both been noted in Fatamid Islamic work of the eleventh century (Ogden 1987). Current research in progress by the author suggests that drawn wire was the most common type used for Fatamid work and that examples of this work presumed to be strip-twisted should perhaps be reexamined.

The earliest description of wiredrawing might lie in a Greek compilation of goldsmiths' recipes. The surviving manuscript dates from 1478 but is almost certainly, for the most part, a copy of far earlier sources (Berthelot [1888] suggests possibly the eleventh century and earlier). This provides a good, but sadly ambiguous early account of drawing silver wire: "Take fine silver, hammer it and cut it into strips and twist [?] it with a rounding [?] iron [?]. Then put it in the drawplate and draw once" (Berthelot 1888:doc. no 33). The part about the "rounding iron" (perhaps roller) is unclear; the original Greek is **και γυσε το εις σιδερον στρογγυλον**. The Greek word used for drawplate is **συρτεν**.

The earliest datable description of wiredrawing is by Theophilus in the twelfth century. His book 3, chapter 8 describes the manufacture of the iron plates through which wires are drawn. Once into the thirteenth century, many documentary references to drawn wire may be found; for example, *filum auri tractum* (Lehmann-Brockhaus 1960:nos 2741, 2743, 2745). Thirteenth- and fourteenth-century English literary texts often refer to gold wire. Although these are almost invariably poetic descriptions of a heroine's hair, the allusion would better suit fine-drawn gold wire than shorter lengths of strip-twist wires. From the second half of the thirteenth century, details of iron and brass wiredrawers in Paris (Boileau 1837:61–63) and a reference to what may be a corporation of gold wiremakers may be found in a document dealing with "Des Batteurs d'or et d'argent à filer." It has been assumed that these were gold wire drawers, and certainly they are distinct from the beaters of gold foil, which are described separately (Boileau 1837:74–78). Unfortunately, the word "filer" could apply to gold threads as well as wires; and the mention of striking with a hammer in the text perhaps makes gold threadmakers more likely than wiredrawers.

Wiredrawing and some quite complex wiredrawing machinery are described at some length by Biringuccio in the early sixteenth century. He notes that wire "can be made in any thinness and length that the craftsman wishes, especially that which is made of gold and silver" (Smith and Gnudi 1943).

The earliest surviving representation of wiredrawing is probably in a manuscript of 1389 C.E. called the "Mendel Brothers Hausbuch," now in Nüremberg. This depiction, illustrated by Oddy (1977), shows a monk drawing wire. The drawplate is held on a heavy wood block or tree stump. The monk, holding the wire with a large pair of tongs, is seated on a swing to allow full leverage by pushing on the ground or wood with his feet. From the sixteenth century onward, representations of jewelry workshops typically show the use of draw benches. Theophilus states that round wires of relatively large diameters for conversion into beaded wires were made by hammering. This might mean that during the twelfth century only thin gold wires were being drawn. If this is so, it would place the invention of the draw

bench and other more powerful drawing equipment into the thirteenth to fifteenth centuries—after Theophilus but before Biringuccio and his contemporaries. On the other hand, some Fatamid Islamic goldwork dating from the eleventh century includes drawn wires of more than 2 mm in diameter.

Old processes can be continued for generations, particularly in small family workshops where tools and skills are handed down from generation to generation. Wiredrawing also suggests the preparation of some stock of raw materials. The fourteenth century monk on the swing, mentioned above, is shown with several coils of wire he had made. A goldsmith would hardly draw just a couple of centimeters of gold wire needed to decorate a single ring bezel.

Biringuccio makes a very perceptive remark when he notes that "goldsmiths also draw gold wire to make the ornamentation of their work easy and more attractive" (Smith and Gnudi 1943). The introduction of wiredrawing clearly facilitated certain decorative and functional ideas. Several types of filigree work only came into their own, in fact, when wiredrawing permitted the easy manufacture of long, thin lengths of gold wire, while such components as suspension loops and hinges made from springlike coils of wire tended to replace the sheet-gold equivalents.

Decorative Wire

A major change in gold filigree decoration during the course of the medieval period was the change from beaded wires to twisted wire ropes. A rope, in jeweler's terminology, is a tight twist of two thin wires. With wiredrawing, it was easier to draw thin wires and twist these into ropes than to hammer or draw a thicker wire and convert this to a beaded wire. Ropes became more and more common during the course of the medieval period and, in the Renaissance, almost totally superseded beaded and other decorative wires in gold jewelry.

Beaded wires had been popular in jewelry from about the seventh century B.C.E. onward. They were originally made by rolling a round section wire under a single or double edge, which would leave one or two grooves around the wire. By rolling the wire and moving the tool sequentially along its length, a series of grooves could be made that would produce a beaded effect. Theophilus describes the use of a double-edged tool for making beaded wires and this ancient process is illustrated schematically in Figure 4. By the late Roman period, some beaded wires were also being produced by swaging; that is, the wire would be stamped between two metal plates, each bearing a line of hemispherical hollows. If the wire were rotated and moved through the swage blocks, a very regular beaded effect could be produced. Swaged, beaded wire typically has very spherical beads, because hemispheres are the easiest depressions to cut in the swage blocks. The heavy beaded wires on the fourth-century Huntress plaque in the British Museum has lateral tool marks that would point to the use of a swage (Ogden and Schmidt 1990). Swaged, beaded wires certainly became usual in early Byzantine and Dark Age times. Theophilus describes the swage for making beaded wires, a tool he terms an *organarium,* literally "little organ," a term found in no other medieval writings.

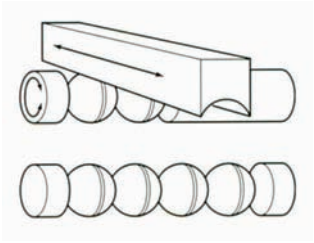

FIGURE 4. *Diagram of the two-edged implement for making beaded wire as described by Theophilus in the twelfth century and used in Roman times, if not earlier.*

Beaded wire is very common in European jewelry well into the medieval period and is found in Northern European goldwork up to the twelfth century, but it is far rarer after that and practically absent in Renaissance goldwork. Duczko points out that beaded wire almost totally disappears in Slavonic jewelry after the early tenth century (1985). There is also an almost total lack of beaded wires in early medieval Islamic jewelry (Ogden 1987).

An alternative type of decorative beaded wire has a groove running around the wire rather like a screw thread (Fig. 5). This type of wire was produced by rolling a round wire under a single edge held at a slightly oblique angle. The process was ideal for thin-gauge wires where true beading was more difficult to produce. This type of wire, which may be called *spiral-beaded* wire, is found from around the middle of the first millennium B.C.E. and, apart from an apparent break during the Roman period, continues well into the Middle Ages. Spiral-beaded wire is characteristic of Viking jewelry (Fig. 6). It is neither mentioned by Theophilus, nor is it found on his book cover in Trier, though it is found on the work of some of his contemporaries, and the technique may have survived into the thirteenth century. Further east we see spiral-beaded wire on some of the Byzanto-Islamic lunate earrings of the tenth century but not in Fatamid or other medieval Islamic goldwork from the mid-eleventh century onward. Just how widespread the technique was remains to be studied, but we can note the presence of some spiral-beaded wires (made from strip-twisted round wires) in Javanese gold jewelry of about tenth to twelfth centuries (Fig. 7).

In Northern European medieval jewelry of the tenth to twelfth centuries one often finds a combination of beaded and spiral-beaded wires, the spiral-beaded wires

FIGURE 5. *Diagram of spiral-beaded wire. A plain round wire is rolled under a single edge at an oblique angle to produce a groove similar to that of a screw thread.*

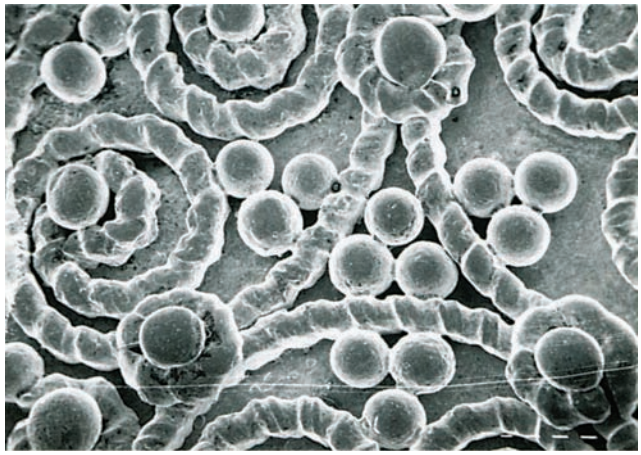

FIGURE 6. *An example of spiral-beaded wire and granulation on a Viking silver pendant from Birka, Sweden, ninth century C.E. (Duszko 1985, no. Bj 943).*

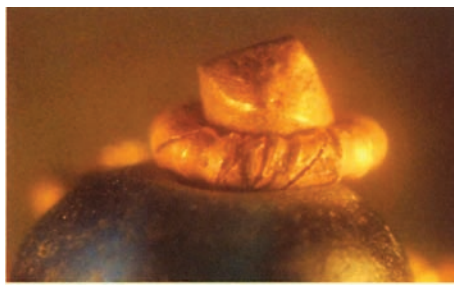

FIGURE 7. *Detail of the wire collar on an ear decoration from Central Java. The wire was made by a strip-twist technique and then rolled under a single edge to form a spiral-beaded wire, tenth century C.E.*

being of finer gauge. We can see this on the Dowgate Hill brooch found in London and dated to the early eleventh century (Figs. 8, 9). This brooch was traditionally seen as a German product, but the flat, nonarchitectural style of the object has led to a recent reassessment of the object as Anglo-Saxon (Westermann-Angerhausen 1983–84). The Townley brooch (Figs. 10–13), of about the same date and said to have been found in Scotland, also incorporates both beaded and spiral-beaded wires, but its more architectural structure points to an Ottonian German origin. It is of interest that neither of these brooches, among all their copious filigree, incorporate any plain, round-section wire.

The use of hollow-beaded wires—in effect, beaded tubes—in Byzantine gold-work has been examined (Ogden and Schmidt 1990). This is another decorative technique that found occasional use well into medieval times. Examples include the famous Konrad crown in Vienna (along the lower edge of the panels and also for the hinges) and a Viking silver ornament from Enggarda (Stenberger 1947:no. 435).

Another type of decorative wire-work that is visually very similar to beaded wire consists of a compact, springlike coil (Fig. 14). This type of coil work, another product of the wiredrawing revolution, is rare prior to medieval times (there are some Etruscan precedents) and seems not to have been widespread. One example is the

FIGURE 8. *A cloisonné enamel and gold filigree brooch found in London at Dowgate Hill, late tenth to eleventh centuries* C.E. *British Museum, MLA 56.7-1.1461.*

FIGURE 9. *Detail of the Dowgate Hill brooch in Figure 8, showing the filigree.*

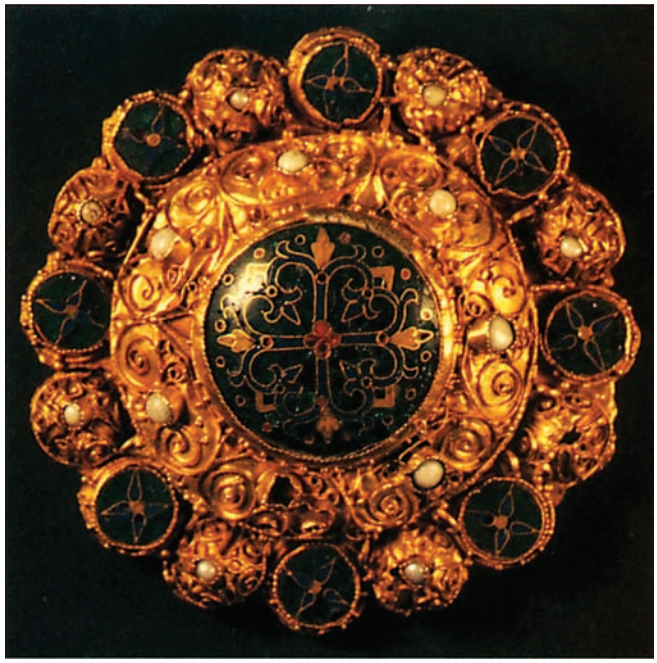

FIGURE 10. *Ornament of cloisonné enamel and applied filigree, the so-called Townley brooch, probably Ottonian German, early eleventh century C.E. British Museum, MLA Townley collection.*

FIGURE 11. *Detail of the back of the Townley brooch in Figure 10, showing the flattened beaded wire forming the framework.*

FIGURE 12. *Detail of the side of the Townley brooch, near right, showing open scrollwork of flattened spiral-beaded wire.*

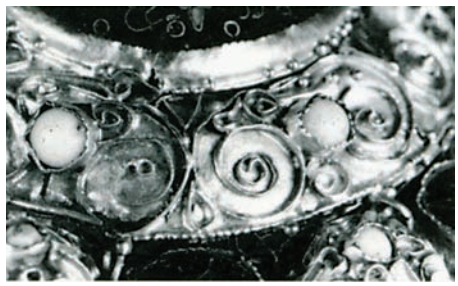

FIGURE 13. *Detail of the upper surface of the Townley brooch, far right, showing applied filigree scrollwork of flattened spiral-beaded wire.*

FIGURE 14. *Diagram of helicoidal spiral wire.*

border of the stone setting on the fifteenth-century Middleham jewel (Fig. 1). This technique might be seen as a late medieval and Renaissance characteristic. A more open springlike coil is also found in medieval goldwork; and a squashed version, providing a series of flat loops, forms a border to stone settings, rims, and other features from about the tenth century onward.

Both beaded and spiral-beaded wires (and occasionally ropes) were flattened for use in filigree work (Fig. 15). In the twelfth century Theophilus describes the process in his book 3, chapter 52, titled *The Art of the Metalworker*, as follows: "Pick up the fine [beaded] wires and hammer them lightly on an anvil so that they become

FIGURE 15. *Diagram of flattened beaded wire.*

somewhat flat and thin, but without the top and bottom of the beads losing their shape" (Dodwell 1986). The wires were shaped into the required forms and soldered to their background. By flattening the filigree wires in this way and then attaching them on edge to the background, the goldsmith could produce precise, fine detail with good depth and, thus, definition. The book cover by Roger of Helmishausen (Theophilus) in the Domschatz at Trier shows just this type of flattened beaded-wire-filigree scrollwork with the occasional granule highlight. These flattened wires were often termed *serrated* in older works when their mode of manufacture from wire was not understood.

Flattened beaded wire and, in particular, flattened spiral-beaded wire, is often found in ancient Iberian and late Hellenistic work. After the end of the Hellenistic period the technique apparently almost disappears until the Dark Age and Viking periods. An early post-Classical example of flattened beaded-wire filigree is on the Hunterstone brooch of about 700 C.E. (Stevenson 1974:pls. 12b, 13b, etc.). There is also flattened beaded wire on the eighth-century Derrynaflan chalice and on the silver trefoil brooch from Kirkoswald, which dates to the mid-ninth century or slightly earlier. Flattened beaded and spiral-beaded wires are common in Viking jewelry of the ninth and tenth centuries (Duczko 1985:210), and one occasionally also finds flattened ropes from this same period, such as on a silver ornament from Eastern Europe (Benda 1967:pl 74). Both flattened beaded and spiral-beaded wires are common on European decorative precious metalwork of the tenth to twelfth centuries, but not much after this. Both the Dowgate Hill and Townley brooches include flattened filigree. The Dowgate Hill brooch has an unusual openwork filigree composed of doubled, flattened spiral-beaded wires highlighted with some granulation. This is reminiscent of the Fatamid openwork with its double wires surmounted with granules (Fig. 9). The entire back framework of the Townley brooch is made up of flattened beaded wire (Fig. 11), while the serpentine openwork scrolls on the side and the scroll filigree on the upper surfaces are made from flattened spiral-beaded wire (Figs. 12, 13).

The gold brooch set with an earlier cameo, shown in Figure 16, is usually seen as an Ottonian product of about the same date as the Townley brooch, but the whole approach to the filigree is different.The cameo brooch employs no beaded or spiral-beaded wire, or flattened wires. Instead, the decoration includes fine twisted-wire ropes, plain (drawn) round-section wires, and perfect lines of regular granules (Fig. 17). The major technical distinctions between the filigree work on the Townley and cameo brooches also serve to separate other supposed Ottonian gold objects. Further research is needed to confirm the origins and relative chronologies of these pieces.

The choice of wires for filigree depended on both practical reasons and personal whim. For example, a gem-set gold cover for a cup in the Fitzwilliam Museum, Cambridge, probably from the late thirteenth to fourteenth century (Fig. 18), employs true beaded wire for the main decoration around the central setting but spiral-beaded wire for the finer gauge decorative wire around the individual stone settings. Here, as in comparable ancient and medieval objects, the choice might well have been practical: The thinner wires were easier to make this way. In other cases, personal choice must have played a part, and perhaps further study will allow more

FIGURE 16. *Granulated and filigree brooch, above, set with an earlier cameo. The goldwork is Ottonian German, tenth century* C.E.*; the cameo is of late Roman date. British Museum, MLA AF352.*

FIGURE 17. *Detail of the side of the brooch shown in Figure 16, revealing granulation and twisted-wire ropes as opposed to beaded and spiral-beaded wires.*

FIGURE 18. *Detail showing the use of beaded and spiral-beaded wire on a gold cover. Probably German, twelfth century* C.E. *Fitzwilliam Museum, inv. M/P.1.1921*

characterization of the workshops in which they were produced. For example, Theophilus's book cover in Trier uses flattened beaded wire. A contemporaneous book cover in the same collection (Ronig 1984:no. 68) uses flattened spiral-beaded wire. The well-known tenth-century portable altar, known as the Egbert shrine, also in Trier (Ronig 1984:no. 23) has flattened beaded-wire filigree but no granulation. The nail reliquary of the same date and supposedly from the same workshop (Ronig 1984:no. 24) has filigree of ordinary beaded wire, not flattened, but including some granulation.

One type of decorative wire work that disappears totally in medieval times is wavy ribbon, which is last seen in Dark Age work of the seventh century C.E. Wavy ribbon was made by coiling a narrow gold strip into a tube, flattening it and then unfolding it. The strip has a series of regular diagonal creases, creating an attractive, wavy appearance. It might not be coincidental that a type of decorative strip made by twisting died out just at the time that round wire made from strip twisting was superseded by wiredrawing. A type of undulating strip that might be seen as a successor to wavy ribbon, again with precedents in Etruscan work, became popular in medieval jewelry right across Europe during the medieval period. An early post-Roman example is seen on a series of gold pendants from Cyprus that probably dates from the seventh century and that also includes what is possibly the earliest drawn-gold wire that has been identified thus far from the ancient Old World (Whitfield 1990). This undulating strip is common in medieval jewelry. For example, it is seen on the Townley, Dowgate Hill, and cameo brooches discussed earlier, and on examples of the lunate type of earring from the eastern fringes of Europe. The gold strip used to form this undulating decoration is often of shallow D-section, which in at least some cases appears to have been produced with a one-sided swage. The serpentine-scroll type of openwork, as seen on the side of the Townley brooch (Fig. 12), is also common in about the eleventh century throughout Europe and in the Islamic world. Sometimes the serpentine scroll is composed of narrow strips of gold sheet. In other cases, as on the Townley brooch, it is formed from flattened spiral-beaded wire.

Cellini notes that skilled exponents of filigree could work without a preliminary drawing, but the best work resulted from careful designing first (Ashbee 1967). Biringuccio also noted that a goldsmith should be a good designer. Guidelines for filigree were sometimes lightly scored on the gold or silver surface. The author has seen lightly incised lines laying out the position of filigree on Anglo-Saxon goldwork. The positions for the settings on the Cambridge gold cover were also marked out by scoring fine lines—perhaps by tracing around the stone, since the settings were clearly designed to receive existing cut gems. Fuller jewelry designs sketched out on other materials, such as paper or vellum, are rare prior to Renaissance times; early examples include flat stones from Ireland with the scratched designs for brooches (Youngs 1989:nos. 154, 155)

Chains

In the ancient world, precious-metal chains were characteristically of the loop-in-loop type. Simple or plain chains—the form most common today—were seldom used, and when they were they were often reserved for particular decorative purposes. During the Byzantine period the ratio of loop-in-loop chains to simple chains changed, but loop-in-loop chain was still typical of much Dark Age and Viking jewelry. After about the tenth-century loop-in-loop chains were rare in goldwork, and the early Renaissance saw their almost total demise. One late example is the chain in the mid- to late-fifteenth-century Fishpool hoard from London (Fig. 19). Yvonne Hackenbroch's corpus of almost one thousand jewels dating between about 1500 and 1600 only includes a single example with any loop-in-loop chain (Hackenbroch 1979:no. 633), and even here the chain might not be original to the piece. Loop-in-loop chain is also surprisingly rare in medieval Islamic jewelry (Ogden 1987).

FIGURE 19. *Detail of two gold chains from the Fishpool hoard, found in London. One chain is of loop-in-loop type, the other of conjoined figure of eight links (the links joining the figures of eight are left unsoldered to avoid possible fusing during the final assembly of the chain). British Museum, MLA 67.12-8.1-9.*

The demise of gold loop-in-loop chains was probably a result of changing taste. The Renaissance chains on the flamboyant figural jewels are attempts at looking mechanical and structural; they bind a monster or constrain a vessel. Loop-in-loop chains are a fairly extravagant use of gold wire, but their massive and elaborate Renaissance successors hardly represented a savings in metal. Loop-in-loop chains continued to be used for silver and base-metal jewelry, particularly the so-called European peasant jewelry. Gold loop-in-loop chains reappeared with late eighteenth-century Neoclassical goldwork and then became popular with the archaeological jewelry styles of the nineteenth century.

The multiple loop-in-loop chain, which has a tightly linked cylindrical form with an almost plaited appearance (often erroneously termed *plaited*), might have inspired the wire-mesh tubes made from a continuous length of wire, like the so-called French or spool knitting with wool produced by generations of children. This type of braided chain, sometimes called Trichinopoly, first appears in Europe in about the eighth century. It is seen on the Tara brooch and a long length forms the principal part of the Trewhiddle scourge. The curious herringbone-braided wire decorations on the Derrynaflan paten and the Ardagh chalice are closely related, if not of identical construction. It has been suggested that Theophilus describes the manufacture of Trichinopoly work in his book 3, chapter 62, when he writes: "First draw

thin or thicker wires of copper or silver and intertwine them, using an awl, in three braids, or in four, five or six, depending on the thickness you want." This braided wire was then drawn through a series of circular holes of diminishing size in a wood block to produce an even, round length. Trichinopoly, made possible by wiredrawing, does not appear to have been produced much after the tenth century in Europe. But similar work in drawn-gold wire can be seen in jewelry from medieval Southeast Asia, and the technique has been used there ever since.

Solder

Several medieval solder recipes have survived ranging from those in the "Mappae Clavicula," and by Eraclius and Theophilus in the West to al-Hamdani and Kashani in the Islamic world. Typically, the solders were binary or ternary alloys of gold, silver, and copper. The choice of proportions depended on the color and melting temperature of the alloy being worked and the inherent or perceived benefits of particular alloy combinations. Solders would generally have been made up as required, usually by alloying a little silver and/or copper to the gold being worked—a procedure recommended in jewelry text books up to recent times. Kashani, writing in the fourteenth century, gives a solder alloy specifically for red gold of the popular Islamic and European type. This solder was composed of two-thirds gold alloyed with one-sixth part each of silver and copper. This would assume that Islamic red gold contained less than 17% copper—which would suit the coinage alloys with up to 15% copper mentioned earlier. Silver solders were typically silver-copper alloys; Biringuccio recommends 75% silver, 25% copper, while a seventeenth-century English silversmith says that silver solder was 67% silver and 33% copper (Jackson 1905).

Solders could be produced as alloys or as copper-salt mixtures. The former could be used as fillings or as cut platelets, the latter called paillons today. A medieval Greek recipe for "royal solder," which is 75% gold and 25% silver, explains that filings would be used for thin gold, paillons for thicker gold (Berthelot 1888:doc. no. 9.) The subsequent recipe says the same about silver solder. Biringuccio also writes of solder cut into small pieces.

Copper-salt solders are assumed to have been used for at least some of the fine granulation work in antiquity and must relate to Pliny's discussion of *chrysocolla* (literally "gold solder" and certainly some type of copper mineral or compound) for soldering gold. The "Mappae Clavicula" and Theophilus describe solders based on a copper salt, probably copper oxide. In one case this was mixed with olive-oil soap, in another, alum. Cellini used a verdigris mixture, which he noted was really not soldering at all because the parts really just fuse together without any solder alloy (Ashbee 1967). A similar technique of soldering without solder is described by Biringuccio. We can note that the granulation and filigree work on medieval goldwork tends to be more flooded than its earlier counterparts.

The "Mappae Clavicula" also contains recipes for gold-mercury solders. The use of mercury amalgam solders for early goldwork is certainly a possibility, but examples have not been detected on extant goldwork. Taruashvili of the Georgian National Museum of Fine Arts suggests that the gold cell walls of the finest cloisonné

FIGURE 20. *Detail of the interior of the brooch in Figure 16, showing two types of join in the sheet metal (indicated by arrows).*

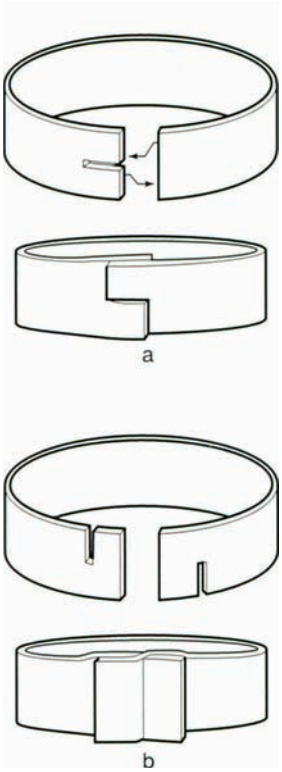

FIGURE 21a, b. *Diagram of the joins in Figure 20.*

FIGURE 22. *Detail of the side of a stone setting on the gold cover in Figure 18, showing sheet metal join.*

enamel work was produced with an amalgam solder. Taruashvili produced successful replicas in this way, but seemingly no analysis work on the ancient enamels was undertaken (Amiranashvili n.d.:18). However, a silver-mercury solder has been identified on a silver spoon from the late Roman Mildenhall Treasure (Lang and Hughes 1984) and examples in gold might well be forthcoming.

By the early Renaissance, borax as a flux for solder was in general use. Borax was noted by the Islamic writer Ibn Hawqal in the late tenth century, and Theophilus in the twelfth century described its use as a flux for niello. According to Biringuccio, the components of filigree work were attached to the substrate with quince-seed paste or gum arabic and then soldered with borax and a gold or silver alloy solder in a little furnace. Bran or dry elder twigs provided the heat. In earlier times chaff or straw were usual sources of heat for goldsmiths.

A variety of medieval work, ranging from some sections of the Konrad crown to the little lunate earring shown in Figure 3, made use of small clippings of wire to fill gaps between components during soldering. The small section of beaded wire so used on the Konrad crown has been fairly well placed to minimize disfigurement. This is not so true of the earrings.

One type of soldered join seen on some medieval goldwork is worth noting. The sheet gold setting borders on the Ottonian cameo brooch in Figure 16 are formed from strips of sheet gold that are slit and overlapped in a manner more frequently seen in sheet-copper and brass work. The cameo brooch shows two type of join (Fig. 20). One is a simple opposed-slit type, the other a more complex interslotting. Both of these assemblies are shown in Figure 21a, b. It is hard to see how the additional strength of such a join would be needed in goldwork, but the technique is not unique; the simple opposed-slit join is also seen on the settings of the Cambridge gold cover (Fig. 22), also supposedly of German origin, and many other examples presumably await discovery. The technique was not universal; it is not seen on the Townley brooch for example, which has the more usual overlap join.

Granulation

Granulation work is just one subsection of soldering. The persistent belief that granulation died out during the Dark Ages in Europe and was only rediscovered by the diligence of nineteenth- and twentieth-century goldsmiths is a product of European

chauvinism. Granulation is found to fine effect well into the medieval period, and some ninth- and tenth-century work is of remarkable quality. In England the Alfred jewel is a fine example, and there are some superb Viking and Eastern European examples from the ninth and tenth centuries. Some eleventh-century Fatamid Islamic granulation work, including the lines of granules soldered on double-wire frameworks, is of exceptional quality.

Later in the medieval period, granulation work became less prominent, perhaps largely displaced by drawn wire filigree; but it was not forgotten, and it often forms highlights on filigree work. We see such granulation on Theophilus's book cover in Trier. Theophilus does not explain the technique of granulation, but he does describe small tweezers for manipulating the individual grains (Dodwell [1961]1986: book 3, ch. 7). A mid-thirteenth-century description of the treasures in St. Paul's Cathedral, London, describes goldwork as "cum margatiti et grani auri," which might be a reference to granulation; small gold beads seem less likely (Lehmann-Brockhaus 1960:no. 2748). The Dowgate Hill, Townley, and cameo brooches (Figs. 8–9, 10–13, 16–17) all have granulation work. In Renaissance goldwork, granulation is relegated to the odd grain and is seldom part of the main decorative scheme.

Casting

As in antiquity, casting was very seldom employed by goldsmiths apart from the initial production of the ingot or blank. Solid and often quite massive gold ornaments that manufacturers would find natural to cast today were generally fabricated from wrought gold. Casting was potentially wasteful of metal and provided little advantage in days when workmanship was relatively inexpensive. Neckham (1867) does tell us that the goldsmith should be skilled "in the work of casting," but no medieval gold jewelry is unequivocally known to have been made by casting. Possibly some of the solid rings were cast, but many undoubtedly were not.

Theophilus describes the manufacture of ingots and blanks by casting—the usual starting point for vessels or other objects—but the only mention of cast gold is for decorative handles and mounts such, as "a cast lion's head very elegantly carved" that could grace the end of the handle of a "gold or silver strainer" (Hawthorne and Smith 1979:ch. 57). Cellini talks about casting silver seals and decorative mounts for silver vessels and also mentions lost-wax casting for gold and silver, but he does not give examples of the type of objects cast (Ashbee 1967).

Cellini also describes the use of cast lead ornaments that would then be worked on by the master and then used as models for the casting of precious metal (Ashbee 1967). Base-metal ornaments were often cast and numerous molds have survived, including those for the ubiquitous lead Pilgrim badges.

Engraving

The medieval use of true engraving, in which a sliver of metal is gouged from the metal surface, contrasts with the methods of earlier periods. The depth and sharpness of engraving on medieval signet rings is noteworthy; the precision possible can

FIGURE 23. *Medieval gold ring brooch with engraved inscription. (The other side says "I am here in place of a friend.")*

be seen in the fine Middleham pendant in Figure 1. The use of engraving in antiquity was probably more common than generally assumed (examples include Mycenaean, Phoenician, and Hellenistic gold rings), but it was not widespread.

Theophilus describes the manufacture of engraving tools with sharp, oblique cutting edges that are nearly indistinguishable from their modern counterparts. An English statute of 1300 underlines the potentially wasteful nature of engraving in its ruling that "gravers, cutters of stone and of seals shall give each [i.e., return to the patron] their weight of gold and silver as near they can" (Jackson 1905:7).

Engraving could be used for functions other than just decorative designs or inscriptions. For example, on the Cambridge gold cover of around 1300, the goldsmith scored a fine line to mark the position of the settings and then used an engraving tool to push up small curls of gold to act as guides to hold the settings in place during soldering.

The texts engraved on medieval jewelry are not always readily readable. In some cases this is due to current lack of understanding of ancient conventions or convolutions. For example, the side of the ring brooch in Figure 23 is not immediately readable and at one stage was assumed to be of magical significance. In fact, the letters are probably the alternating letters of the names Robert and Marger [?]. In some cases, the literacy of the engravers must legitimately be doubted. From 1487 we hear of problems when an apprentice engraver noted for his expertise in engraving "all manner of letter" was found to be unable to read or write (Prideaux 1896–97:28).

Another form of engraving, the *pointillé* (dot) engraving that became common toward the end of this period, had a long history and can be traced back to dotted inscriptions on Classical vessels.

Enamel and Niello

In medieval work, three main types of enamel may be distinguished. These are champlevé, in which the enamel is applied in hollows in the metal; cloisonné, in which the enamel is held in cells bounded by thin walls of metal strip; and enamel *en ronde boss,* in which there is an overall coating of a three-dimensional figure, usually with white enamel. Cloisonné enamel, employing thin, soldered strips of metal, was best suited to gold, while champlevé enamel, using engraved depressions, required thicker metal and was thus most common with copper alloys. These manufacturing differences can often obscure the stylistic similarities of the final work. The Dowgate Hill and Townley brooches (Figs. 8–9, 10–13) both have fine cloisonné enamel centers.

Medieval European texts often describe enameled precious-metal objects in the most glowing terms, describing it as of the finest work and of robust beauty (Lehmann-Brockhaus 1938:2838, 2842). References are made to Anglo-Saxon enameled regalia and to enameled objects from Constantinople (Lehmann-Brockhaus 1938:2972, 2857). We can assume that most of this enamel was of the cloisonné type which can be seen on Dark Age goldwork and which was fairly widespread through medieval times from Britain to the Byzantine and Islamic worlds. Early medieval English examples include the late ninth-century Alfred jewel. Fine cloi-

sonné enamel in late ninth- to early tenth-century contexts in Eastern Europe includes recently excavated gold lunate earrings with circular cloisonné enamel motifs (Vazarova 1980:pl. 7).

Westermann-Angerhausen (1983–84) argues for a native Anglo-Saxon origin and an early eleventh century date for the Dowgate Hill brooch. The even more recent study and publication of a group of English cloisonné enamel copper alloy brooches of late tenth to early eleventh-centuries leads Buckton to state (1986:16):

> This would establish the existence of a previously unsuspected centre of *cloisonné* enamelling in England at a time when *cloisonné* enamel in Europe, particularly in the German and Lotharingian centres of the Rhineland, Regensburg and Trier, was at its peak.

Champlevé enamel was an old European tradition dating back into the Iron Age. In medieval times champlevé work on copper alloys was associated with the town of Limoges, and documentary references to *opere Levovitico, labore Limogiae, opere Lemovicensi,* and so on, occur from the mid-twelfth century onward (Gay [1887]1928:s.vv. *email* and *Limoges*). Champlevé enamel was used on medieval goldwork and possibly can be seen as largely taking over niello on goldwork. Examples of champlevé work on gold include the Middleham jewel (Fig. 1), although only traces of the blue enamel filling the engraved lines now remain. Champlevé enamel is also found in silver and copper-alloy rings of medieval Islamic origin (Ogden 1987). A regulation of Edward II dated 1370 notes that "cutters of seals and enamelers shall return to each his weight of gold and silver as near as they can save it" (Prideaux 1896–97:doc. no 440). This certainly implies champlevé enamel, where the precious metal would need to be cut out with engraving tools.

The mention of enameled silver is interesting since it is almost entirely absent in ancient work. We can assume that this was due to problems relating to adhesion and relative coefficients of expansion. Something of the sort is suggested by Biringuccio who states, "each kind of gold, silver or copper requires enamel harmonious to its nature else it does not respond." In Paris in the early fourteenth century, enamelers agreed to enamel only on silver and gold of high standard and not to use lead glass, which was suitable only for silver of fraudulent alloy (Lightbown 1978:83). The continued use of niello on silver, compared to black champlevé enamels on gold, must relate to the difficulties in enameling silver.

The final coating of a three-dimensional gold object with a layer of enamel (enamel *en ronde boss*) was known in Hellenistic Italy but became popular in the second half of the fourteenth century. This type of enamel is particularly ubiquitous in Renaissance jewelry, where the general delicate and piecemeal construction of the underlying goldwork can usually be contrasted with the cast and often coarse work of much of its nineteenth-century imitators.

Filigree enamel, in which filigree wires form the boundaries of the enamel, was typical of Hellenistic work, but is very rare in medieval jewelry and only reappears in the Renaissance when it was supposedly introduced into Italy from the Balkans by the Venetians (Hackenbroch 1979). A text of about 1400 seems to refer to a type of

mastic inlay used to imitate enamel (Gay [1887]1928:s.v. mastic); this might relate to the use of bitumen as an imitation of niello in some medieval Islamic jewelry.

Niello is a black sulphide of silver or a mixed sulphide including silver and lead. This material was fused into designs engraved on a gold or silver surface and polished. In some case a form of niello was used to paint designs straight onto a metal surface. This attractive technique is described in the "Mappae Clavicula" and can be seen quite frequently on medieval Islamic gold jewelry. Niello appears in late Roman gold jewelry and continued to be popular through the Dark Ages and into the medieval period. A fine mid-ninth-century English example is a ring with the name of King Ethelwulf (British Museum, MLA 29.11-14.1).This miter-shaped ring is made from heavy hammered gold sheet with an overlap join at the back. The design is deeply engraved to hold the niello.

The addition of lead to the niello makes it far more fluid and improves the bond with the surrounding metal. As far as analyses show, the use of leaded niello in Europe was a development of the medieval period and perhaps does not predate the tenth century (Oddy et al. 1983). Both the "Mappae Clavicula" and Eraclius provide niello recipes that include lead (Smith and Hawthorne 1974:chs. 56, 58, 195, 196; Merrifield 1849:ch. 48).

Both silver and gold with niello decoration are mentioned in late thirteenth- and fourteenth-century documents; one account of 1396 tells how a French goldsmith had to reniello a goblet when he repaired it (Lightbown 1978:75). Cellini notes in the introduction to his book that the art of niello had fallen into disuse by the early sixteenth century, although the process was still discussed by a few old men (Ashbee 1967).

The Dawn of the Renaissance

In many ways the goldsmiths of the early Renaissance continued the same traditions of their forebears, which in turn harked back to the Hellenistic and earlier times. Goldwork was usually assembled from sheet gold and decorated with filigree. However, there were considerable stylistic changes and changing fashions in decorative processes.

The Renaissance signaled the rebirth of an affection for the ancient Classical world; Renaissance jewelers looked back on classical goldwork with awe and admiration. The highest praise, quoted by the ever-vain Cellini, was Michelangelo's statement that one of Cellini's jewels was "so beautiful that I do not think any goldsmith of the ancient world ever fashioned anything to match it" (Ashbee 1967). In view of this, one must ask why those perennials of Hellenistic and Etruscan work—loop-in-loop chain, beaded wire, and granulation—were almost totally banished from the Renaissance jeweler's repertoire.

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References

AMIRANASHVILI, S.

n.d. *Medieval Georgian Enamels of Russia*. New York: Abrams.

ASHBEE, C. R.

1967 *The Treatises of Benvenuto Cellini on Goldsmithing and Sculpture*. New York: Dover.

BENDA, K.

1967 *Ornament and Jewellery*. Prague: Artia.

BERTHELOT, M.

1888 *Collection des anciens alchimistes grecs*. Paris: G. Steinheil.

BOILEAU, E.

1837 *Réglemens sur les Arts et Métiers de Paris rédigés au xiii siècle*. G. B. Depping, ed. Paris: Impr. de Crapelet.

BUCKTON, DAVID

1986 Late 10th- and 11th-century cloisonné enamel brooches. *Medieval Archaeology* 30:8–18.

COMBE, T.

1806 Copy of a Indenture, made in 1469, between King Edward IV and William Lord Hastings, Master of the Mint. *Archaeologia* 15:164–78.

CRIPPS, W. J.

1880 *Old French Plate*. London: J. Murray.

1914 *Old English Plate*. 10th ed. London: J. Murray.

DE CUYPER, F., G. DEMORTIER, C. J. DUMOULIN, AND J. PYKE

1987 *La croix byzantine dy Trésor de la Cathédrale de Tournai* (*Aurifex* 7). Louvain: Université Catholique de Louvain.

DIDEROT, D. AND J. D'ALEMBERT

1751–57 *Encyclopédie ou dictionaire Raisonne des sciences, des arts et des metiers. Recueil de planches sur les sciences, les arts libéraux et les arts méchaniques, avec lur Explication: Orfèvrerie joaillerie*. Paris: Chez Briasson.

DODWELL, C. R.

[1961] 1986 *Theophilus: De Diversis Artibus*. Reprint. Oxford: Oxford University Press.

DUCZKO, W.

1985 *Birka V: The Filigree and Granulation Work of the Viking Period*. Stockholm: Kungl. Vitterhets Historie och Antikvitets Akademien.

DUNLOP, D. M.

1957 Sources of Gold and Silver in Islam according to al-Hamdani. *Studia Islamica* 8: 29–49.

FREEMANTLE, C. W.

1870 *First Annual Report of the Deputy Master of the Mint*. London: Royal Mint.

GAY, V.

[1887] 1928 *Glossaire archéologique du moyen âge et de la Renaisance*. 2 vols. Reprint. Paris: Libraire de la Société Bibliographique.

GORDUS, A. A., AND D. M. METCALF

1980 Neutron activation analysis of the gold coinages of the Crusader states. In *Metallurgy in Numismatics* 1:119–150. D. M. Metcalf and W. A. Oddy, eds. London: Royal Munismatic Society.

HACKENBROCH, Y.

1979 *Renaissance Jewellery*. London: Sotheby, Parke Bernet.

HAWKES, S. C., J. M. MERRICK, AND D. M. METCALF

1966 X-ray fluorescence analysis of some Dark Age jewellery. *Archaeometry* 9:98–138.

HAWTHORNE, J. G., AND C. STANLEY SMITH

1979 *Theophilus: On Divers Arts*. New York: Dover.

HENDY. M. F.

1985 *Studies in Byzantine Monetary Economy c. 300 –1450*. Cambridge: Cambridge University Press.

JACKSON, C. H.

1905 *English Goldsmiths and their Marks*. London: Macmillan.

KUHN, S. M., AND J. REIDY

1963 *Middle English Dictionary*. Ann Arbor: University of Michigan Press.

KUNZ, G. F.

[1917] 1973 *Rings for the Finger*. Reprint. New York: Dover.

LANG, J., AND M. J. HUGHES

1984 Soldering Roman silver plate. *Oxford Journal of Archaeology* 3(3):77–107.

LEHMANN-BROCKHAUS, O.

1938 *Schriftquellen zur kunstgeschichte des 11 und 12 Jahrhunderts für Deutschland, Lothringen und Italien*. Berlin: Deutscher Verein fuer Kunstwissenschaft.

1960 *Lateinische Schriftquellen zur kunst in England, Wales und Schottland vom jahre 901 bis zum Jahre 1307*. Munich: Veröff. d. Zentralinst. f. Kunstgesch.

LIGHTBOWN, R. W.

1978 *Secular Goldsmith's Work in Medieval France*. London: The Society of Antiquaries.

LUCAS, A., AND HARRIS, J. R.

1962 *Ancient Egyptian Materials and Industries*, 4th ed. London: Arnold.

MARYON, H.
1971 *Metalwork and Enamelling,* 5th ed. New York: Dover.

MERRIFIELD, M. P.
1849 *Original Treatises Dating From the XIIth to XVIIth Centuries on the Arts of Painting,* vol 1. London: J. Murray.

NECKHAM, A.
1867 *De Nominibus Utensilium*. A. Scheler, ed. In *Lexicographie latine du XIIe et du XIIIe siecle*. 114–116. Leipzig. (Translated in Lightbown 1978:4–5.)

NICOLINI, G., AND B. BOUCHET
1990 Les feuilles d'or de placage des casques celtiques d'Amfreville et d'Agris. *Gallia* 47:67–77.

ODDY, W. A.
1977 The production of gold wire in Antiquity. *Gold Bulletin* 10(3):79–87.

ODDY, W. A., M. BIMSON, AND S. LA NIECE
1983 The composition of niello decoration on gold, silver and bronze in the antique and medieval periods. *Studies in Conservation* 28(1)29–35.

ODDY, W. A., AND S. LA NIECE
1986 Byzantine gold coins and jewellery. *Gold Bulletin* 19(1):19–27.

OGDEN, J. M.
1982 Jewellery of the ancient world. London: Trefoil.
1987 Islamic goldsmithing techniques in the early medieval period. In *Islamic Rings and Gems,* 408–27. D. J. Content, ed. London: Philip Wilson.
1991 Classical gold wire: some aspects of its manufacture and use. *Jewellery Studies* 5:95–105.
n.d. *Gold Jewellery in Ptolemaic, Roman and Byzantine Egypt.* Leuven: Peeters. In press.

OGDEN, J., AND S. SCHMIDT.
1990 Late antique jewellery: pierced work and hollow beaded wire. *Jewellery Studies* 4:5–12.

PEGOLOTTI, F. BALDUCCI
1936 *La Pretica della Merctura*. A. Evans, ed. Cambridge, Mass.: The Mediaeval Academy of America.

PRIDEAUX, W. S.
1896–97 *Memorials of the Goldsmith's Company: Being gleaned from their records between the years 1335 and 1815*. London: Privately printed.

RONIG, F. J.
1984 *Schatzkunst Trier*. Trier: Spee.

ROYAL MINT
1874 *Fourth Annual Report of the Royal Mint*. London: Royal Mint.
1884 *Fifteenth Annual Report of the Royal Mint*. London: Royal Mint.

RUDING, R.
1812 Some accounts of the trial of the Pix. *Archaeologia* 16:164–170.

SINGER, C. J., E. J. HOLMYARD, AND A. R. HALL
1957 *A History of Technology,* vol. 3. Oxford: Oxford University Press.

SMITH, C. STANLEY, AND M. T. GNUDI
1943 *The Pirotechnia of Vannoccio Biringuccio*. New York: The American Institute of Mining and Metallurgical Engineers.

SMITH, C. STANLEY, AND J. G. HAWTHORNE
1974 *Mappae Clavicula: A Little Key to the World of Medieval Technology*. Translated by the American Philosophical Society. n.s. 64(4).

STENBERGER, M.
1947 *Die Schatzfunde Gotlands der Wikingerzeit: II Fundbeschreibung und Tafeln*. Lund: Kungl. Vitterhets Historie och Antikvitets Akademien.

STEVENSON, R. B. K
1974 The Hunterston Brooch and its Significance. *Medieval Archaeology* 18:16–42.

STUBBES, P.
1583 Tricks of goldsmiths and Vintners. In *Anatomy of the Abuses in England in Shakspere's Youth,* part 2.1, series 6, no. 16. New Shakespeare Society, London: Trübner.

UCCELLI, A.
1948 *Storia della Tecnia dal Medio evo ai nostri giorni*. Milan: U. Hoepli.

VAZAROVA, Z
1980 Parures d'or du tombeau 27 à Pliska. *Archeologiya* 1:52–56.

WESTERMANN-ANGERHAUSEN, H.
1973 *Die Goldschmiedearbeiten der Trierer Egbertwerkstatt*. Trier: Spee.
1983–84 Ottonischer Fibelschmuck, neue Funde und Überlegungen. *Jewellery Studies* 1:20–36.

WHALLEY, J. I.
1982 *Pliny the Elder: Historia Naturalis*. London: Sidgwick and Jackson.

WHITFIELD, N.
1990 Round wire in the early Middle Ages. *Jewellery Studies* 4:13–28.

YOUNGS, S.
1989 *The Work of Angels: Masterpieces of Celtic Metalwork, 6th–9th centuries* A.D. London: British Museum Press.

Biography

Jack Ogden is a specialist in the materials and technology of early goldwork and has written and lectured widely on the subject. He is currently director of the Cambridge Centre for Precious Metal Research and editor of *Jewellery Studies,* the journal of the Society of Jewellery Historians of which he was a founder in 1977.