TECHNICAL ANALYSIS OF RENAISSANCE BRONZES FOR PROVENANCE STUDIES:

PILOT PROJECT

BY

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INTRODUCTION

Using traditional art historical methods in the study of Renaissance bronze sculptures, it is difficult to make reliable attributions to specific artist, to date the sculptures or even to establish a region of origin. With little historical documentation available, attributions for most sculptures fall along a continuum from very uncertain to relatively certain. This situation is not unique to Renaissance bronzes. In order to address this problem, museum laboratories have in the recent past developed programs of technical studies of art objects aimed at contributing to provenance determinations. Examples are long-term studies of Chinese bronzes (Bagley 1987) and of Sasanian silver (Harper and Meyers 1981). These and other studies serve as examples demonstrating the usefulness of combining technical examination with stylistic studies.

Renaissance bronzes have as yet not been subjected to such comprehensive examinations although technical studies have been carried out at the Victoria and Albert Museum, the Metropolitan Museum and the National Gallery. For example, the work at the Metropolitan Museum has produced especially interesting results (Stone 1982). It is therefore highly likely that a comprehensive long-term project of technical studies of Renaissance bronze sculptures will provide significant results and will considerably enhance our understanding of the production of Renaissance bronzes by establishing relationships between artists, workshops, regional developments and dates.

This pilot project was initiated to investigate whether or not technical data, when combined with art historical information, can contribute to provenance determinations of Renaissance sculptures and to establish the possible extent of such contributions. It is intended to be the first stage of a long-term technical program. The basic research design follows that of a similar project with Himalayan bronzes, in which technical studies proved to be extremely useful in identifying a probable region of manufacture (Reedy and Meyers 1987).

Well documented sculptures were made available to us for study by courtesy of the Kunsthistoriches Museum, Vienna during an exhibition at the Los Angeles County Museum of

Art entitled "Renaissance Master Bronzes", 1987. A majority of the pieces in this collection were made for the Hapsburg Kunstkammer or known collectors, and have some historical documentation. This group of bronzes was supplemented by pieces from the Getty Museum. To be comprehensive and as accurate as possible in its conclusions, it is essential that this project be expanded to include other Renaissance bronze collections.

The project began with visual examination of sculptures, noting the surface and structural characteristics for determining the fabrication technique. This study of casting and decorating methods was supplemented with X-ray radiography. When possible, samples of clay core materials were removed for a mineralogical analysis by thin section petrography. A stepwise discriminant analysis was used to interpret these datasets in relation to art historical attributions.

Some metal samples have also been taken for future analysis by atomic absorption spectrometry when the equipment becomes available to the Getty Conservation Institute. The alloy composition of some of the sculptures was determined by energy-dispersive X-ray fluorescence analysis. However, the metal compositions have as yet not been included in this pilot study.

In this report we review the current status of the project at the end of its first year: what has been completed thus far, what results have been obtained, and in what direction we believe the project should continue.

Personnel

Ms. Billie Milam, Associate Conservator of Sculpture at the J. Paul Getty Museum, is the project coordinator. Dr. Chandra Reedy, Associate Research Scientist at the Los Angeles County Museum of Art, is in charge of the mineralogical and statistical analyses. Ms. Carol Sussman, assistant for the project, worked with Ms. Milam on the study of casting and decorating methods, coded and entered those data for the statistical work, and is in charge of data management.

Dr. Reedy and Ms. Milam developed a working check sheet (see Appendix 3) of variables to record which combined art historical information with casting and decorating characteristics. Decisions about which characteristics to use were initially based on those features that proved useful in the Himalayan project that served as a model for this study, but were then tailored specifically to the casting and decorating features found on Renaissance bronzes. Refining of the check sheets and description of the categories used on them (see Appendix 2), and subsequently determining how the features of each sculpture should be recorded in accordance with those forms, was done after extensive examination of each piece by Ms. Milam with the aid of Ms. Sussman. Ms. Sussman coded the casting variables into numerical form and entered that data into a computer in a format suitable for statistical analysis. The X-ray radiography was undertaken by Ms. Milam and Dr. Pieter Meyers at LACMA, and by Ms. Milam and Richardson X-ray Company at the Getty Museum with a portable X-ray tube. The casting core samples were taken by Ms. Milam, mounted by Quality Thin Sections, and analyzed through thin section petrography by Dr. Reedy. Dr. Chandra Reedy, in consultation with Dr. Terry Reedy, completed the multivariate statistical analysis of all datasets. Metal samples were taken by Ms. Milam for future analysis by atomic absorption spectrometry by Dr. David Scott of the Getty Conservation Institute. Alloy analysis by X-ray fluorescence was carried out on polished areas of some of the bronzes by Mr. Michael Schilling. Dr. Frank Preusser (GCI) has gathered together published material on metal analyses of Renaissance bronzes, which he has entered into a computer at GCI for inclusion in the project at a later date.

MATERIALS AND METHODS

Sculptures Selected for Analysis

A total of 64 sculptures from the exhibition entitled "Renaissance Master Bronzes" from the Kunsthistoriches Museum in Vienna (Leithe-Jasper 1986) were analyzed. The sculptures were examined and sampled during the installation of the exhibition at the Los Angeles County Museum of Art; during the deinstallation they were examined again and X-ray radiography was carried out. Time constraints precluded the full recording of data from all objects in the exhibition, and we therefore have some missing data for casting and decorating techniques which should be completed.

A total of 39 objects from the J. Paul Getty Museum permanent collection and loan sculptures were also analyzed with owner approval (as well as one piece from the Museum of Fine Arts, Houston that was made available to us by LACMA with approval from MFA). Some of these objects have a relatively plausible provenance, others are more uncertain, with alternate regional and chronological attributions possible. It is expected that their inclusion in this long-term study will eventually provide support for a more accurate attribution. At this time, examination of specific attributions is not possible because we have analyzed too few sculptures at this stage of the project. Additionally, some of the casting and decorating entries are not yet complete for this group.

A list of all sculptures thus far included in the study and their identification numbers used in the data table is given in Appendix 1.

Art Historical Data

Art historical attributions concerning the possible region of production, artist, and date of manufacture were collected through discussions with Dr. Manfred Leithe-Jasper, Dr. Peter Fusco and Prof. Carlo Pedretti. (It is suggested that Dr. Peter Mellor, another art historian, can also be consulted on attributions as the project continues.) Although information is absolutely certain in only a few cases, constructing at least plausible hypotheses concerning attribution was necessary to organize the sculptures for statistical analysis of the data. The attributions chosen remain open to re-examination as the project progresses. In some cases the attribution that can be hypothesized is more exact (e.g., Milan) than in other cases (e.g., Italy). In all cases the most exact attribution possible was given, although for purposes of statistical analysis some categories were later combined. The art historical categories recorded are listed in the key to the dataset (Appendix 6). At this stage of the project these categories are not realistic and had to be combined into more general groups, as we are restricted by the small number of objects.

Casting and Decorating Techniques

The casting and decorating technology employed in sculpture production involves many steps, with alternative choices of methods available at every step. It is possible that patterns of similar techniques may exist that are related to region of production, artists workshops, or date of manufacture. To determine variations in casting and decorating technology, the combination of surface examination and X-ray radiography was used to record a total of 86 different features.

A few of these features are arithmetic variables (e.g., height, width, depth); most are categorical. In some cases only presence or absence of a feature was recorded (e.g., threaded chaplets, pins located in cracks, and casting in separate pieces that were joined in the metal). In other cases several choices were available within a particular category (e.g., thickness of the metal of a hollow casting piece is thin, average or thick).

The 86 features recorded can be very generally categorized as pertaining to (1) the structure of the piece, (2) the treatment of repairs of casting flaws, (3) the construction of the core and degree of hollowness of the piece, (4) decoration and finishing, and (5) the patina.

All of the features recorded are listed and defined in Appendix 2. When the numbers of occurrences of each feature were tallied, we noted that many of these technical features are so infrequent that they occur extremely rarely, or never, in our groups of more plausible attribution, so at this stage cannot contribute to the provenance studies. Thus, as the project progresses, some categories may eventually be combined or eliminated.

The data were recorded with the aid of a form designed specifically for this project (see Appendix 3). Since two people worked to record the features, testing for consistency and repeatability was possible. Although other analysts may have selected a somewhat different set of features to record, a set of definitions for all characteristics included (Appendix 2) was prepared so that other analysts should be able to identify those same features.

Clay Core Mineralogy

Samples of core material were available for 64 sculptures in the study. Analysis of this material was expected to be especially useful for regional and workshop characterizations, since core materials were most likely collected at the site of sculpture manufacture. Our hypothesis was that the mineralogical composition of clays from different geographic regions would very likely show considerably more variation between regions than within a single region. It is also possible that artists from different workshops and/or time periods would select materials of different composition or texture for constructing clay cores.

The loose-grained samples were mounted in Lakeside 70 on a glass slide by Quality Thin Sections of Tucson, Arizona. They ground the samples down to .03 mm thickness with silicon carbide powder, and cover glasses were mounted with Canada Balsam. This thin section preparation permits microscopic measurement of the optical properties of the minerals in the samples, thus allowing them to be identified by reference to standard tables of mineral optics (Kerr 1977; Deer, Howie and Zussman 1980).

Appendix 4 gives the full description of all mineral features recorded. The percentage of quartz present in each thin section was estimated by reference to models for visual estimation of percentage composition of rocks (Williams, Turner and Gilbert 1982:593-597). Other quartz features recorded were the most common size of the grains, degree of sorting, shape of the grains, and eight textural characteristics.

Organic matter appears in both uncarbonized and carbonized forms. The percentage present and the overall size for each were determined. Carbonates, when present, were categorized as rare, abundant, or very abundant, and the most common size was recorded. If rounded edges or rhombic shapes were present, these were noted. The presence of possible dolomite or siderite were also noted. After the final totals of occurrences in each category had been determined, the carbonate categories were collapsed for statistical analysis into only the degree of abundance and the size.

Hematite, if present, was recorded as rare, abundant, or very abundant. The presence of plagioclase feldspar was originally recorded along with its approximate percentage. The percentage of alkali feldspars were also recorded, broken down into microcline or orthoclase categories. For the statistical analysis, however, only presence or absence of the three feldspar types was used.

For micas, presence or absence was recorded for muscovite, biotite and chlorite. If clinopyroxenes or orthopyroxenes were present, the type was determined whenever possible. Amphiboles were divided into either hornblende or other. Lithic fragments were primarily metamorphic or volcanic, but some sedimentary and plutonic lithics were also seen.

In addition, presence or absence was recorded for the following minerals: epidote, clinozoisite, apatite, zircon, rutile, spinel, tourmaline, garnet, glauconite, gypsum, serpentine and olivine. The remainder of the casting core consists of clay minerals of one type or a mixture of types. These cannot be further identified in thin section.

The form used to record petrographic data for this project is shown in Appendix 5. The categories included on the form represent those minerals and mineral textures actually encountered when working with Renaissance bronze core materials.

STATISTICAL PROCEDURES

Descriptive statistics were first obtained for each variable (using the BMDP program 1D, Dixon 1985:74-79). For each arithmetic variable, these are the number of valid values, mean, standard deviation, and extreme values. For categorical variables, the number of sculptures (frequency) in each category was counted. Aside from their own interest, these summaries help check data entry and plan further analyses. The pattern of missing values limits the analyses that can be done. Also, technical features which occur infrequently are unlikely to be discriminating since they may never occur in the plausible groups, or if they do they will be so rare that they will not be useful in characterizing the group as a whole. It is then worthwhile considering whether, for purposes of the statistical analysis, they should be ignored or combined with other variables.

The primary statistical procedure used to interpret the datasets was stepwise discriminant analysis (BMDP 7M, Dixon 1985:519-537). This procedure starts with groups formed by art historical criteria (region, artist, or time period), using only those objects that are relatively more certain (plausible). The major problem addressed so far was whether or not it is possible to discriminate between the groups using technical variables. Later, when more sculptures have been analyzed for each group, we will determine if the sculptures of stylistically more uncertain provenance can be assigned to any of those groups based on the discriminating technical criteria.

The primary objective of a stepwise discriminant analysis is to identify a minimal group of variables that gives maximal discriminating power. These variables are combined to construct a set of classification functions, one for each group. When these functions are applied to a specific object they give a score for its relative similarity to the central tendency of each of the groups. An object is then classified into the group for which it has the highest similarity score. When applied to objects in the "known" (relatively plausible attribution) groups, the percentage of objects correctly classified measures the performance of the classification functions.

In classical applications of discriminant analysis the objects in the known groups are assumed to be correctly classified. In this study, as is frequently the case in art historical research, the attributions were merely plausible, and not definitely known. Therefore, as the project progresses and more sculptures and data become available, we will re-examine how well the initial art historical attributions assigned to the sculptures in the plausible groups compare to the mathematical classifications arrived at through the discriminant analyses with various datasets (casting and decorating, core materials, metals).

Some variables that might be individually significant may not appear discriminating when many variables are included in the analysis. This is because variables that are highly correlated with each other are partially redundant. Extraneous variables that add nothing additional to the discrimination are left out because they detract from the performance of the classification functions when applied to new, uncertain, objects.

A total of 11 discriminant analyses were carried out. The groups used for analysis were formed in consultation with the art historians and curators previously mentioned. However, we were limited in the manner in which we could construct groups for analysis by the fact that the dataset is still very small. For statistically significant results we would prefer to have a minimum of 20 objects in each group. When group sizes are very small, artificially high classification success can result. For that reason, most of the results of this preliminary phase of the project must be considered as indications of the degree of success we can expect when larger numbers of sculptures are analyzed, and not considered to be final results.

The regional groups used for discriminant analysis are as follows:

1. Italy (Italy + North Italy + Padua + Milan + Mantua + South Italy + Florence + Venice) [66 objects] versus all other groups [33 objects];
2. Venice + Germany [13 objects] versus all other Italy [58 objects] versus all others [28 objects];
3. North Italy (North Italy + Padua + Milan + Mantua) [36 objects] versus Venice + Florence [16 objects].

Chronological periods were divided as follows for the analysis:

1. Early (1450 - 1525 A.D.) [24 objects];
2. Middle (1525 - 1600 A.D.) [34 objects];
3. Late (later than 1600 A.D.) [20 objects].

The art historical suggestion was that we use four date ranges, with 1500-1525 A.D. being a separate category. However, we do not yet have enough objects of plausible date in that time range to permit a separate group to be analyzed at this time.

There are currently no artists of plausible attribution for which we have enough samples to analyze separately as a group (the attribution of a specific artist is uncertain for most of the sculptures). We therefore grouped the sculptures that can be plausibly attributed to a specific artist into three broad groups of artists who may have been working together or in contact with one another. With more input from art historians as the project progresses, alternative groupings can also be tested.

1. Group 1 - Jacopo Sansovino, Tiziano Minio, Alessandro Vittoria, Nicolo Roccatagliata, Campagna [10 objects];
2. Group 2 - Tiziano Aspetti, Giambologna, Antonia Susini, Adrien de Vries [9 objects];
3. Group 3 - Antico, Bertoldo di Giovanni, Johann Gragor van der Schardt, Kaspar Gras, Gerhard, de Keyser, Cellini, Francesco Bertos, Giovanni Foggini, Palma, F.B., Girardon [18 objects]. (This group is composed of all others not in the first two groups.)

As additional sculptures whose artist is relatively certain become available for technical study, we hope to be able to further divide these groupings down to individuals, or at least to very closely associated artists.

Because of the missing data, all of the above groupings were used for discriminant analyses using the casting and decorating data alone, and separately for analyses using the mineralogical data alone. At this point in the research the more uncertain objects were excluded, as the necessary first step is to determine how well (if at all) we can discriminate between these groups of more plausible attribution using the analyzed technical variables. With so many groups still of very small size, it would be premature to attempt to classify the stylistically uncertain objects at this stage in the project.

We tried one discriminant analysis (using the three time periods) with both the casting and decorating techniques and the mineral data combined. Since the number of objects that currently have both types of data available is smaller than the number of objects with either data set alone, it does not make sense to combine the datasets for any of the other discriminant analyses at this time, as the group sizes are just too small.

The exact set of features that form the discriminant function, as well as the degree of separation between groups, varies depending upon which groups are being compared and how many sculptures are included. A visual representation of the separation between groups is shown with plots whose axes can equivalently be denoted as "canonical variables", "discriminant functions", or principal component axes". Regardless of the name used, the first axis is the direction of greatest separation between all of the group means (using a linear combination of the variables in the final classification function). The second axis is the perpendicular direction with the greatest remaining separation. The maximum number of axes which can be extracted by this means is the lesser of the number of discriminant variables and the number of groups minus one. Thus for cases where only two groups are being compared the full amount of separation that exists is plotted with a histogram, and a two-dimensional plot is used for three or more groups.

RESULTS

Casting and Decorating Features

Discriminant analysis requires a complete data matrix with no missing values. For the casting and decorating variables, there are many cases where we still have missing data, particularly where the sculptures in Vienna need to be re-examined, or where X-ray radiography has not yet been carried out. Variables that are currently missing for most objects were ignored for the statistical work. In addition, variables that through the descriptive statistics were found to have the same value for nearly all the sculptures were also eliminated. Sculptures currently missing the remaining variables were then dropped from the analysis, leaving 62 sculptures and 66 variables. When the data matrix is more complete, more objects and variables can be included.

The results of all of the discriminant analyses are summarized in Table 1. In this and the following result tables, "Number" refers to the number of sculptures plausibly attributed to the group listed. "Reassigned" refers to the number of those sculptures that were found to be more similar to the sculptures of a different group than they were to their own group. The percentage of objects "Correctly Classified" refers to the total number of sculptures of

TABLE 1
DISCRIMINANT ANALYSIS RESULTS, CASTING AND DECORATING FEATURES

Groups	Number	Reassigned	Correct	Discriminating Variables
Regions:				
Italy	37	2	88%	Size of chaplets
All other regions	12	4		Cracks in casting
				Repairs of casting flaws
				Hollowness, secondary torso
				Hollowness, secondary arms
				Bubbled patina
Venice + Germany	7	3	76%	Amount of Porosity
Italy	31	4		Metallic flakes in patina
All other regions	11	5		Number of casting flaws
Venice + Florence	9	0	100%	Hollowness, secondary torso
Other North Italy	23	0		Degree of finish on back
				Puddling of repairs
				Tooling used for texture
				Evenness of patina
				Amount of porosity
				Rivets in repairs
				Chaplets removed and not patched
				Hollowness, primary arms
				Shape of repairs
Time Periods:				
Early	18	6	74%	Density of repairs
Middle	29	8		Silver inlaid eyes
Late	15	2		Hollowness, primary arms
				Separate pieces joined in the wax
Artist Groups:				
1	6	0	100%	Hollow/solid base
2	7	0		Chipped patina
3	9	0		Hollowness, secondary arms
				Pins in cracks
				Distribution of porosity

plausible attribution in that discriminant analysis whose technical features classify them into the same groups into which they were art historically classified. Thus on the first line of Table 1, out of 49 objects of plausible attribution (37 Italy, 12 Other), 6 were reassigned (2 labelled Italy were technically more similar to the Other group, and 4 in the Other group were more like the Italy sculptures). This leaves a total of 88% that could be correctly classified into their plausible attribution using the technical data. The closer to 100% correct classification, the better we will be able to later classify the art historically uncertain objects into one of the groups on the basis of technical data. The "Discriminant Variables" are those technical features which, when taken together, provide the maximum amount of discrimination possible between the groups being compared.

Regional Comparisons. When casting and decorating features are used to discriminate between Italy versus all other regional groups, a total of 88% of all sculptures are correctly classified. For this dataset, we start with 37 attributed to Italy and 12 attributed to the other regions. Two from Italy are found to be more like the "other" group, and thus reassigned to that group, and four from the "other" group are indistinguishable from Italy. Six variables form the discriminant function in this comparison. Figure 1 shows the histogram illustrating the separation between these two groups using a linear combination of the variables in the discriminant function.

When Venice and Germany were combined (for art historical reasons it was hypothesized that these two groups could be similar) and compared with all other sculptures from Italy, and with all other regional groups, only 76% were correctly classified. Out of 31 in the Italy group, 27 were correctly assigned to Italy. However, out of the 11 in the "other" group, 5 were called Italy; out of 7 in the Venice plus Germany group, only 4 could be distinguished as a separate group.

The best success came in the attempt to discriminate Venice plus Florence from other North Italian sculptures. A total of 100% of the sculptures were correctly classified (Figure 2).

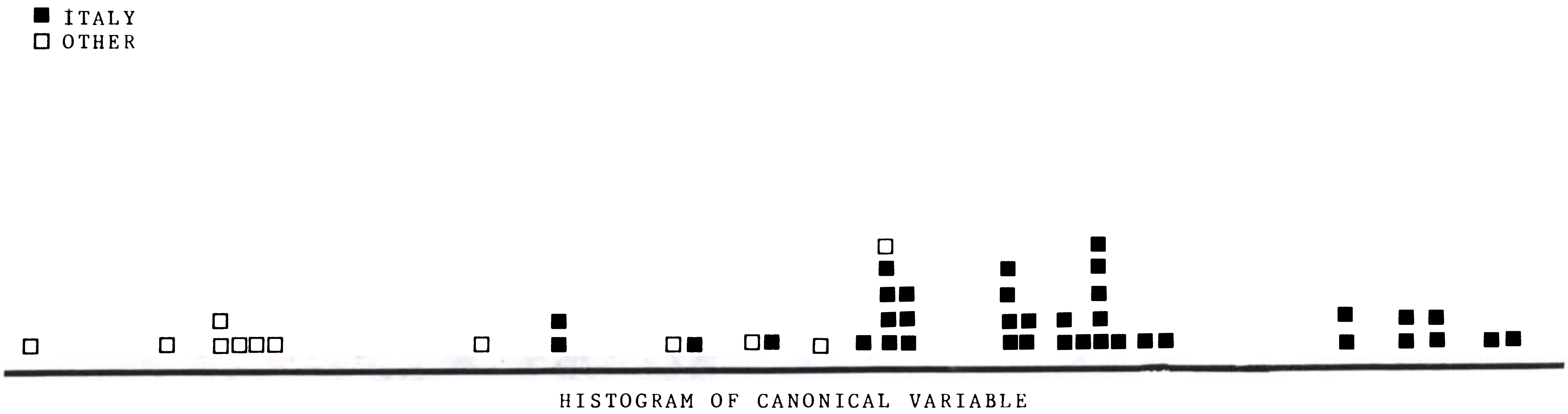

FIGURE 1
CASTING AND DECORATING TECHNIQUES

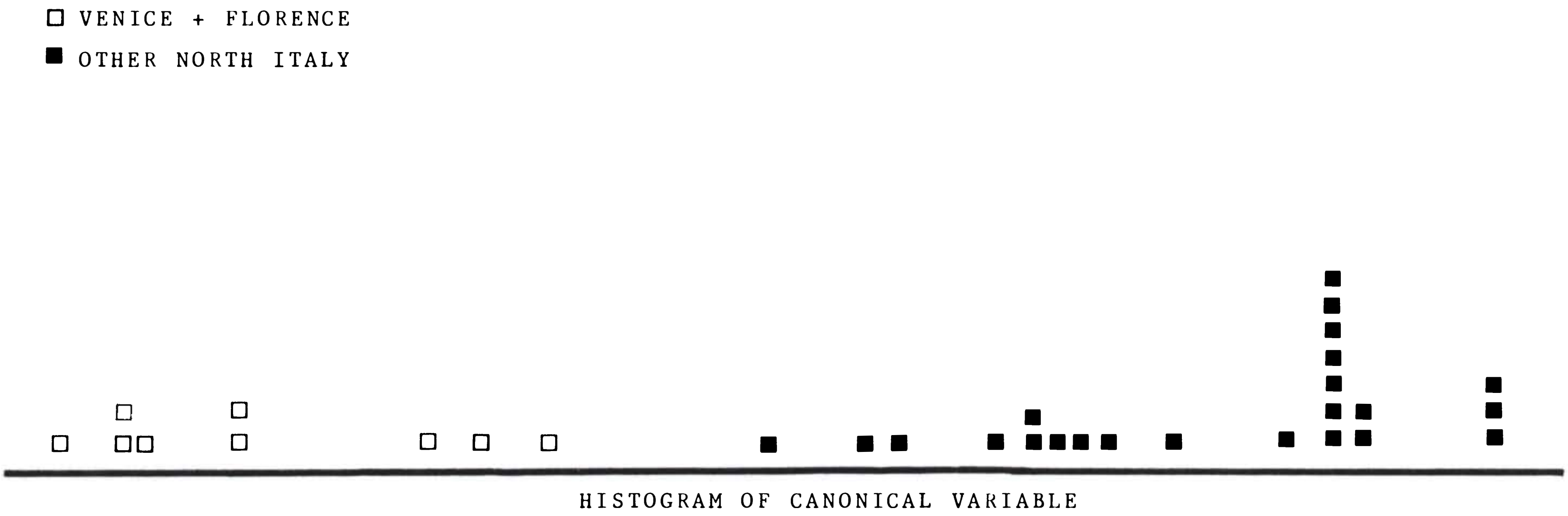

FIGURE 2
CASTING AND DECORATING TECHNIQUES

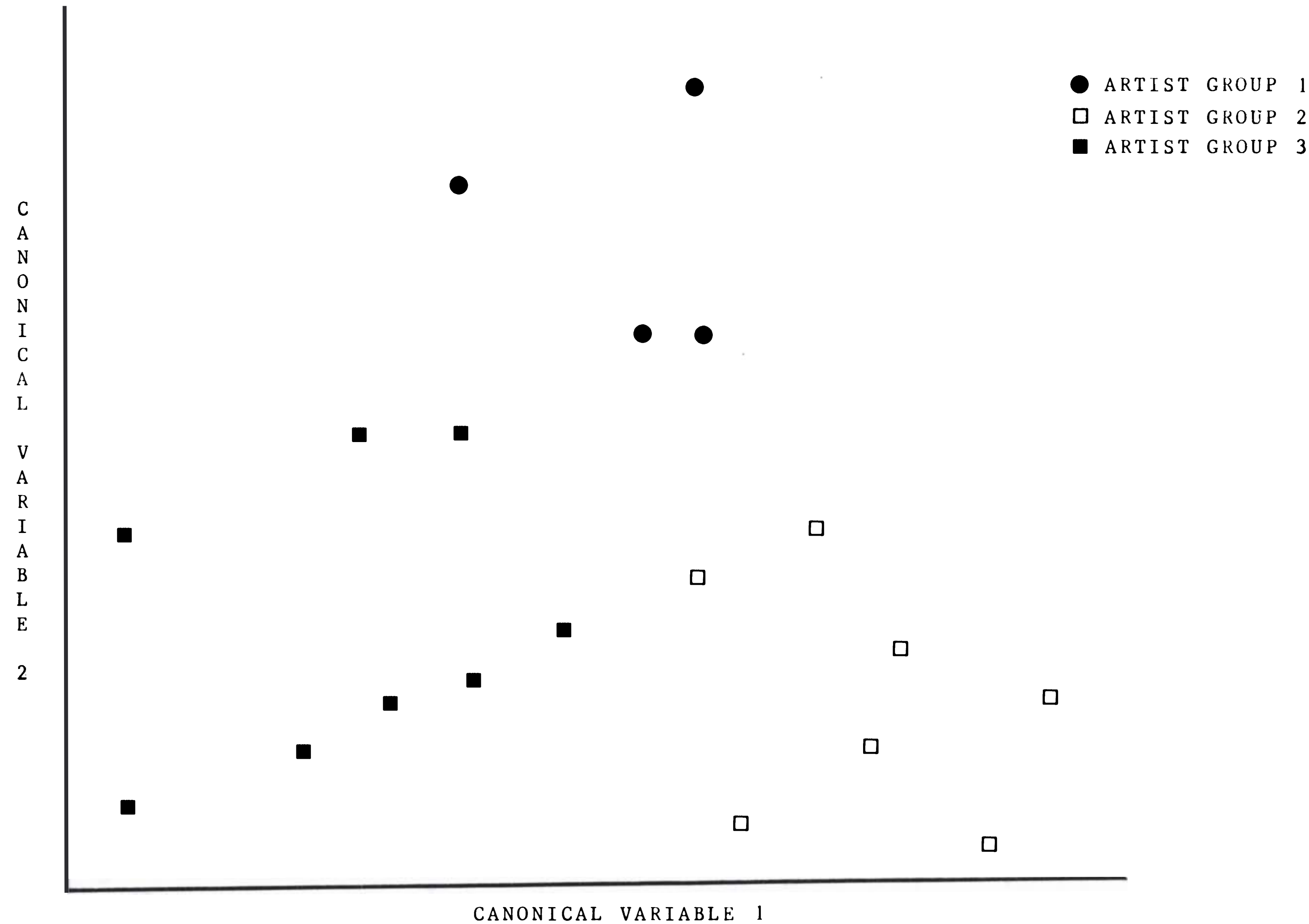

FIGURE 3
CASTING AND DECORATING TECHNIQUES

However, it must be noted that we still have very small group sizes (9 Venice + Florence and 23 other North Italy). Ten variables entered into the discriminant function.

Chronological Comparisons. When the three date ranges were compared using this dataset alone, only 74% of the sculptures were correctly classified. Out of the 18 Early sculptures, 12 were correctly assigned, but 6 could not be distinguished from the Middle group. Of the 29 in the Middle group, 21 were correctly classified as Middle, with 2 called Early and 6 called Late. Of the 15 in the Late group, 13 were correctly called Late and 2 were called Middle. Thus there was no overlap between Early and Late, the only problem is that the Middle category grades into Early and Late with no clear line of distinction. The discriminant function is formed by four variables.

Artist Groups. When the three artist groups were compared, 100% were correctly classified (Figure 3). However, given the extremely small group sizes this result must be seen as only a preliminary indication that we will probably be able to separate related groups of artists by casting and decorating techniques. We currently have only 6 sculptures of plausible attribution to Group 1 artists, 7 to Group 2, and 9 to Group 3. Five variables formed the discriminant function.

Mineralogical Data

There were 64 sculptures in the project with core material available. For all 64 the full list of variables was recorded, leaving none with missing data. Therefore the complete set of 64 could be used. The results of all discriminant analyses are summarized in Table 2.

Regional Comparisons. For Italy versus all other groups, 89% of the sculptures were correctly classified (37 out of 39 for Italy, and 12 out of 16 for "others"). Six variables entered into the discriminant function.

For Venice plus Germany versus Italy versus all others, the Venice plus Germany "group" is nonexistent, as none in the category can be distinguished from the other two groups. This leaves a total of only 62% correctly classified.

Again, the greatest success is in distinguishing between Venice plus Florence and the rest of North Italy (Figure 4). 100% of the sculptures are correctly classified (23 for North Italy and 10 for Venice plus Florence). Seven variables entered into the discriminant function.

Chronological Comparisons. We would not expect the mineralogical data to prove useful in distinguishing between time periods, except to the extent that the different time periods represent differing regional emphases in numbers of sculptures produced. That hypothesis was borne out by these results -- only 60% of the 37 sculptures in the chronological groups could be correctly classified using minerals alone.

Artist Groups. 100% of the available sculptures were correctly classified (Figure 5). Thus it is possible that each of these groups of artists may have worked in the same general region or constructed their clay cores with a similar type of material in comparison to the other groups. Here our dataset is extremely small (only 4 sculptures of plausible attribution to the artists in Group 1, 5 in Group 2, and 7 in Group 3). These results are very preliminary, but do indicate that given enough samples of core material from sculptures for which the artist is relatively plausibly known, we may be able to classify sculptures to a group of related artists. If it were possible to find enough sculptures of each individual artist, we could then try to narrow the discrimination down even further.

Combination of Casting and Mineral Data

As an experiment to see if combining the two datasets results in improved discrimination, an analysis was done for the three date ranges. The results are summarized in Table 3. As mentioned above, with minerals alone we had 60% correct classification when comparing these groups, and with casting and decorating data alone, 74%. Combining the two datasets results in 94% correct classification (Figure 6). Because the number of objects in each group is drastically reduced when we require that both datasets be complete, these results are very

TABLE 2
DISCRIMINANT ANALYSIS RESULTS, MINERALOGICAL DATA

Groups	Number	Reassigned	Correct	Discriminating Variables
Regions:				
Italy	39	2	89%	Carbon size
All other regions	16	4		Gypsum
				Authigenic quartz
				Plagioclase feldspar
				Spinel
				Orthoclase feldspar
Venice + Germany	8	8	62%	Carbon size
Italy	35	12		
All other regions	12	1		
Venice + Florence	10	0	100%	Quartz shape
Other North Italy	23	0		Microcrystalline quartz
				Fibrous quartz
				Carbonates
				Microcline feldspar
				Muscovite
				Apatite
				Rutile
Time Periods:				
Early	13	4	60%	Polycrystalline quartz
Middle	21	12		Quartz size
Late	8	1		

TABLE 3
DISCRIMINANT ANALYSIS RESULTS, DATA COMBINATION

Groups	Number	Reassigned	Correct	Discriminating Variables
Time Periods:				
Early	10	0	94%	Scooping of core
Middle	19	1		Metallic flakes on patina
Late	5	1		Hollowness, primary legs
				Hole on top
				Bubbled patina
				Repair of casting flaws
				Glauconite

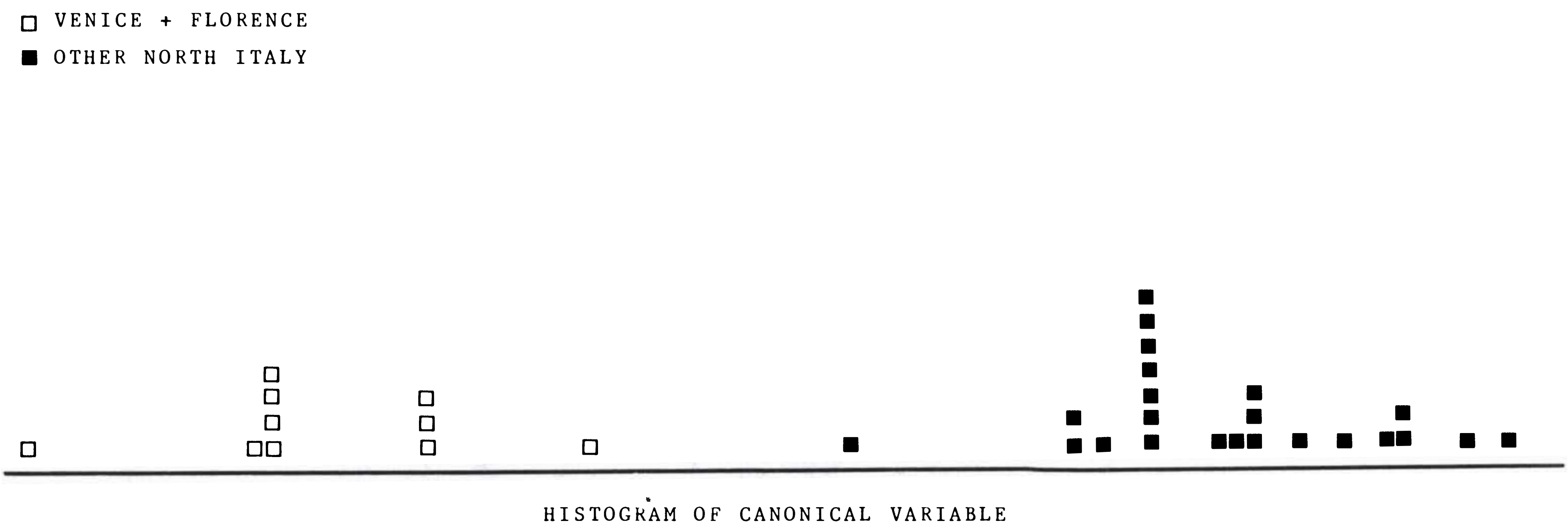

FIGURE 4
MINERALOGICAL ANALYSIS

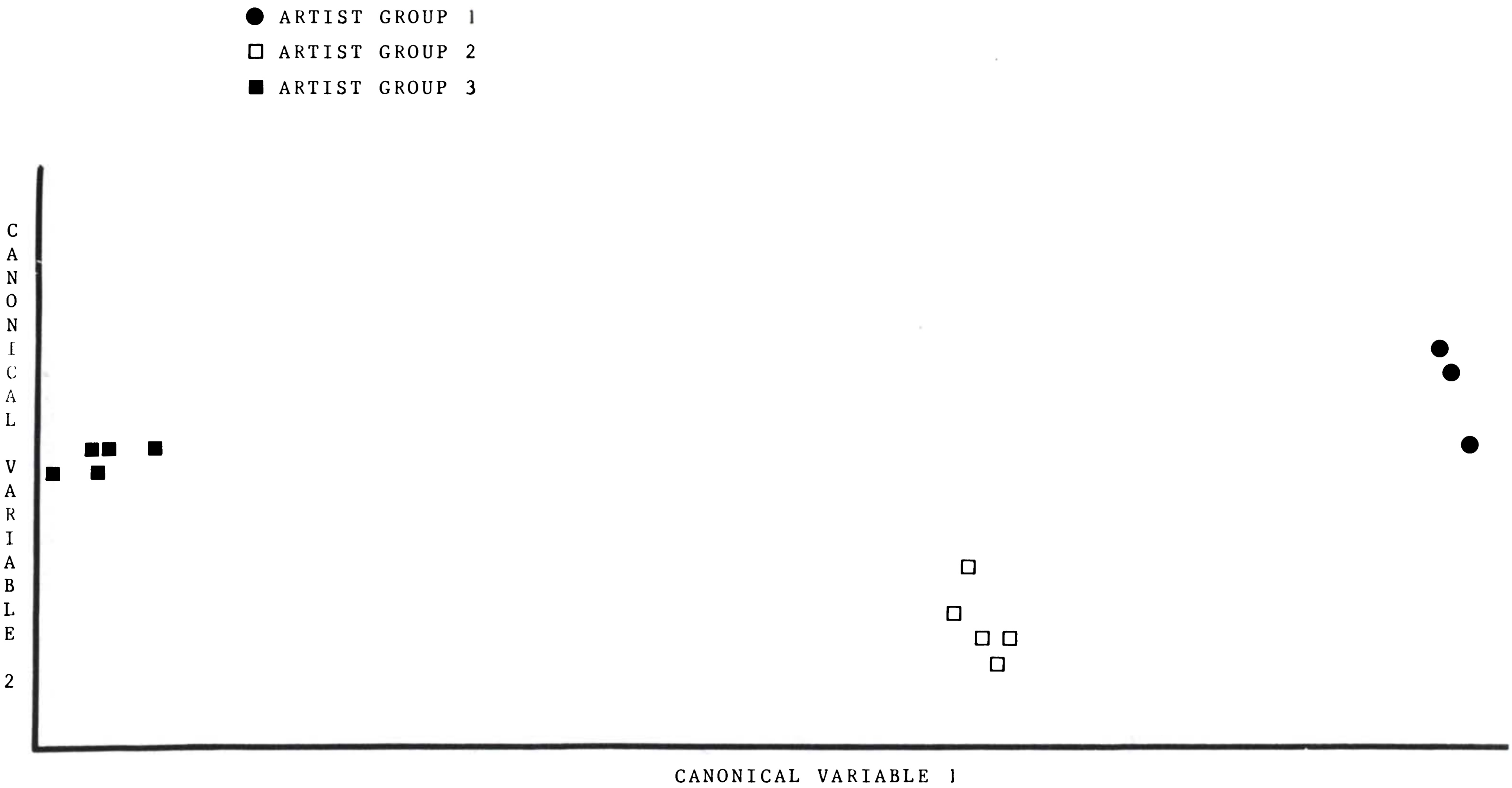

FIGURE 5
MINERALOGICAL ANALYSIS

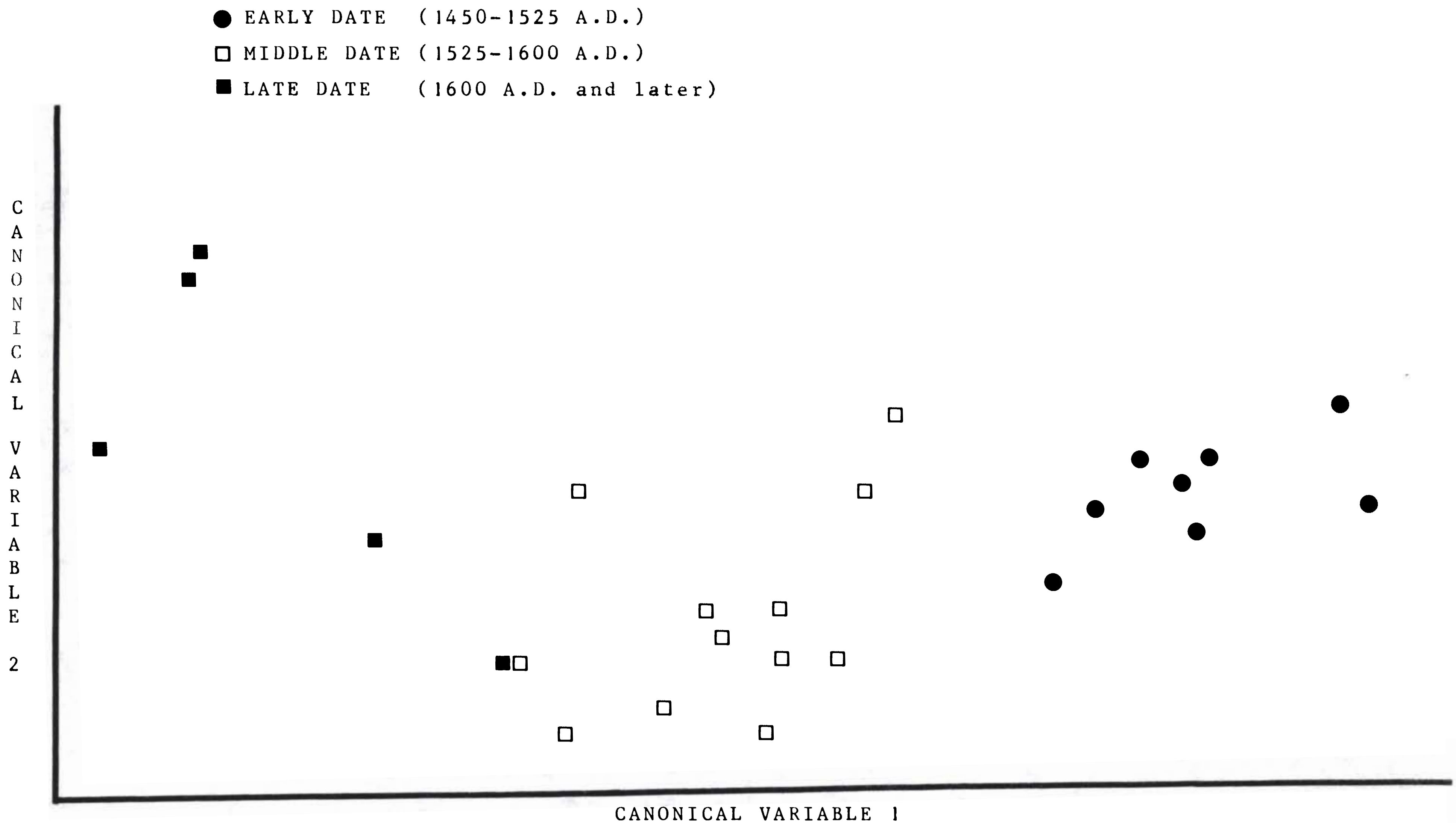

FIGURE 6
COMBINED DATA

preliminary (all 10 in the Early group are correctly classified, 18 out of 19 in the Middle group are correct with 1 misclassified as Early, and 4 out of 5 in the Late group are correct with 1 misclassified as Middle). However, these results do indicate that whenever possible both types of data should be recorded, as combining them will probably improve our ability to discriminate between groups. This makes sense, since the more types of data we have to characterize a group the better we should be able to distinguish it from other groups. Six out of seven of the variables that form the discriminant function are from the casting dataset, and one mineral variable is included (glauconite, an iron-rich mineral that is often found with hematite).

FUTURE WORK

In order for this project to be definitive and useful in a practical way, it must be continued beyond the preliminary experiments that we have now completed. A long-term project is necessary to adequately collect the data necessary for reliable results, and to confidently attempt to classify uncertain objects. As part of that expanded research we will need greater input from people in the various disciplines involved: art historians, conservators and scientists.

The next logical step in the project is to complete the X-ray radiography and sampling of core materials and metals. In addition, Ms. Milam and Ms. Sussman need to re-examine the sculptures in the Kunsthistorisches Museum and the Getty Museum that currently have incomplete data sheets. When these missing data are added, we will be able to add to and improve on the statistical work.

Data on metal compositions have not yet been included in the project. We do not know how much those data may improve our ability to discriminate between art historically-defined groups. However, it is probable that when combined with the other datasets in a multivariate statistical analysis, metal compositions may contribute to provenance identifications. We therefore hope to work with the scientists from the Getty Museum and Getty Conservation Institute to add these data in the future. It would be most useful if the first metal data collected were for objects already included in the project. Some metal samples from the Kunsthistorisches Museum were removed at the National Gallery in Washington D.C. following their exhibition there, under the supervision of Gary Carriveau. The analytical results, or the samples themselves, need to be obtained so we can incorporate them into the project.

As part of a long-term study, the next step after filling in the missing data for our current group of sculptures will be to include objects from other museums with major collections of Renaissance bronzes. Objects should be chosen by art historians and curators to fill out the dataset in such a way that we can more effectively test specific hypotheses in the statistical analysis. For example, we wish to obtain data for as many sculptures as possible that have a more certain attribution for region, date, and/or artist. Also, we should to expand the group categories that are currently extremely small, such as objects from Germany and France.

It has also been suggested that we create a computerized database to store, organize and retrieve the data that the we have collected, and make it available to other scholars. The database would permit quick retrieval of the information and observations that have been recorded, in any configuration. For example, one could extract all the mineralogical data for the sculptures with a "more certain" attribution to Mantua, then for all the sculptures that were possibly from Mantua. The database could be entered with DBase III (currently in use by Mr. Ben Kessler and Dr. Laurie Fusco at the Getty Museum for art historical data collected by the slide library and the education department). By using the same system and their abbreviations, we could plan to combine our scientific, conservation and art historical data with other information. This would increase the information on Renaissance bronzes accessible to scholars working in the field.

In order to obtain reliable results we need approximately 20 sculptures for each group included in the statistical analysis. We therefore need to expand our corpus of objects. The more pieces included the narrower the groupings we can examine. Ideally, we hope to continue this project over a long enough time period to permit us focus on discriminating between specific workshops and cities, rather than the more general workshop groups and larger regions thus far examined. It is our opinion that a long-term commitment (three to five years) to the project is necessary to achieve this goal.

CONCLUSION

Because of the currently small group sizes, these results must be considered preliminary, and we cannot yet attempt to classify the uncertain objects. However, the results obtained thus far indicate that there is a strong potential for technical studies to contribute to provence identifications of these sculptures. With the difficult art historical issues involved, and the controversy and uncertainty in many attributions, bringing in additional data from technical analyses could be an important contribution to provenance studies of Renaissance bronzes.

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APPENDIX 1

SCULPTURES EXAMINED

Kunsthistoriches Museum pieces are denoted "K" followed by their catalog number in the exhibition catalog, Renaissance Master Bronzes.

data number	sculpture	artist/region if unknown
K02	Bellerophon taming Pegasus	Bertoldo di Giovanni
K07	Jupiter	North Italy
K08	Venus felix	Antico
K09	Hercules and Antaeus	Antico
K11	Standing Hercules	North Italy
K12	Venus of Cardinal Granvella	North Italy
K13	Seated female panther	North Italy
K14	Ambling horse	North Italy
K15	Bull	North Italy
K16	Crab	North Italy
K17	Toad	North Italy
K18	Armored horseman	North Italy
K19	Seated bacchante with wreath	North Italy
K22	Marsyas	North Italy
K23	Warrior	North Italy
K32	Fat man	Unknown
K33	Venus	North Italy
K35	Negro Venus	Unknown
K36	Hercules or Cain	Florence
K37	Satyr	Italy
K38	Pegasus	North Italy
K39	Crouching gladiator I	North Italy
K40	Crouching gladiator II	Prague
K41	Barbarian on horseback	Milan
K42	Jupiter	Jacopo Sansovino
K43	Neptune in his chariot	Tiziano Minio
K44	Allegory of winter or A philosopher	Alessandro Vittoria
K45	Venus Marina	Tiziano Aspetti
K46	Adam and Eve	Nicolo Roccatagliata
K47	Putto with drum and flute	Nicolo Roccatagliata

data number	sculpture	artist/region if unknown
K48	Putto playing the flute	Nicolo Roccatagliata
K49	Mercury	Johann Gregor van der Schardt
K50	Venus Urania	Giambologna
K51	Flying Mercury	Giambologna
K52	The centaur Nessus abducting Deianira	Antonio Susini
K54	Christ at the column	Adriaen de Vries
K57	Crane	Unknown
K58	Lion attacking a bull	Antonio Susini
K59	Putto riding a dolphin	Unknown
K60	Chronos -- Saturn	Italy
K61	Greyhound	Unknown
K63	Standing putto	North Italy
K64	Pacing horse	Unknown
K66	Emperor Ferdinand III on horseback	Caspar Gras
K67	Mercury and Psyche	Caspar Gras
K68	Warbler	Florence
K69	Nereid	Netherlands
K70	Triton with a fish	Unknown
K71	Two horses gamboling	Hubert Gerhard
K72	Mars, Venus and Cupid	Hubert Gerhard
K73	River-god	Unknown
K74	St. Jerome	Unknown
K75	Venus or Amphitrite	Netherlands

J.Paul Getty Museum pieces are assigned data numbers as follows:

data number	museum #	sculpture	artist/region
G01	74.SB.16	Venus Marina	France
G02	74.PB.17	Rape of Proserpine by Pluto	France
G03	74.PB.18	Rape of Orithyia by Boreas	France
G04	84.SB.90	A Warrior on Horseback	de Keyser
G05	85.SB.60	Venus	Italy
G06	85.SB.61	Prancing bull	Padua
G07	85.SB.66	Venus chastising Cupid	Italy

data number	museum #	sculpture	artist/region
G08	85.SB.68	Female Virtue or Allegory	Venice
G09	85.SB.69	Satyr	Cellini
G10	85.SB.72	Kicking horse	Caspar Gras
G11	85.SB.73.1	Stupidity and Fortune	Francesco Bertos
G12	85.SB.73.2	Industry and Virtue	Francesco Bertos
G13	85.SB.74	Eleven figures	Francesco Bertos
G14	85.SB.75	Mars and Venus	Flemish
G15	85.SB.184	Mercury	Allesandro Vittoria
G16	85.SB.413	Laocoon	Giovanni Foggini
G17	85.SB.418.1&.2	Two Sphinxes	Italy
G18	L.86.SB.55	St. Stephen	Nicolo Roccatagliata
G19	L.86.SB.134	San Giorgio	Nicolo Roccatagliata
G20	L.86.SB.143	Jupiter	Palma
G21	L.86.SB.144	Francoflemish Venus	Unknown
G22	86.SB.488	Rearing Horse	Adrien de Vries
G23	86.SB.688	Bust of a Young Man	Antico
G24	86.SB.734	Putto or Infant Christ	Campagna
G25	87.SB.50	Venus with Cupid and dolphin F.B.	
G26	L.88.SB.39.1 (88.SB.73)	Rape of Orthiyia by Boreas	Marsy
G27	L.88.SB.39.2 (88.SB.74)	Rape of Proserpine by Pluto	Girardon
G28	44.5.86	Virgin and Child (from Museum of Fine Arts,Houston)	Susini
G29	74.560C (49.26.2)	Palissey (ceramic) from Los Angeles County Museum of Art	
G30	L.83.SB.20	Andromeda (French)	Robert LeLorrian
G31	85.SB.63	Kneeling Satyr	Riccio
G32	85.SB.67	Triton	Unknown
G33	85.SE.55	romanesque aquamanile ca. 1220 Hildesheim or Magdeburg	Lower Saxony
G34	86.SB.5.1	Dog	Germany
G35	86.SB.5.2	Bear	Germany
G36	L.87.DE.98	Palissey basin (ceramic)	
G37	87.SB.50	F.B. Venus Same as #25	
G38	L.87.SB.102	Hercules and Hydra	Giambologna
G39	L.87.SC.101 (88.SC.42)	Bust of Mme Recamier (ceramic) Chinard	

APPENDIX 2

CASTING AND DECORATING FEATURES: DEFINITION

CASTING AND DECORATING FEATURES: DEFINITION

Certainty of Regional Attribution:

certain - a known fact as to where workshop was located (not necessarily where the artist was from)

uncertain - there are several choices where the workshop could have been located

Certainty of Attributed Artist:

certain - artist signed bronze with verified signature or there is strong historical or art historical evidence proving that the work can be attributed to a particular artist

uncertain - art historical nor historical evidence cannot reasonably prove an attribution to a certain artist

Certainty of attributed date: (date range 50 years: example 1450 would indicate 1425-1475)

certain - dated or documented, scholars agree on date stylistically, there is art historical and historical evidence that links the sculpture to an attributed date

uncertain - scholars disagree or are unsure of date

fake - examination has proven the sculpture to be of a much later date of fabrication and it was made in a style to deceive

Data Available:

visual examination - object available for examination in lab or formerly viewed in the lab and adequate notes were taken

x-ray radiograph - available for examination

XRF - taken from polished area

metal sample - taken for future use for atomic absorption

core sample for TL - test was run

core sample for thin section - core sample mounted and read for mineral characterization

Another similar image exists (multiple castings possible) - scholar refers to a similar image which possibly could have come from the same mold or it is a reoccurring image from the period

Structure:

Number of separately cast pieces:

One - appears to originally be cast in one piece

more than one - appears to have been originally cast in more than one piece, or unsure if repaired or original attachment removable parts present - parts which can be slid or threaded into or out of position

How separately cast pieces are attached:

cast on - part of the piece is cast and attached to mold before the rest of the object is cast

Brazing - or welded with a alloy with a high melting point

Soldering - attached with a low melting alloy

Pins - attached with a dowel within the piece

Rivets - a pin which reaches the surface and the end is expanded

Screws - threaded rivets

Sleeve - the overlapping of two hollow parts, in which one is slightly smaller in diameter and fits inside the larger

Hoop (interior) - an interior ring of metal attaching two hollow parts

Size of Chaplets:

small - 1/8" or less

large - greater than 1/8"

Shape:
none - 0

round - a fairly regular circular form

squared - a geometric shape with corners

Number of chaplets:

none - 0

few - relative to the surface area of the sculpture many - number is relative to the surface area of the sculpture, there are several scattered over the surface

Chaplets are:

similar alloy - color of one or more chaplet is visually similar to the alloy of the sculpture

noticeably different alloy - one or more chaplets are a different color visually form the rest of the sculpture

Iron chaplets remain: one or more chaplets appear to be made of iron, or have been checked with a magnet whenever possible

Chaplet density in radiograph:

light - more dense than the alloy of the sculpture itself

same as the sculpture - the alloy of the chaplet appears equal in density to the alloy of the sculpture or the color of the chaplets vary

dark - the alloy of the chaplet is less dense than the alloy of the sculpture itself

Chaplets:

voids remain - regular holes in the sculpture which appear where chaplets have been lost or removed

lacing chaplets - chaplets which go all the way through the piece in a continuous back and forth motion which would be continuous to extremities before chaplets are cut and chased

chaplets go all the way through piece - chaplets go in one end of the sculpture and come out the other side

pins located in cracks - a crack or casting flaw which has been stopped by a pin at one or both ends of the crack or, which has been repaired at an intermediate point

threaded chaplets - chaplets which appear to have threads in the radiograph, or when possible visually evident from interior examination

pegs - interior dowels which are evident in the radiograph which extend in from an interior wall and appear to serve no purpose

wires used for chaplets - at least one wire is used to function as a chaplet

Only wire holes remain - a wire or wires used for chaplets have been lost or removed number of armatures - whenever possible the number of armatures which appear in the radiograph are counted

alloy of armature:

iron - magnetic attraction to the piece follows the lines of an interior armature evident in the radiograph or checked with a magnet

copper alloy - armature is nonmagnetic

Armatures are:

knarled - armature is bunched up with random bends

hooped - armature follows the interior curvature of of the sculpture

wired - two or more wires which have been tied together with another wire twisted around them

straight - armature wire is not bent

Intertwined - two or more wires are twisted together at various points

continuous - armature wires are connected to one another in one or a combination of methods listed above

discontinuous - armature wires are not connected

Distribution of porosity:

even - porosity appears on the radiograph to be consistent overall

uneven - porosity appears on the radiograph in selected area

Size of pores:

small - the pores (air pockets) are 1/32" or less

large - the pores are much greater than 1/32"

Amount of Porosity: (a ratio of the surface)

small - a slight amount of porosity is visible on the radiograph

medium - there is an average amount of porosity in comparison to several other bronzes

large - there is a generous amount of pores overall

none - there are no pores visible in the radiograph

Thickness of metal:

thin - the walls of the sculpture, relative to the size of the piece appear to be very narrow when viewing the opacity in the radiograph

average – the walls of the sculpture, relative to the size of the piece are thicker than the thin walled bronzes, and thinner than the thick walled bronzes

thick – the walls of the sculpture relative to the size of the piece have much more mass than usual

even – the walls are relatively the same thickness overall

uneven – the thickness of the walls varies greatly overall

solid – the sculpture has been cast without a core

Dripping implying slush casting: this is a fabrication technique thought to first be used by Antico in the Renaissance; drips of excess wax accumulate within the interior of the sculpture as the dripping molten wax cools before it can be poured off, thereby forming corresponding variations in the radiograph of the metal sculpture

Lost Wax – the most common method of fabrication, is a technique in which a wax model is made and invested in a clay mold, the wax is heated and melted away, and replaced by molten metal poured into the mold

Sand Casting – a fabrication technique not used before the 16th century, and more commonly used in the 19th century. A rather angular core forms the interior. With this technique the piece is formed from several separately cast pieces, depending on the complexity of the model.

mold lines present: mold lines (flashings – ridges of metal which follow a possible mold pattern) which are left unchased on the surface

Cracking of casting: breaks in the metal which occur on the surface of the sculpture, and which may continue into the wall of the sculpture

Back mounting hole: a hole intentionally formed for the mounting of the sculpture or for the removal of the core and left open

Hole on top of head: a hole intentionally formed on the top of the sculpture perhaps for the removal of the core and left open

Hole on the underside: a hole intentionally formed on the lower surface which could be used for the removal of the core and then left open magnetic metal:

overall - when there is magnetic attraction over the entire surface of the sculpture indicating that there is a high iron content in the alloy

local-magnetic attraction in specific areas which may be identified as either a chaplet or armature

Pieced in wax: at least one or more parts or sections were added or revised in the wax model for composition changes, repairs or for technical reasons for the fabrication of the sculpture; in the radiograph the seam appears dense

Cast in pieces and joined: at least one or more parts or sections were cast in separate pieces and attached in the metal by mechanical or thermal methods; in the radiograph the seam appears to be less dense or light

Repairs: all repairs, casting flaws, and later repairs are identified unless the repairs can absolutely be identified as a later repair

Casting Flaws:

few - three or less obvious casting flaws

numerous - more than three obvious casting flaws

repaired - a least one flaw has been repaired

open - at least one flaw has not been repaired

shape of repairs:

irregular - amorphous shaped repairs visible on the surface of the sculpture or visible in the radiograph

regular - geometric or regularly shaped repair formed by the working with tools

repairs are:

puddled - hot metal is poured into damaged or flawed area

mechanically added (tapped) - damage or flaw has been repaired by hammering cold metal into the area

lead repairs - lead is used in the filling of the voids

solder - low melting point metal, or higher melting point metal used to braze the damaged or flawed area

rivets - a pin which reaches the surface and the end is expanded

threaded - a pin which has spiral groves which give tooth to the join

pinned - an interior dowel which attaches two pieces

Core :

Hollowness - figures are consistently examined in the following order: man, woman, animal, when more than one of the same from top to bottom

Torso:
solid - body and head are completely solid cast
mostly solid - head is solid, and the body is only partially solid
mostly hollow - body is hollow and head is solid
hollow - body and head are hollow

Arms:
solid - arms are completely solid cast
mostly solid - upper arms are hollow
mostly hollow - whole arms are hollow
hollow - arms and hands are hollow
differ - arms have different hollowness from one another

Legs:
solid - whole legs solid
mostly solid - thighs are hollow
mostly hollow - whole legs are hollow
hollow - legs and feet are hollow
differ - legs have different hollowness from one another

Appendages - other than arms and legs:
solid - entire appendage is solid
mostly solid - less than half hollow appendage
mostly hollow - greater than half but less than entirely hollow appendage
hollow - entire appendage is hollow

Attributes: hollowness determined as appendages

Base: when base is visible in radiograph or visually examined
solid - base is solid, or it can be solid with small holes which extend into the interior of the sculpture
Hollow: base is hollowed, or it is solid and hollowness extends from a large void in the sculpture

Core is:
carefully modeled - core follows the contours of the figure with the possible exception of the limbs or attributes which can be solid or partially solid

partially modeled - core follows only some of the contours of the figure

not modeled - core is a blocked shape

Core is removed:
none - no core removal is evident from the radiograph or

from visual examination

some - core has been partially removed evident from visual or radiograph examination

much - most or all of the core material has been removed determined from visual examination

Scooping out of core for armature: in the radiograph one can see a rounded, less dense area at the end of an armature and sometimes along the length of it

Local scooping: radiograph shows less dense areas where it appears as though the core has been removed in a particular area

Decoration and Finishing:

Silver inlaid eyes
Probable inlaid eyes missing
Silver feet
Silver leaf
Gold Leaf
Mercury Gilding

Tooling:
fine - meticulous working where tool marks are not evident
medium - tool marks may be evident, but surface is not as finely worked
crude - tool marks are rough and very evident, unchased and unpolished

Stroke:
Short-abrupt or interrupted tool marks
Long-continuous or sweeping tool marks
Punching - small circular indented tool marks

Tooling used for:
texture - tooling used to decorate the form in addition to the minimal design
design - tooling used to define form minimally

Relief: design extends to front and sides, and not the back

In the round: sculpture which can be viewed form all angles including the back

Degree of finishing on back:
low-small amount of finishing on the back, not well chased or polished
average - surface is somewhat worked on the back to a defined degree of finishing
high - surface on the back is finely worked
same - the degree of finishing is the same as the finishing

on the front of the sculpture
different - the degree of finishing is different from that on the front

Design continues under attributes: the form is modeled under an attribute which may or may not have been added later

Flashing left on surface (unchased): irregular ridges of metal left on surface, a ridge filling a fissure

Fissure / interior flashing (light) - dense, jagged lines in the interior of the sculpture, which are visible in the x-ray and correlate to an interior flashing cause from a cracking of the core during casting

Cracks in metal (dark)-less dense, jagged lines visible in the radiograph of the sculpture which correlate to cracks in the metal not readily apparent on the surface of the sculpture

Patina:

Color:
red-brown
brown
green
black
golden-patina color as opposed to color of metal showing through nor does this refer to surface gilding

Translucent-the color of the metal shows through a non-opaque patina

Opaque - the color of the patina does not allow the color of the metal to show through

Even - color of coating is consistent overall

Uneven - color of coating is varied

Streaked - linear variations in color of patina

Splotched - spotty, isolated areas of various colors

Mottled - undulating variation of color of patina

Chipped - platelettes of patina have lifted off exposing the metal below

Worn - areas where more metal is exposed due to loss of patina from some sort of abrasion

Bubbled - small spots where there was a conglomeration of pigment in a varnish patina

Bubbled and burst - small spots where patina has lifted and spalled off

Metallic Flakes Applied - varnish patina or fills which have a luster due to metallic shavings or flakes

Old Certain-patina appears to be original according to our current level of knowledge on Renaissance patinas

New Certain - patina appears to be modern, not consistent with the date of fabrication, it shows no logical signs of wear, varnish, or chemical patination "looks recent" to the trained conservators eye

Age Uncertain - unsure of age of patina, there may be signs of wear, but varnish or chemical patina is not "typical" of that which a trained conservator would expect

Combination - an older patina which has been chipped and worn, with a modern patina which covers over all areas

Degree of patinated surface fineness:

high - a chemical or varnish patina which has a consistent quality, although it may be worn

medium - a patina, with more inconsistencies and less of a polished look

crude - a patina which has many inconsistencies and flaws in its application, and is non-polished, with a dull surface

APPENDIX 3

CASTING AND DECORATING FEATURES: DATA FORM

RENAISSANCE BRONZES: CASTING TECHNIQUES

Sculpture No.: Subject:
City: Region: Country:
Certainty of regional attribution: certain plausible uncertain
Artist: Certainty of attributed artists: certain plausible uncertain
Date: Certainty of attributed date: certain plausible uncertain fake
Height: in. Width: in. Depth: in.
cm. cm. cm.
Wt.(kg): Not weighed: very light normal very heavy
Data available: visual exam x-radiography XRF metal sample
core sample for: TL thin section
Another similar image exists (multiple castings possible)

Structure:

No. of separately cast pieces: one more than one Removable parts present
How separately cast pieces are attached: cast on brasing soldering welding
pins rivets screws sleeve hoop (interior) flange
Size of chaplets: small medium large Shape: round squared
No. of chaplets: few average many Iron chaplets remain
Iron replaced with other metal: similar alloy noticeably different alloy
Only voids remain Lacing chaplets Chaplets go all the way through piece
Pins located in cracks Threaded chaplets Pegs
Wires used instead of chaplets Only wire holes remain
No. of armatures: Material: iron copper alloy
Armatures are: knarled hooped wired continuous discontinuous
Distribution of porosity: even uneven size of pores: small medium large
amount of porosity: small medium large ~~none~~
Thickness of metal: thin average thick even uneven solid
Dripping implying slush casting lost wax sand casting Mold lines present
Cracking of casting back mounting hole hole on top of head hole on underside
magnetic metal: overall or local pieced in wax cast in pieces and joined

Repairs:

Casting flaws: few numerous repaired open
Shape of repairs: irregular regular
Repairs are: cast on mechanically added (tapped) lead repairs solder used
rivets used threaded pinned

Core:

Hollowness:		solid	mostly solid	mostly hollow	hollow	differ
1st	Torso					
	Arms					
	Legs					
	Appendages					
2nd	Torso					
	Arms					
	Legs					
	Appendages					
	Attributes					

Base: solid hollow Plaque: solid

Core is: carefully modelled not modelled partially modelled

Core removed: none some much

Color of core: red white black brown multi

Scooping out of core for armature Local scooping

Decoration and finishing:

Silver inlaid eyes probable inlaid eyes missing silver feet

Silver leaf Gold leaf Mercury gilding

Tooling: fine medium crude

Stroke: short -abrupt long -continuous punching

Tooling used for texture or design Relief In the round

Degree of finishing on back: low average high same different Quality of finishing on back: low average high

Design continues under attributes (implying possible later additions of attributes)

Flashing left on surface (unchased) Flashing on interior(lt) Cracks in wax interior(dk)

Patina:

Color: red brown green black golden translucent multi

even uneven streaked splotched mottled

Chipped Worn Bubbled and burst Metallic flakes applied

Old-certain New-certain Age uncertain Combination

Degree of patinated surface fineness: high (burnished and polished) medium crude

APPENDIX 4

PETROGRAPHIC DATA: DEFINITIONS

DESCRIPTION OF PETROGRAPHIC DATA RECORDED

Quartz. The percentage of quartz present in each thin section was estimated by reference to models for visual estimation of percentage composition of rocks (Williams, Turner, and Gilbert 1982:593-597). The most common size for quartz grains was recorded as fine (less than .1 mm), medium (.1 mm - .4 mm), or coarse (greater than .1 mm). The degree of sorting of the coarser grains in each section was determined to be poor (there is a wide range of grain sizes), moderate, or good (most of the grains are approximately the same size); shape of the quartz was originally recorded as angular, subangular, subrounded, or rounded (Pettijohn 1975:57), though later these categories were collapsed into just angular or rounded.

The following textures were recorded for the quartz grains: (1)polygonized - two to three subcrystals present in a single grain

(2) polycrystalline (a) four to ten subcrystals present in a single grain, or (b) more than ten subcrystals present in a single grain (the percentage of quartz grains that are polycrystalline was also noted); these categories were later combined to simply presence or absence of polycrystalline quartz

(3) microcrystalline - aggregate in which individual grains are less than .03 mm in size, as in chert

(4) fibrous - the chalcedony form of silica

(5) undulous (a) slightly - grain goes extinct in 1-5 degrees of microscope stage rotation, or (b) strongly - grain goes to complete extinction only with more than 5 degrees of microscope stage rotation; these were later combined to presence or absence of undulous extinction

(6) vacuoles - negative crystal inclusions in the grain, often filled with liquid and having the same crystallographic orientation as the main quartz grain; these could include either many small ones or one or a few large ones

(7) authigenic overgrowths - secondary growth along the edges of the grain boundary

(8) inclusions of other minerals in the quartz grains

Organic Matter. This appears in both uncarbonized and carbonized form. For both forms the overall percentage present and the most common size were determined in the same manner as for quartz grains.

Carbonates. When present, these were recorded as rare, abundant, or very abundant. The most common size was determined to be fine, medium, or coarse, using the same criteria as for the quartz grains. If rounded edges or rhombic shapes were present, these were noted. The presence of possible dolomite (rhombic shape, cloudy center and clear rim) or siderite (yellow-brown color from alternation to limonite) were also noted.

Hematite. If present, was recorded as rare (one has to hunt to find any on the slide), abundant (easy to find), or very abundant (permeates the slide).

Feldspars. The presence of plagioclase feldspar was recorded with its approximate percentage computed in the same manner as for percentage of quartz grains. The percentage of alkali feldspars were also recorded, broken down into microcline or orthoclase categories. Only data on the presence or absence of these feldspars was used for the statistical work.

Micas. Presence or absence was recorded for: muscovite, biotite, phlogopite, chlorite, and chloritoid. Phlogopite and chloritoid were so rare in these samples that they were dropped for the statistical analysis.

Pyroxenes. The presence or absence of clinopyroxenes was recorded. If present, the type was determined whenever possible. Orthopyroxenes were recorded as either enstatite or hypersthene.

Amphiboles. Only hornblende was seen in these samples.

Lithic Fragments. These were primarily metamorphic or volcanic, although some sedimentary and plutonic lithics were also seen.

Other Minerals. The presence or absence was recorded for the following minerals: epidote, clinozoisite, apatite, zircon, rutile, spinel (which was either magnetite or ilmenite), tourmaline, garnet, glauconite, gypsum, serpentine and olivine. In a few samples sphene and graphite were also seen, but these were too few to include in the statistical analysis.

Clay. The remainder of the casting core consists of clay minerals of one type or a mixture of types. These cannot be further identified in thin section.

APPENDIX 5

PETROGRAPHIC DATA: FORM

data number	museum #	sculpture	artist/region
G08	85.SB.68	Female Virtue or Allegory	Venice
G09	85.SB.69	Satyr	Cellini
G10	85.SB.72	Kicking horse	Caspar Gras
G11	85.SB.73.1	Stupidity and Fortune	Francesco Bertos
G12	85.SB.73.2	Industry and Virtue	Francesco Bertos
G13	85.SB.74	Eleven figures	Francesco Bertos
G14	85.SB.75	Mars and Venus	Flemish
G15	85.SB.184	Mercury	Allesandro Vittoria
G16	85.SB.413	Laocoon	Giovanni Foggini
G17	85.SB.418.1&.2	Two Sphinxes	Italy
G18	L.86.SB.55	St. Stephen	Nicolo Roccatagliata
G19	L.86.SB.134	San Giorgio	Nicolo Roccatagliata
G20	L.86.SB.143	Jupiter	Palma
G21	L.86.SB.144	Francoflemish Venus	Unknown
G22	86.SB.488	Rearing Horse	Adrien de Vries
G23	86.SB.688	Bust of a Young Man	Antico
G24	86.SB.734	Putto or Infant Christ	Campagna
G25	87.SB.50	Venus with Cupid and dolphin F.B.	
G26	L.88.SB.39.1 (88.SB.73)	Rape of Orthiyia by Boreas	Marsy
G27	L.88.SB.39.2 (88.SB.74)	Rape of Proserpine by Pluto	Girardon
G28	44.5.86	Virgin and Child (from Museum of Fine Arts,Houston)	Susini
G29	74.560C (49.26.2)	Palissey (ceramic) from Los Angeles County Museum of Art	
G30	L.83.SB.20	Andromeda (French)	Robert LeLorrian
G31	85.SB.63	Kneeling Satyr	Riccio
G32	85.SB.67	Triton	Unknown
G33	85.SE.55	romanesque aquamanile ca. 1220 Hildesheim or Magdeburg	Lower Saxony
G34	86.SB.5.1	Dog	Germany
G35	86.SB.5.2	Bear	Germany
G36	L.87.DE.98	Palissey basin (ceramic)	
G37	87.SB.50	F.B. Venus Same as #25	
G38	L.87.SB.102	Hercules and Hydra	Giambologna
G39	L.87.SC.101 (88.SC.42)	Bust of Mme Recamier (ceramic) Chinard	

OTHER MINERALS

Plagioclase Feldspar	Approximate %
Alkali Feldspar	Approximate %
Microcline	
Orthoclase	
Other	
Muscovite	
Biotite	
Chlorite	
Clinopyroxene	Type
Orthopyroxene	
Enstitite	
Hypersthene	
Amphibole	
Hornblende	
Other	
Epidote	
Clinozoisite	
Apatite	
Zircon	
Rutile	
Spinel	
Magnetite	
Ilmenite	
Lithic Fragments	
Metamorphic	
Sedimentary	
Volcanic	
Plutonic	
Tourmaline	
Garnet	
Glauconite	
Gypsum	
Serpentine	
Olivine	
Other:	

APPENDIX 6

KEY TO THE DATA TABLE

Key to the Dataset

(The column numbers not listed refer to blank columns)

column(s)	type of data	key
1◊2◊3	Sculpture number	G: Getty + assigned number K: Kunsthistorisches + catalog number
5	Line of Data	1
7	Region	A: Flemish D: Padua E: Netherlands F: France G: Germany I: Italy L: Florence M: Milan N: North Italy (Padua, Milan, Mantua) P: Spain R: Prague S: South Italy T: Mantua U: Uncertain V: Venice
8	Artist	U: Uncertain A: Antico B: Bertoldo di Giovanni C: Jacopo Sansovino D: Tiziano Minio E: Alessandro Vittoria F: Tiziano Aspetti G: Nicolo Roccatagliata H: Johann Gragor van der Schardt

		I: Giambologna
		J: Antonio Susini
		K: Adrien de Vries
		L: Caspar Gras
		M: Hubert Gerhard
		N: de Keyser
		P: Cellini
		Q: Francesco Bertos
		R: Giovanni Foggini
		S: Palma
		T: Campagna
		V: F.B.
		W: Girardon
9	Date Range (50 years)	A: ca. 1400
		B: ca. 1425
		C: ca. 1450
		D: ca. 1475
		E: ca. 1500
		F: ca. 1525
		G: ca. 1550
		H: ca. 1575
		I: ca. 1600
		J: ca. 1625
		K: ca. 1650
		L: ca. 1675
		M: ca. 1700
		N: ca. 1725
		P: ca. 1750
10	Date Certainty	0: uncertain
		1: certain
		2: fake
12◊13◊14	Height in centimeters	XX.X
16◊17◊18	Width in centimeters	XX.X

20◊21◊22	Depth in centimeters	XX.X
24	Number of separately cast pieces	1: one 2: more than one

How separately cast pieces are attached:

25	Cast on	0: no	1: yes	3: no
26	Brased/Welded	0: no	1: yes	separate
27	Soldered	0: no	1: yes	pieces
28	Pins	0: no	1: yes	
30	Rivets	0: no	1: yes	
31	Screws	0: no	1: yes	
32	Sleeve/interior hoop	0: no	1: yes	

Chaplets

34	Size	0: none 1: 1/8" or less 2: greater than 1/8"
35	Shape	0: none 1: round 2: squared
36	Color in x-ray	0: none 1: light 2: dark 3: same/medium/varies
38	Number	0: none 1: few 2: many
39	Iron chaplets replaced	0: no chaplets 1: Iron remains 2: ..w/ similar alloy 3: ..w/ different alloy

40	Voids remain	0: no 1: yes
41	Chaplets go through piece	0: no 1: yes
43	Pins located in cracks	0: no 1: yes
44	Threaded chaplets	0: no 1: yes
45	Wires used instead of chaplets	0: no 1: yes 2: wire holes remain
47	Number of armatures	9: nine or more (number is indicated if less than nine)
48	Armature material	0: none 1: iron 2: copper alloy
49	Armatures are:	0: no armature 1: not knarled 2: knarled
50	Armatures are:	0: no armature 1: not straight 2: straight
52	Armatures are:	0: no armature 1: not hooped 2: hooped
53	Armatures are:	0: no armature 1: not wired 2: wired

54	Armatures are:	0: no armature 1: not intertwined 2: intertwined
55	Armatures are:	0: no armature 1: discontinuous 2: continuous
57	Distribution of porosity	0: none 1: even 2: uneven
58	Size of pores	0: none 1: 1/32" or less 2: greater than 1/32"
59	Amount of porosity	0: none 1: small 2: medium 3: large
60	Thickness of metal	0: thin 1: average 2: thick 3: solid
62	Thickness of metal	0: even 1: uneven 2: solid
63	Technique	0: slush 1: lost wax 2: sand
64	Mold lines present	0: no 1: yes
65	Cracking of casting	0: no 1: yes

66	Hole in back	0: no 1: yes
68	Hole on top	0: no 1: yes
69	Hole underneath	0: no 1: yes
70	Magnetic metal	0: none 1: local 2: overall
71	Light, dense area at join (joined in wax)	0: no 1: yes
72	Dark line at join (joined in metal)	0: no 1: yes
74	Casting flaws	0: none 1: few 2: numerous
75	Casting flaws	0: none 1: repaired 2: open 3: both
76	Shape of repairs	0: none 1: irregular 2: regular 3: both
78	Repairs are:	0: no repairs 1: not cast on 2: cast on
79	Repairs are:	0: no repairs 1: not mechanically added 2: mechanically added

80	Repairs are:	0: no repairs 1: not puddled 2: puddled	
1◊2◊3	Sculpture number		
5	Line of data	2	
7	Repairs are:	0: no repairs 1: not lead 2: lead used	
8	Repairs are:	0: no repairs 1: not soldered 2: soldered	
9	Repairs are:	0: no repairs 1: not riveted/pinned 2: riveted/pinned	
10	Repairs are:	0: no repairs 1: not screwed 2: screwed	
11	Repairs are:	0: no repairs 1: not less dense material 2: less dense fills used	
Hollowness of:			
13	1st figure torso	0: none	(key for
14	1st figure arms	1: solid	13-21)
15	1st figure legs	2: mostly solid	
16	1st figure appendages/attributes		
18	2nd figure torso	3: mostly hollow	
19	2nd figure arms	4: hollow	
20	2nd figure legs	5: differ	
21	2nd figure appendages/attributes		

23	Base	0: non-metal/not original 1: hollow 2: solid
24	Core	0: none (solid) 1: not modelled 2: partially modelled 3: carefully modelled
25	Core	0: no core 1: none removed 2: some removed 3: much removed
27	Scooping of core	0: no core 1: no scooping 2: for armature 3: local scooping
29	Silver eyes	0: no 1: yes 2: inlay missing
30	Gilding	0: none 1: leaf 2: mercury
31	Tooling	0: fine 1: medium 2: crude
32	Stroke	0: short 1: long
34	Tooling for texture (decorate form)	0: no 1: yes

35	Tooling for design (defines form)	0: no 1: yes
36	Format	0: relief 1: in the round
38	Back finishing	1: same as front 2: less than front
40	Flashing left on surface	0: no 1: yes
41	Flashing on interior(light)	0: no 1: yes
42	Flashing in wax interior(dark)	0: no 1: yes
44◊45	Color of patina (44 is primary color; 45 is secondary color.)	0: none (for one color) 1: red-brown 2: brown 3: green 4: black 5: golden
46	Transparency	0: none 1: transparent 2: opaque
47	Patina	0: even 1: uneven
49	Streaked patina	0: no 1: yes
50	Splotched/mottled	0: no 1: yes

51	Chipped patina	0: no 1: yes
52	Worn patina	0: no 1: yes
53	Bubbled and/or burst	0: no 1: yes
55	Metallic flakes	0: no 1: yes
56	Patina	0: old 1: new 2: both- two types 3: uncertain
57	Degree of patinated surface fineness	0: high or shiny 1: medium 2: crude

Line 3:

1,2,3	Sculpture number	
5	Line of data	3
7	Quartz percentage	0: absent 1: 1-5% 2: 5-10% 3: 10-20% 4: 20-30% 5: 30-40% 6: 40-50% 7: > 50%
8	Quartz size	0: inapplicable 1: fine 2: medium 3: coarse
9	Quartz sorting	0: inapplicable 1: poor 2: moderate 3: good
10	Quartz shape	0: inapplicable 1: angular 2: rounded
11	Polygonal quartz	0: absent 1: present
12	Polycrystalline quartz	0: absent 1: present
13	Microcrystalline quartz	0: absent 1: present
14	Fibrous quartz	0: absent 1: present
15	Undulous quartz	0: absent 1: present
16	Quartz vacuoles	0: absent 1: present
17	Authigenic quartz	0: absent 1: present
18	Quartz inclusions	0: absent 1: present

20	Uncarbonized Organics	0: absent 1: present
22	Carbon percentage	0: absent 1: 1-5% 2: 5-10% 3: 10-20% 4: 20-30% 5: 30-40% 6: 40-50% 7: > 50%
24	Carbonate amount	0: absent 1: rare 2: abundant 3: very abundant
25	Carbonate size	0: inapplicable 1: fine 2: medium 3: coarse
27	Hematite amount	0: absent 1: rare 2: abundant 3: very abundant
29	Plagioclase feldspar	0: absent 1: present
30	Microcline feldspar	0: absent 1: present
31	Orthoclase feldspar	0: absent 1: present
33	Muscovite	0: absent 1: present
34	Biotite	0: absent 1: present
35	Chlorite	0: absent 1: present
37	Clinopyroxene	0: absent 1: present
38	Orthopyroxene	0: absent 1: present
39	Amphibole (hornblende)	0: absent 1: present

41	Epidote and clinozoisite	0: absent 1: present
43	Apatite	0: absent 1: present
44	Zircon	0: absent 1: present
45	Rutile	0: absent 1: present
47	Spinel	0: absent 1: present
49	Metamorphic lithics	0: absent 1: present
50	Sedimentary lithics	0: absent 1: present
51	Volcanic lithics	0: absent 1: present
52	Plutonic lithics	0: absent 1: present
54	Tourmaline	0: absent 1: present
55	Garnet	0: absent 1: present
56	Glauconite	0: absent 1: present
58	Gypsum	0: absent 1: present
59	Serpentine	0: absent 1: present
60	Olivine	0: absent 1: present

APPENDIX 7

DATA TABLE

```
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K04 2
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K08 3
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K10 2
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K11 2 11112 4444 0000 031 3 1101 011 1 010 4220 00000 020
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K12 2 12111 1110 0000 000 0 1011 011 1 000 2320 01000 031
K12 3
K13 1 N EO 295         13333 333 112 2110 000 0000 0000 1121 01000 11100 111 112
K13 2 11111 4440 0000 032 1 1001 011 1 000 4020 00000 020
K13 3 612111111101 1 2 21 1 101 111 000 0 110 0 0100 000 001
K14 1 N EO 185         20001 000 113 2 01 000 1 12 1112 1111 01000 00 01 212 111
K14 2 11211 4111 0000 031 1 0011 011 1 000 2520 00110 031
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K15 1 N EO 122         13333 333 113 2 00 000 0000 0000 0000 01010 00 00 112 121
K15 2 11111 4110 0000 031 1 0011 011 1 001 5210 01010 031
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K27 2
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K60 1 IUI1 241          20101 000 112 1 00 000 3 12 1111 2221 11000 00 01 000 000
K60 2 00000 3234 0000 222 1 0001 111 1 001 1520 00110 031
K60 3 113200010000 0 1 11 1 100 001 000 0 000 0 0000 000 010
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