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Mineralogy of the Louvres Merovingian garnet cloisonné jewelry: Origins of the gems of the first kings of France

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ABSTRACT

Proton-particle induced X-ray emission (p-PIXE) analyses have been performed on cloisonné jewelry from a necropolis excavated in 1987 at Louvres (North Paris) that dates from the Early Middle Ages (fifth through sixth centuries). Stylistic analysis of the jewelry indicates that they may have belonged to members of the close entourage of Childéric I or Clovis I, the Frankish kings that founded the French monarchy. The analyses suggest that all red cloisonnés of the treasure are garnets of three types: rhodolite (type I), pyrope (type II), and Cr-rich pyrope (type III). These garnets have moderate-to-high Mg contents (40 to 70 mol% pyrope). Surprisingly, no common almandine garnets were found. Type III garnets are likely to have originated in the Podsedice area (Bohemia, Czech Republic). Types I and II garnets probably originated from granulitic-type terrains, which are relatively rare in the ancient world. India-Sri-Lanka, Central Europe, and Scandinavia are the most likely origins for these garnets but it is not possible here to constrain these origins more accurately. These results emphasize the variety of possible sources for raw material used in Merovingian cloisonnés. The most aristocratic sepultures contain the geologically rarest garnets (i.e., the garnets richest in pyrope end-member). This correlation may suggest a relatively modern knowledge by the Franks in their evaluation of gem garnets (i.e., the geologically rarest gems are the most precious). This concept is more consistent with the Arab gemological writings of the fifth through ninth centuries than with those of the Roman lapidaries of the first through seventh centuries.

INTRODUCTION

Jewelry of the Early Middle Ages (approximately fourth through ninth centuries) is characterized by the emergence of a unique fashion that spread to all Europe: the cloisonné art. Stylistically, this jewelry consists of thin sections of red and translucent materials (usually judged by eye to be garnet) that are fixed to the base of the jewel using a putty or gypsum-based cement (Arrhenius 1985). Every cell is separated from the others by a metallic wall (a cloison, the wall of a cell), which gave its name to this style. Precious metals (usually gold, silver, and bronze) form the structure of the jewel (Fig. 1). Rarely, some cloisonnés are found inlaid with green glass (another luxury item at that time), ivory, chalcedony, or polished rocks such as marble. To enhance the brightness of the garnet cloisonné, a thin metallic and patterned foil (called paillon) is inserted between the cement and the garnet. This jewelry has been discovered in many sepultures together with weapons (axes and scramasaxes, a kind of large sword of that time), glass-based items (e.g., bowls and bottles), and many other artifacts as well as human remains.

Cloisonnés have been discovered in nearly all of Europe and were produced by so-called Barbarians, i.e., various tribes coming from Scandinavia or Asia that invaded central and western Europe. They precipitated the decline of the Roman Empire. Among others, these included the Huns, Awaren, and Goths in Germany; Franks and Burgonds in France; Ostrogoths in Italy, Wisigoths in Spain, as well as the Vandals who finally established themselves in Tunisia. Inlays were never more appreciated than during the Early Middle Ages. Indeed, the cloisonné style characterizes sepultures of major figures of that period, including kings and queens, and more particularly the first monarchs of France: Childéric I (deceased in 481 or 482: Kazanski and Perin 1988) or Aregonde (buried between 565 and 570: Fleury and France-Lanord 1992), one of the wives of King Clothaire I.

Identification of the geological (and geographic) origins of raw gem materials helps historians to better un-

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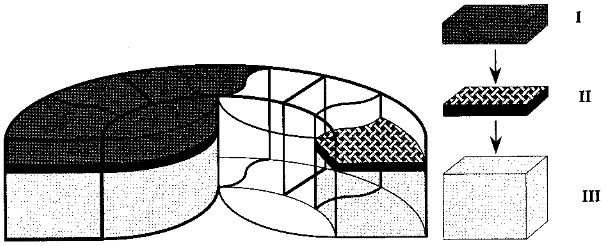

FIGURE 1. Structure of a typical piece of jewelry of the Early Middle Ages showing the technique of the cloisonné. I: thin sections of translucent materials (garnet, glass, ivory, marble). II: Paillon (a thin metallic and patterned foil). III: Putty or gypsum-based cement. Walls are metallic (gold, silver, or bronze).

TABLE 1. Richest Merovingian sepultures found in 1987 at Louvres

Sepulture	Sample	Description	Largest dimension (cm)	Number of garnet cloisonnés
SP123	LM 1	Disk brooches (gold)	2.6	16 (1 missing)
	LM 2			16 (1 missing)
	LM 3	Bracelet (silver)	7	14 (2 missing)
	LM 4	Bracelet (silver)	7	14 (2 missing)
	LM 5	Ring (gold)	2.2	4
SP 124	LM 14	Belt pendants	4.5	1 (1 missing)
	LM 15	(gold-plated silver)		1 (1 missing)
	LM 21	Digited brooches	11	10
	LM 22	(gold-plated silver)		10
SP 125	LM 40	Eagle brooches (gold)	3.0	7 (2 missing)
	LM 41			7 (2 missing)
	LM 57	Pendant (gold-plated silver)	10	1
SP 126	LM 50	Eagle brooches (gold)	2.5	8 (1 missing)
	LM 51			8 (1 missing)
SP 159	LM 71	Buckle (gold-plated silver)	3.5	1

derstand the gem production and commercial exchange during a period that was poorly documented (Perin and Vallet 1992). An important question is whether these Barbarians had large or confidential connections with their potential enemies from the South (mostly Romans and Northern Africans). Information on the geological origins of the garnets can be used to better understand if Merovingians were more Europe-oriented (Arrhenius 1985) in their trading or more open to Africa and Asia (Roth 1981). This question is highly debated among historians and archaeologists because it has dramatic consequences on the way that most Occidental societies have been founded by these Merovingians after the decline of the late Roman Empire.

Initial attempts to characterize the red cloisonnés were based on the measurement of physical properties (refractive index, density, and inclusions; Mellis 1963). Recently, X-ray fluorescence data (Binsom et al. 1982) and X-ray diffraction analysis (XRD) to determine the garnet cell parameter (called the diffraction value by Arrhenius 1985) have been used to characterize a large collection of garnet cloisonnés. However, determination of the geological origins of the garnets is difficult on the basis of X-ray diffraction methods only (see Deer et al. 1986). Studies of garnet inclusions or their trace-elements patterns have been unsuccessful (Arrhenius 1985). The lack of information on major, minor, and trace elements hinders efforts to constrain the geological origins of these garnets.

Proton-particle induced X-ray emission (p-PIXE) is one of several techniques that has been recently introduced in studies of art, history, and archaeology. PIXE allows measurement of elemental concentrations for major and trace elements on surfaces that cannot be subjected to extensive sample handling, such as gemstones of great historical value. The present experiments were conducted at the AGLAE (Accélérateur Grand Louvre d'Analyse Elémentaire; Menu et al. 1990) PIXE facility, located beneath the Musée du Louvre in Paris. The main goal of this unique facility, which cannot readily be achieved in conventional laboratories, is to aid in the characterization of valuable objects (for example, jewelry and paintings) with the maximum amount of chemical information possible, a minimum of particle-matter interactions, and yet with stringent safety precautions befitting the value of the objects under study.

ARCHAEOLOGICAL DETAILS

Inlays of the Saint-Rieul necropolis

The cloisonné jewelry was found in 1987 in five sepultures that belong to a large Merovingian necropolis located at Louvres, close to the Paris-Charles de Gaulle International Airport (Huet 1992). The quality and the richness of these five sepultures place these among the best examples of Merovingian garnet jewelry ever discovered in France. The persons buried in these five particular sepultures clearly belonged to the Frankish aristocracy, i.e., the close entourage of the first kings of France, Childéric I (deceased in 481 or 482) or Clovis I (ca. 466–511) (Huet 1992).

Four of the five sepultures, (SP 123, 124, 125, and 126) are particularly rich in gold, silver, bronze, glass, and cloisonné objects. They most likely belonged to four aristocratic women (Huet 1992). Several types of objects were found: brooches with different shapes (disk, hand, and eagle), neck and belt pendants, bracelets, rings, and buckles (Table 1; Fig. 2). The cloisonnés have a bright red-purple color and were identified as red garnets by archaeologists during excavations. Very few inclusions were observed within the stones, so the so-called garnets are all of excellent gemological quality. The sizes of the cloisonnés are sometimes relatively large, up to 15 mm long (their surface may exceed 1 cm^2). The fifth sepulture (SP 159) belonged to a Frankish warrior because of the presence of an iron sword, together with its leather scabbard, covered with seven red cloisonné artifacts (this is the only example of a scabbard known from the Early Middle Ages).

All cloisonnés were analyzed (i.e., 118 of them) except for seven on the scabbard of the warrior sepulture. The extreme fragility of the oxidized sword prohibits any han-

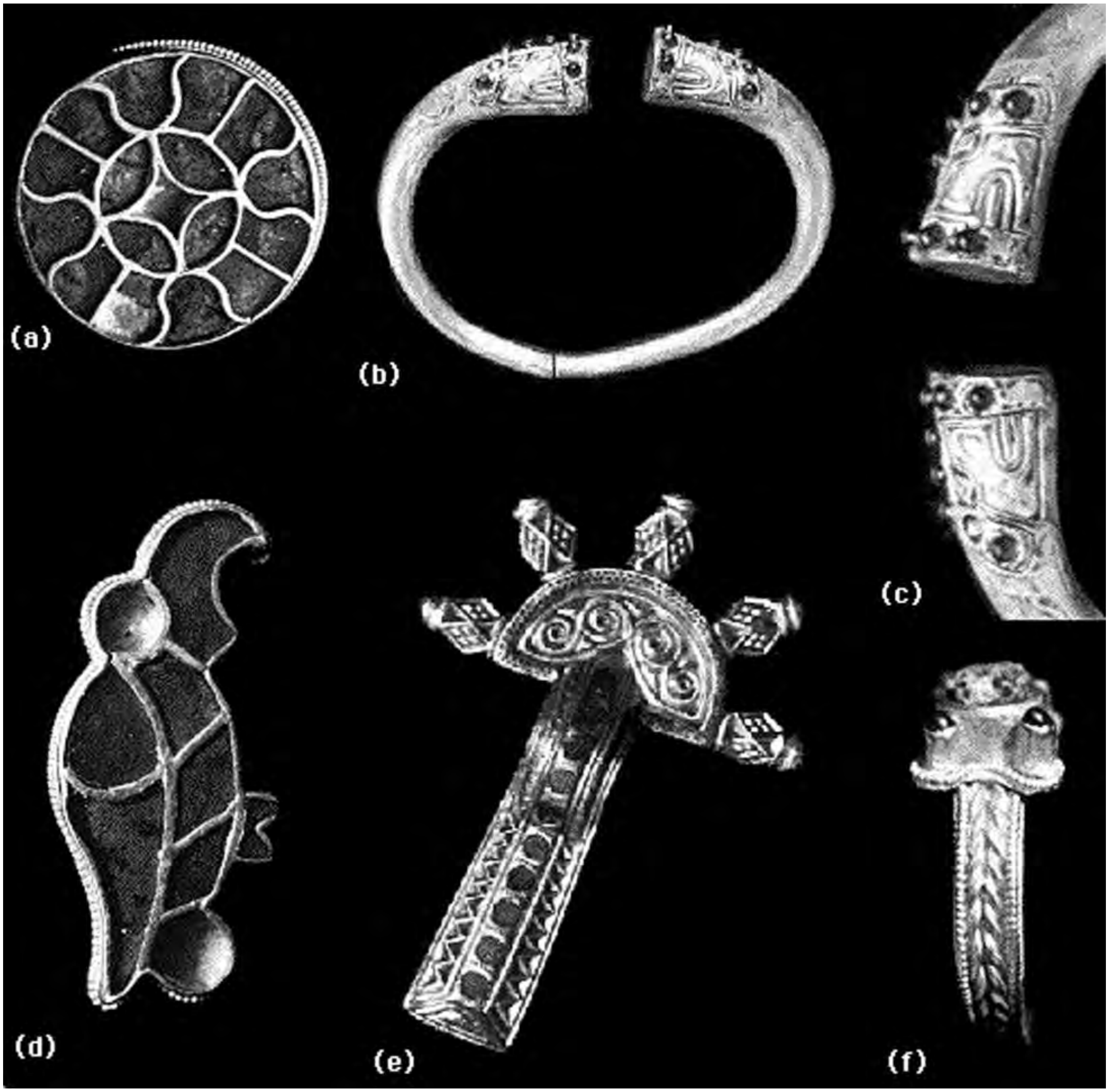

Figure 2. Selected artifacts from the Louvres Frankish necropolis. (**a**) Disk brooch LM 1 (diameter: 2.6 cm; gold and garnets). (**b**) Bracelet LM3 (length: 9 cm; silver and garnets). (**c**) Detail of the two heads of bracelet LM 3 (length: 2 cm; silver and garnets). (**d**) Eagle brooch LM 40 (length: 3 cm; gold, garnets, and Cu-doped green glass inlay on the top-left). (**e**) Brooch LM 21 (length: 11 cm; gold-plated silver and garnets). (**f**) Ring LM5 (diameter: 2.2 cm; gold, garnets, and ivory or bone at the top of the ring). Pictures: P. Brout-Duperron, Mairie de Louvres.

dling or removal from the showcase at the Louvres Museum.

EXPERIMENTAL DETAILS

PIXE

Proton-PIXE was used instead of X-ray fluorescence (XRF) or electron microprobe analysis (EMA) because quantitative PIXE analyses (with a minimum detection level as low as 1 ppm in routine use) can be performed on valuable samples that cannot be altered in any way. For these precious artifacts, it is important to avoid depositing a thin conductive layer on the sample surface (usually carbon, which avoids charging effects that can occur when electron beams are used). Also, PIXE is less sensitive to surface effects than electron-beam based methods. Therefore, no extensive surface sample preparation (see below) such as polishing or cleaning is needed prior to data collection.

The AGLAE PIXE facility is based around a 6SDH-2 2 MV tandem Pelletron from National Electrostatics Corporation (Menu et al. 1990). To measure Mg, Al, and Si concentrations, AGLAE was set to operate at 0.65 MeV accelerating proton energy together with beam currents of 2–10 nA, into primary vacuum. Other experiments were completed at 1 and 3 MeV energy proton to get emission spectra for elements heavier than Ca. A macrobeam section of about 1 mm^2 was used to minimize chemical inhomogeneity effects (e.g., zonation and inclusions). Objects were set on a 3-D sample holder monitored by video that usually ensured a correct position of the beam normal to the garnet surface. A primary vacuum was used to improve data collection in the soft X-ray region of the emission spectra (at 1–2 keV). An Eg and G Ortec 7900 Si(Li) detector was used, characterized by a 30 mm^2 area collimator, a 8 μm thick Be window, a resolution of about 150 eV at 6 keV. At 0.65 MeV proton energy, no filters are needed in front of the Si(Li) detector to protect it from backscattering protons because of their initially low incident energy (8 μm thick aluminum filters were used at 3 MeV protons energy). After pre-amplification, the outcoming signal is collected on a Seiko EGG 7800 multi-channel analyzer and dead-time corrected (less than 5%). The multi-channel analyzer was calibrated in energy using the Mg, Al, Si, Ca, Mn, and Fe$K\alpha$ emission lines. The linearity of the channel-energy conversion was verified at the 99.5% confidence level. The X-ray count rate and the charge induced by the beam current are monitored, respectively, by a Enertec 7143 linear ratemeter (1000 counts/s during 15 min) and a Brookhaven Instrument Corporation 1000A current integrator. Energy-dispersive PIXE raw data were reduced assuming a cubic spline to estimate the background and to normalize the emission peak for matrix absorption. The number of counts for each emission line of interest was calculated by integrating the peak surface. The calculated background spectra were nearly identical for all PIXE spectra (model compounds and cloisonnés, details later), which makes the PIXE normalized spectra comparable together for a given integration time. All experiments were conducted under the same experimental conditions, with periodic checks on garnet standards for the reproducibility in the calculated emission line surfaces (~5% on average).

Internal standards were used to extract elemental concentrations from the emission line surfaces, because this gave more consistent results than ab-initio calculation of the PIXE spectra at the 10% level uncertainties, as follows. According to the classic PIXE formalism, for a given emission line of the element *Z*, the measured number of X-rays that hit the Si(Li) detector holds (Johannson and Campbell 1988):

$$Y_z = \left(\frac{N_{\mathrm{Av}} w_z b_z e_z}{A_z}\right) N C_{z_i} \qquad (1)$$

in which N_{Av} is the Avogadro's number; w_z = the fluorescence yield of the concerned element; b_z = the branching ratio of the emission line considered; e_z = the detector's efficiency; A_z = molar mass of the element Z; N = the number of incoming protons on the target; C_z = the desired concentration of the element *Z*; and i is a complex integral that takes into account the chemical nature of the sample matrix considered. If we use a standard chemically similar to that of the unknown and for which the spectrum is collected in the same manner as for the unknown the integral i is therefore similar for both samples. The concentration of element *Z* for the unknown can be simply described from that of the standard according to a simple ratio law:

$$C^{z}_{\mathrm{unknown}} = \frac{C^{z}_{\mathrm{standard}}}{Y^{z}_{\mathrm{standard}}} \cdot Y^{z}_{\mathrm{unknown}}. \qquad (2)$$

Therefore, special care was taken to choose standards that show a PIXE spectrum similar to these collected on the cloisonnés from Louvres. From a set of 40 red garnets from various localities throughout the world, we identified four samples representative of the Louvres garnets (Table 2). The term rhodolite (Table 2) is not an IMA-approved name but it is often used by gemologists because it conveniently refers to gem garnets that are intermediate in composition between almandine and pyrope. These reference garnets were analyzed (Table 2) using EMA methods (15 kV, 10 mA, and a spot size of Å 2–3 μ^2: CAMPARIS facility, Université de Paris 6) to provide a calibration for the garnets of historical value.

Sample preparation

Because of their fragility and historical value, cloisonnés surfaces cannot be polished or extensively cleaned. Due to their gemological nature, the polish of the stones is usually fair, except for the few cloisonnés that were split or broken. The possibility that surface variations of the emission lines was caused by the presence of both fractures and organic compounds on the garnet surface was tested on a red garnet sample from Arendal, Norway (author's personal collection). Unclean surfaces did not affect emission line surfaces at the 5% level due to the low absorbance of thin layers of C-rich materials at these proton and X-ray energies. In contrast, split surfaces resulted in detectable self-absorption, which prohibited a quantitative analysis of the four broken cloisonnés on digited brooches LM 21 and LM 22.

RESULTS

Representative p-PIXE spectra are shown in Figure 3 and PIXE analyses of the cloisonnés are given in Table 2. All red materials were found to be garnets because major emission lines arising from Mg, Al, Si, Ca, and Fe in relative proportions were identical to those measured for reference garnets (Fig. 3). The calculated formulas for the 118 cloisonné garnets analyzed are presented in the ternary diagram for pyrope-almandine-spessartine (Fig. 4). No red glass was found inlaid in Louvres Merovingian jewelry, because no alkali-rich silicate composition was discovered in any red cloisonné. In contrast, the two

TABLE 2. Average electron microprobe and proton probe analyses for garnet standards and some cloisonnés

	Standards (electron microprobe analyses)				Cloisonnés (PIXE proton analyses)					
	Almandine Petzthal Austria	Rhodolite* Arendal Norway	Pyrope Monastir South Africa	Cr-pyrope Zöblitz Saxony Germany	LM 1 inlay no. 11	LM 40 inlay no. 1a	LM 5 inlay no. 4	LM 57 inlay no. 1	LM 3 inlay no. 4	LM 3 inlay no. 11
SiO_2	38.1	39.1	41.7	42.7	39	40	39	40	42	4
Al_2O_3	21.5	22.1	22.3	21.8	22	22	24	21	22	2
MgO	5.8	8.3	18.8	23.0	13	14	17	19	24	2
FeO	31.9	23.9	12.6	6.5	21	20	15	13	3.6	3
CaO	1.9	5.3	3.7	3.8	1.4	2.5	1.1	1.4	3.1	2
MnO_2	1.0	1.3	0.2	<0.1	1.3	1.3	2.2	1.5	0.8	0
Cr_2O_3	0.1	<0.01	0.3	1.9	0.3	<0.01	0.1	0.07	3.7	3
TiO_2	0.1	<0.01	0.8	<0.01	<0.01	0.11	0.12	0.12	1.8	1
Total	100.4	100.0	100.4	99.8	98.0	99.9	98.5	96.1	101.0	99
Almandine	73	55	29	15	49	46	36	30	8	9
Pyrope	19	28	62	73	43	44	57	63	65	68
Spessartite	5	14	1	0	3	3	4	3	2	2
Knorringite	0	0	1	7	1	0	<1	<1	11	10
Grossular and andradite	2	14	13	5	3	7	3	4	14	11
Type	—	I	II	III	I	I	II	II	III	III

Note: Analyses are in wt%. Components are in mol%.
* Gemological term for pyrope-almandine garnets.

green inlays (one in each of the eagle brooches LM 40 and 41) are rich in Na and Si (with some Fe and Cu), so they are probably made from a green soda-silicate glass.

Three geochemical types of garnets are identified (Table 2, Fig. 4). Type I garnets are found in the majority of the cloisonnés (one inlay in LM 5, all garnets in LM 1, 2, 4, 14, 15, 21, 22, 40, 41, 49, 50, and 71). Their average structural formula is $Alm_{50\pm5}Pyr_{40\pm5}Spe_{5\pm2}Gro_{5\pm1}$, where the numbers for Alm, Pyr, Spe, and Gro represent the molar percentage of almandine, pyrope, spessartine, and grossular end-members present in the garnet analyzed by PIXE (Table 2). Type I garnets are typical rhodolites, i.e., calcic pyrope-almandine garnets (Deer et al. 1986). Type II garnets are richer in the pyrope component ($Alm_{30\pm4}Pyr_{60\pm5}Spe_{5\pm2}Gro_{5\pm1}$). Only a few of these were found (three in ring LM 5 and the large one of the neck-pendant LM 57). Type III garnets are characterized by a high pyrope content ($Alm_{5\pm1}Pyr_{70\pm6}Spe_{<1}Gro_{5\pm1}$) and are relatively rich in Cr (up to 6.5 wt%; Table 2). The presence of Cr in these garnets is expressed using the knorringite end-member (Kno; $Mg_3Cr_2Si_3O_{12}$), which can represent up to 20 mol%. Type III garnets were all found in a single item, the silver bracelet LM 3.

DISCUSSION

The geochemical information derived form the chemical analyses of the Louvres cloisonné artifacts suggests that these garnets are relatively rich in pyrope (from 40 to 70 ± 5 mol%). The absence of the common red almandine garnet (i.e., garnets with almandine content above 75 mol%) is striking. This result differs from the analyses performed by Arrhenius (1985) that showed the presence of a large amount of Fe-rich garnets (mostly almandine) in the cloisonné jewelry that she studied. The relatively high Mg contents of the Louvres garnets provide important constraints on the possible geological sources for the raw material because Mg-rich garnets are more scarce than Fe-rich ones. The well-known occurrences for red-purple gem almandine such as the Zillertaler (Austria), Collobrières (France), Langesundfjord and other related Scandinavian occurrences, Rajastan (North India), or throughout the Himalaya (e.g., Nepal and Afghanistan) are definitively excluded as an origin for Louvres garnets. We now examine in detail the geochemical criteria for the three types of garnets found.

Type I garnets: rhodolites

Type I garnets, like many cloisonné garnets, have probably undergone secondary metamorphism, responsible for a tectonic cleavage that favors the production of thin sections of garnet and therefore suitable for cloisonné cutting, as shown by Mellis (1963). Type I garnets contain roughly the same amounts of almandine and pyrope components (rhodolite). Two principal types of geological origins are possible: granulitic or eclogitic terrains. The first possibility is favored according to the Meyer-Tsäı classification (Deer et al. 1986), which found that eclogitic rhodolites usually have greater Ca contents (as the Petzthal garnet in Fig. 3 left) when compared to their granulitic counterparts. Therefore, due to their relative low Ca contents (<15 mol% of grandite end-members), e.g., type I garnets are more likely of granulitic origin (e.g., charnockites).

Plausible granulitic-type occurrences are the South India-Sri Lanka area, outcrops in the Moldanubicum area (Bavaria, South-Bohemia, Saxony, Austria; Deer et al. 1986) and Scandinavia (Tröger 1953). A survey of the literature suggests that the large granulitic outcrops in Central Europe are less likely to have produced type I garnets because Central European garnets are usually too rich in almandine (average $Alm_{90-70}Pyr_{1\text{-}20}Spe_1$; Deer et al. 1986), compared to type I garnets (these origins are not

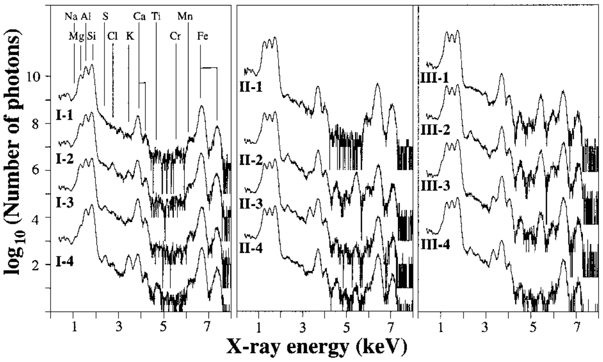

Figure 3. PIXE (0.65 MeV protons) spectra collected for garnets cloisonnés as compared to garnets standards. Left: PIXE spectra for type I garnets. I-1 = cloisonné no. 8 in LM1; I-2 = cloisonné no. 3 in LM 41; I-3 = eclogitic Mg-almandine from Petzthal, Austria; I-4 = almandine from Zillertaler, Austria. Middle: PIXE spectra for type II garnets: II-1 = analysis no. 1 in LM57; II-2 = Cr-pyrope from Merofritz, Bohemia, Czech Republic; II-3 = charnockitic pyrope from Arendal, Norway; II-4 = eclogitic pyrope from Kimberley, R.S.A. Right: PIXE spectra for type III garnets: III-1 = cloisonné no. 12 in LM3; III-2 = Cr-pyrope from Podsedice, Bohemia, Czech Republic; III-3 = Cr-rich pyrope from Zöblitz, Saxony, Germany; III-4 = eclogitic pyrope from Monastir, R.S.A.

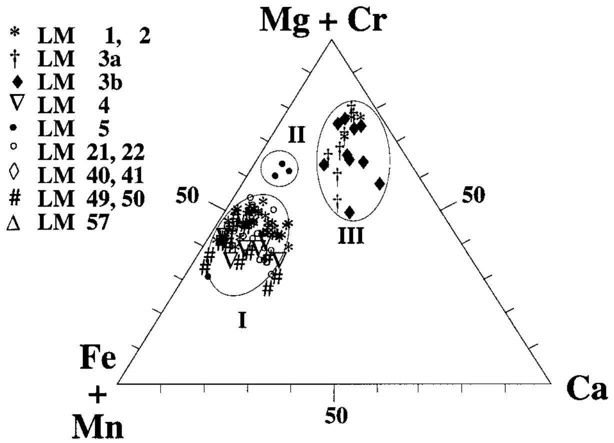

Figure 4. Ternary diagram for garnet cloisonnés compositions measured on Louvres artifacts showing the three types of garnet composition.

excluded but are less plausible). If the large and well-cleaved gem garnets from the Arendal (Norway) have a similar composition compared to type I garnets (Table 2), their bright red color does not fit with the red-purple color of Louvres cloisonnés. In contrast, those of Halland, Sweden, (Arrhenius 1985) and various small occurrences throughout Scandinavia may be possible candidates too. However, the South India-Sri Lanka area is, by far, the most important center of production for type I garnets. These famous outcrops were mined intensively during the Early Middle Ages, and extensive garnet trading has been reported (Mahroof 1989). Finally, many small rhodolite outcrops throughout Europe can be considered if one wants to be exhaustive (including Germany, France, Spain, and the United Kingdom). However, most of them do not produce significant amounts of large red garnets of gem quality that can be split as thin slices of garnets (which is required for most cloisonné jewelry; Mellis 1963).

Type II garnet (pyrope)

Because of their low Cr and Ti contents (Table 2), type II garnets (pyrope) are also likely to originate from deep crustal formations, i.e., granulite-type rocks, like charnockites. The Sobolev criterion (Deer et al. 1986) suggests that granulitic pyropes have usually lower Sc contents (<20 ppm) when compared to eclogitic ones. No Sc$K\alpha$ emission line was detected in the PIXE spectrum collected for type II garnet (detection limit for Sc is 10 ppm for these experiments; Fig. 3 middle). This lack of detection suggests (according to the Sobolev criterion) that type II garnets are more likely from granulitic terrains. Therefore, type I and II garnets, although significantly different in their composition (rhodolite and pyrope, respectively), may have formed in similar types of rocks. As for type I garnets, several occurrences of granulite-type rocks known throughout the ancient world may provide such pyropes, i.e., Scandinavia, Central Europe, and the South India-Sri Lanka gem area. At this point, it is difficult to distinguish between these possibilities.

Type III garnet (Cr-rich pyrope)

The relatively high Ti and Cr contents for these pyropes clearly suggest an ultra-basic origin. Therefore, only a few occurrences in the ancient world could have produced these rare pyropes: Norway, Saxony, and various localities in Bohemia. Non-European origins are unlikely. Several arguments favor a Bohemian origin and more precisely the Podsedice area. First, the PIXE spectra for type III garnets are very similar to these measured for Podsedice garnets (Si, Mg, Ti, Cr, Fe; Fig. 3 right). Second, Cr-rich pyropes from Zöblitz (Saxony) are known to show slightly higher Mg contents when compared to type III garnets (Tröger 1952), which is consistent with our PIXE analyses on pyropes from Saxony and Bohemia. Third, the Podsedice area is the only one that could have produced large quantities of gem pyrope. Fourth, because of their alluvial occurrences, the Bohemian pyropes are easy to extract, in contrast to Saxonian and Norwegian ones. Fifth, these Bohemian outcrops are known to have been used since the time of the Neanderthals, owing to the discovery of garnet necklaces in this area (Reban 1985), although the pyrope mining industry started during the sixteenth century (Schlüter and Weitschat 1991). A final argument is based on the size of Bohemian pyropes. Bohemian garnets are still mined from sedimentary placers, in a relatively small area located about 50 km north of Prague, Czech Republic. These pyropes are derived from serpentinized garnet peridotite and garnet-bearing basalts (Schlüter and Weitschat 1991). The geological origin of the stones (i.e., the high-pressure ultrabasic context) favors the presence of quantities of small stones. Furthermore, the secondary alluvial deposition process makes these gems mostly of the same rounded shape and easy to extract. Interestingly, the 22 garnets on bracelet LM 3 from Louvres have the same morphologic criteria. The average diameter of each LM 3 cabochon is 2 mm, a value close to the average of garnet sizes found today in the gravels at Podsedice (2.5 mm; Schlüter and Weitschat 1991).

Merovingians and Sri-Lanka.

The possible presence of Sri-Lankan garnets in Merovingian jewelry is controversial (Roth 1980; Arrhenius 1985). Roth (1980) reported the import of alabandenum (most likely any type of almandine-pyrope garnet) from Taprobane (i.e., Sri-Lanka) on the basis of writings of a fifth century merchant, Kosmas Indikopleustes. Arrhenius (1985) ruled out the possibility of imports of almandine from Sri-Lanka. She suggested that the red gemstones quoted by Kosmas Indikopleustes were probably grossular instead of almandine, because all six Sri-Lankan stones X-rayed by Arrhenius have cell parameters indicative of grossular. However, it is clear that this last selection of Ceylonese garnets is untypical because several types of gem garnets (rhodolite, almandine, and grossular) are common in Sri-Lanka (see, among others, Gunawardene and Rupasinghe 1986). If rhodolite garnets are, by far, the best and most common red stones extracted today (Zwann 1982), this should also be true in the past. This is because almandine and pyrope end-members are the most abundant components in charnockitic rocks when compared to grossular (Meagher 1982), and they are known to be extracted at least since the fifth century (Mahroof 1989).

Imports of red precious stones from the Orient to the Late Roman Byzantine Empire were so important during the fifth through sixth century that the minerals called carbunculis and alabandenum were taxed at the entrance of the Roman Empire at Alexandria (see Codex Justinensis; Schoff 1912). The names carbunculis and alabandenum refer probably to a class of red stones (according to the Roman's classifications, mostly following Plinius's Historia Naturalis; de Saint-Denis 1972), including garnets, ruby, and spinel. Therefore, despite strong evidence for Bohemian sources for Early Middle Age cloisonné garnets, Sri-Lankan sources also remain highly plausible.

Archaeological implications

Compared to previous studies of Merovingian garnet cloisonné mineralogy (see Arrhenius 1985 and references therein), an usual amount of geologically rare garnets have been found in the Louvres sepultures. The relative proportion of pyrope vs. almandine component in these red garnets is a direct function of their number per sepultures. Sepulture 123 contains the most complex and valuable artifacts, has the highest number of cloisonnés (66), precious materials such as gold, silver, glass, and bronze, and also the garnets richest in pyrope (its average pyrope content is ~60 mol%). In contrast, sepulture 159 contains the fewest garnet cloisonnés (7), almandine-rich garnets (60 mol% on average), and some iron weapons. Sepultures 124, 125, and 126 are intermediate (18 to 24 cloisonnés per sepulture with an average pyrope content of ~50 mol%, together with some glass, bronze, gold, and silver artifacts). The hundreds of other sepultures of the necropolis did not contained any valuable jewelry.

The most technically complex jewelry (i.e., that with the greatest number of cloisonnés) contains the rarest garnets (i.e., those richest in pyrope) and also the greatest amount of previous metals (gold and silver) and artifacts (glass and ivory). Therefore, it is possible that the hierarchical position of the personages buried at Louvres can be qualitatively estimated according to the number and quality of the items found in their respective sepultures. It is therefore proposed here that the pyrope content of the garnets gives some direct insights on the hierarchical position of the personages buried at Louvres.

The lack of almandine (i.e., Alm $>$ 70 mol%) gems at Louvres is intriguing. Almandine garnets can provide nearly the same transparency and color panels as the more scarce rhodolite garnets (Cr-rich pyropes have a very deep red color). Was the Frankish society able to distinguish between geologically common and geologically rare garnets? If so, that prospect (obvious for the modern mineralogist) would be in sharp contrast with the academic Roman lapidaries of this period (Plinius, Isidorus). Indeed, most previous Latin and Greek books are more medicine-oriented, often using color or symbolism (even mysticism) for mineral identification (therefore the value of a gem is not based on its geological rarity but on its artistic or medicinal properties). The more scientific way of evaluating gems (based on composition and not on symbolism) is traditionally reported to have been developed largely by Arab lapidarists, several centuries later (during the eighth through ninth centuries) (cf. books by Hrabanus Maurus; Hunain Ibn Ishak and others; Sobott 1986). Therefore, the possibility of a previously unknown gemological culture at some point in the history of the Frankish society needs to be evaluated by historians.

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