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Laboratory Studies of Some European Artifacts Excavated on San Salvador Island

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ABSTRACT

Recent excavations at The Long Bay Site uncovered artifacts of European manufacture intermingled with native Indian artifacts. These include seven very small glass beads (and fragments of three others), a coin, a small metal buckle, a "D-ring", 32 sherds of *melado* ware, and two small sherds of white-glazed ware. Laboratory studies have been conducted to help determine the origins and dates of these artifacts.

The glass beads are wire-wound and have an extremely unusual high-lead chemical composition. The coin is a billon *blanca* of Henry IV minted between 1471 and 1474. Both buckles were found to be lightly-leaded bronzes. The melado ware has a lead glaze, as do the white wares, although the latter also contain tin.

All of the artifacts contain intentionally-added lead. Their isotope ratios spread over a range, but all are consistent with Spanish origins. The data indicate that the San Salvador artifacts were made in three locations within Spain.

INTRODUCTION

At the outset of this conference, debate still continues as to the identity of Guanahani, Columbus's San Salvador. The debate has, indeed, recently intensified with the announcement of a claim by a team working under the auspices of the National Geographic Society,[1] disputing the widely-held opinion that Columbus's San Salvador is the present day Bahamian island bearing that same name. Although the present authors have certain reservations regarding the case as so far stated for Samana Cay, we will leave the navigational, historical, and observational aspects of that subject to be argued out by those better qualified than we. Instead, this paper deals with the archaeological finds recently made on San Salvador. Until now, these finds appear to be the only archaeological evidence yet uncovered which might plausibly relate to Columbus's first landing in The New World. Whether or not these finds remain unique will depend upon future excavations both there and at other sites, including Samana Cay. But one thing is readily apparent. An entirely new dimension — archaeological studies — has now been added to the investigation of Columbus's voyages of discovery. This new dimension comprises not only the newly uncovered artifacts dealt with here, but also the application of archaeology in general which will contribute to a clearer understanding of the people whom Columbus encountered during his voyages into their homelands.

Whichever translation one uses of the Bartoleme de Las Casas abstract of Columbus's journal of his first voyage, there seems to be no disagreement as to his description of certain events of October 12th recorded in his entry for October 13th. As worded in Morison's version,[2] along with Las Casas' remarks that these particular passages quote the Admiral's own words, Columbus wrote: "I, in order that they might develop a very friendly disposition towards us. . .gave to some of them red caps, and to others glass beads, which they hung on their necks, and many other things of slight value, in which they took much pleasure. . . .later they came swimming to the ship's boats in which we were, and brought us parrots and cotton thread in skeins and darts [spears?] and many other things, and we swopped them for other things that we gave them, such as little glass beads and hawk's bells." On October 13th he also noted ". . .they readily bartered for any article we saw fit to give them in return, even such as broken platters and fragments of glass. I saw. . .sixteen balls of cotton thread. . .given for three Portuguese *ceutis* (sic)." In the days which follow, Columbus made several more entries referring to glass beads and other trifles traded to the Indians. For October 15th he stated that the Indian he met traveling over open water possessed a basket containing some glass beads and two Spanish *blancas*. From this Columbus surmised the man had come from San Salvador. On December 3rd, having by then become involved in an exploration of Cuba, Columbus set out up river from the coast with an armed party, and trekked through heavily wooded country until they came upon a large village, whose inhabitants the Admiral gave ". . .hawk's bells and brass rings and green and yellow glass beads, with which they were well pleased." Later in the day, during a decidedly less friendly encounter, he pacified a group of Indians and ". . .demanded their darts, for which I gave to some a hawk's bell, to others a brass ring, to others some beads, so that all were pleased. . .".[3]

From the foregoing, it is evident that among the small items Columbus and his crew traded or used as gifts on his first voyage, were hawk's bells, metal rings (described as "brass"), low-denomination copper-based coins, (*ceutis* at Guanahani and *blancas*, by implication, at Guanahani), fragments of broken glass and pottery, and glass beads — specifically green and yellow glass beads. Another reference, without citing a primary source, adds to this list "fragments of shoe-latchets."[4] That the Indian recipients were delighted is to be expected, because the same results had been obtained with the same items (augmented by more substantial goods when serious trading began) by Portuguese merchants and explorers working down the West Coast of Africa. Indeed, Columbus was probably involved in that trade himself, and would naturally have taken an ample supply of the same such trinkets on his voyage to "The Indies."[5]

In another paper at this conference, Charles Hoffman has described his excavations at The Long Bay Site.[6] The coastal area around the bay had been surveyed previously by John Winter.[7] These excavations produced a number of European-made artifacts intermingled with Lucayan Indian artifacts which normally would be considered prehistoric. The objective of the present study was to learn as much as possible about the European-made artifacts through laboratory examinations and analyses in the hope that the results might lead to conclusions regarding their dates and places of manufacture.[8]

THE OBJECTS STUDIED

The European-made finds consist of the following: Seven tiny glass beads with fragments of three others, one coin, one small buckle, one somewhat larger metal D-ring, a sherd of *melado* (or honey-glazed) ware, and two sherds of plain white-glazed ware, (possibly "majolica" in The New World usage), three planking nails, one copper grommet, one metal hook, and fragments of metal which might have come from knives or swords.

The objects discussed in this paper, along with some parallels, are described in the catalogue of samples and illustrated in Figures 1 through 9. Table 1 summarizes the analyses and tests carried out on each object.

Only minute samples of the objects were sacrificed for study. Approximately one-half of each of the two smallest glass bead fragments was removed. The original fragments consisted of only about one-quarter of a bead and measured no more than 1.5 mm in greatest dimension. A tiny snippet of the perimeter of the coin was removed from an edge which was already bent and about to become dislodged. The buckle and D-ring, being larger and less fragile, were sampled by drilling thin shallow holes into the metal. The holes were then filled and painted over to minimize the slight disfigurement which otherwise would have been visible. Minute portions of glazes and bodies were removed from the edges of two of the pottery sherds and petrographic thin sections were prepared. The nails, hook, grommet, and knives or sword fragments have not yet been analyzed.

The Glass Beads

The seven glass beads and three fragments are all of the same type. (Figures 2 and 3.) This is a rather distinctive type; once seen and handled, other examples should be easily recognized. On the other hand, without having examined them, a casual observer could easily be misled into thinking these beads are the same as other far more familiar and ubiquitous types of seed beads.

The San Salvador beads are varieties VIDle and VIDlf in the typology defined by Marvin Smith and Mary Elizabeth Good in their publication on early Spanish beads found in The New World.[9] The beads correspond to nos. 105 and 106 in Figure 7 of that publication.[10] The San Salvador beads have a distinct shape and are best described as tiny "ringlets," although they are not always perfectly round. They are small, measuring only 2.5-3.5 mm in "maximum diameter" and have relatively large, roughly circular perforations[11] ranging from 1.5 to 2.3 mm. Most are somewhat thicker on one side than the other.

These beads were unquestionably made by winding, as is evidenced by the internal cords (striations) which spiral through the bead and around the axis of the perforation. They contain quite a few seed (small bubbles) which are generally sphericalized. The seed occasionally occur in bubble chains which follow the cord patterns. In all examples there are protrusions on the thicker portion corresponding to "winding-thread pull-offs," that is, places where the thread of glass was separated from the main body of the bead during its manufacture. Most of these once had sharp, cracked-off edges which have since been worn down by erosion, but some were originally rounded, having become fire-polished during manufacture.

The perforations are straight-sided and have surfaces which, weathering effects aside, are what one expects to see on beads wound around a wire. No traces of scale or other metallic corrosion products are preserved on the surfaces, although one bead (5714) does contain a few black flakes (which look metallic) trapped inside the glass itself. In places, elliptically-shaped half bubbles are seen on the walls of the perforations. These resulted from air trapped between the softened glass and wire when the beads were wound. The half bubbles are elongated in the direction of winding.

The ringlet form of these beads is distinctly different from the shape of most tiny seed beads — which, by the way, are often even smaller than the San Salvador beads in outside diameter. The vast majority of seed beads were made by drawing out hollow tubes of glass, giving them a shape which is usually distinctly drumlike and more cylindrical than the ringlet shape of the wirewound San Salvador beads. It is fortunate in terms of this investigation that the excavated beads have such a distinctive and recognizable form, for that separates them sharply from the far more abundant drawn beads, thereby offering greater promise for locating their places and dates of manufacture. Moreover, one of the colors is also quite unusual. Of the ten beads and fragments, nine are a bright green transparent color, and one a rather pale yellowish amber. The green transparent is not a true emerald green; nevertheless it is distinctly brighter than, and distinguishable from, the iron green of most early glasses. This distinctive, sparkling color should also be of help in identifying the place and date of manufacture.

The glasses are heavily weathered although few traces of weathering products still adhere, having been eroded away by the action of the soil in which they were buried. Nevertheless, all show the heavy tell-tale pitting characterizing glasses which have been weathered over the course of two or three centuries or more.

Marvin Smith, then of the University of Florida, and the late Charles Fairbanks, have provided four additional samples of beads which are virtually identical to the San Salvador specimens. The differences between them and the San Salvador beads (except that one is yellow opaque) are visible only under magnification. They have the same ringlet form, approximately the same dimensions and proportions, a very similar sparkling green color, and were also made by winding. They differ only by being somewhat less weathered, and slightly less seedy. Unfortunately, only one, 5700, comes with a provenance. It is from Nueva Cadiz, and should date between 1515 and 1545. The others were obtained from dealers and are said to come from the Sinu region of Colombia and from Peru. As was borne out by the analyses discussed below, these four beads are clearly very closely related to the San Salvador specimens in a chemical sense as well as in their physical appearance.

Quantitative chemical analyses were made of all six of the beads described above: two fragments from San Salvador and the four comparative specimens. Quantitative determinations of the major and minor elements of the four latter glasses were carried out by atomic absorption, and semi-quantitative analyses of the trace elements by emission spectrography. For these glasses, the silica was estimated by difference from 100%. Because the samples of the San Salvador beads were so small, they were analyzed by the electron microprobe. The results are reported in Table 2.

Two important observations can be made immediately. First, all six of the glasses are very similar in composition; similar enough that we are willing to attribute them to the same general region and traditions of manufacture — possibly, even, to the same factory. Second, the composition is extremely unusual. It is really a two-component lead-silica glass ($PbO:SiO_2$). The presence of lead, even in rather sizeable concentrations, is not unusual throughout the history of glassmaking, however, these 65-75% lead oxide contents are much higher than those seen in virtually any other category of early lead glasses from the Western World.[12] The very high lead contents result in the very high specific gravities and indices of refraction measured for some of the beads and reported in Table 2. This is useful to know because it affords a means of estimating the lead contents of suspected parallels to the San Salvador beads without subjecting them to chemical analysis.

The high lead content of the San Salvador beads produced a glass with a low softening point which would have allowed it to have been drawn out in threads and wound around a wire at relatively low temperatures. From the viscosity-temperature curve for a very similar glass, we estimate that glasses with the composition of the San Salvador beads would have been soft enough to have been worked in this manner at a temperature of 750-800°C. This would be some 250-300° lower than required for a soda-lime glass. It is probable that such beads could have been made with an alcohol lamp equipped with a small blowpipe. One could visualize a kind of cottage industry in which cullet, or perhaps glass already drawn into thin rods or threads, was softened and formed into the beads in small workshops. Indeed, it is difficult to visualize how such tiny beads could have been made at all in large numbers if the glass would have had to have been worked at the glory hole of a furnace.

Although copper produces a blue transparent color in soda-limes and other common glasses, the sparkling, bright green of these beads is typical of the color produced by copper in a high-lead matrix. The yellowish amber glass is probably a so-called "carbon amber."[13] The yellow opaque bead (5721) from Colombia is obviously colored with the $PbSnO_3$ yellow colorant-opacifier. (Microscopic flakes of the pigment can be seen in the glass.) This pigment is related to the better-known $Pb_2Sb_2O_7$ antimony compound used in ancient glasses. The tin pigment gradually replaced the antimony pigment starting sometime around the 1st-2nd cent. A.D.[14] Although both were used from time-to-time after that, the tin-containing pigment, judging from analyses of mosaic tesserae, appears to have seen somewhat wider use from Medieval times onward.[15]

The analyzed chemical compositions of the six glasses were used to back-calculate batch formulas which could have been used to prepare the glasses. The mean of the $PbO:SiO_2$ ratio is 2.94, indicating that the basic recipe, on a weight basis, was probably 3.0 parts of litharge to 1.0 part of sand. The deviation of the calculated ratio from this ideal 3:1 ratio is only about 2 relative percent. This deviation is readily accounted for by the alumina, iron, and other impurity oxides which affect the calculation. Transformed to a volume basis, the basic recipe is very close to a 1:1 ratio of sand to litharge[16] with a deviation amounting to only 6%. Both of these recipes conform to common sense, and the choice of one over the other depends only upon whether one chooses to believe that glassmakers of the period worked with weight batches or with volume batches.[17] In either case, a small quantity of copper-containing colorant was also added to form the green color. We believe this was in the form of an oxide scale from a piece of scrap brass. Calculations show that the colorant could have been an alloy with a composition 78Cu:19Zn:3Sn. This is reasonable for a brass of the period.[18]

One further point deserves consideration. The composition of these glasses is actually closer to the composition of enamels than it is to glasses ordinarily used for vessel manufacture. It would not be surprising to find that these beads originated in some location where glass or metal enameling was practiced.

In summary, the San Salvador beads are all very closely related to one another, and to the four comparative beads from early Spanish Colonial sites in The New World. They are a distinctive and recognizable type visually, were made by the relatively rare wire-wound technique, and share an unusual chemical composition which can be explained on a reasonable technological basis. The next question arising is where these beads might have been made. The possibilities which come to mind are Spain, Portugal, and Venice. The authors have not yet had opportunities to investigate this question as thoroughly as required, and glass specialists consulted so far have been helpful but have not provided definitive answers. Venice is always first among the usual suspects rounded up as the source of any glass bead. Although records exist which document the export of Venetian beads through commercial trading centers (including Lisbon) it would do an injustice to Spanish glass industries of the time to settle too hastily upon Venice in this instance. There were fluorishing glass industries in Spain at the time of Columbus's departure, and they should be considered prime candidates for the place of manufacture. Elena Ramirez-Montesinos has told us she believes that green glass beads with very high lead contents might have been made at Maria or Puebla de Don Fadrique.

The Metal Buckles

The two excavated buckles, (4691 and 4692) are illustrated in Figures 3 and 4. No. 4692 is quite small, measuring 2.4 cm across the straight shank. It might have been a shoe buckle. No tongue was found to accompany this buckle but perhaps it never had one. It is said that imitation buckles, never intended to be worn, were sometimes made for use as trade trinkets. Such buckles would not show any wear along the straight side where the tongue would have been mounted. Indeed, this buckle does not show such wear, but one wonders if a real buckle would show wear either if it were this heavily corroded. For the moment then, this point remains unresolved.

Jaime Barrachina has recently published the archaeological finds excavated at *El Castell de Llinars del Valles*, a castle near old Barcelona.[19] Among the finds were assorted types and sizes of bronze and/or brass buckles, some of which resemble the San Salvador buckle in form and in size. In a personal communication Dr. Barrachina has stated that the example he sees as being the closest parallel for the San Salvador find[20] was common in the early 15th century at his site, and that that type was made until at least as late as 1485.

There are two differences between the buckles from Llinars and the San Salvador object. The groove for the tongue in the San Salvador buckle is triangular in section, as if it (or the prototype for the mold in which it was cast) had been cut with the edge of a file. The grooves on the buckles from Llinars seem instead to be square in section. There is also a more subtle conceptual difference between the designs. The rounded portion of the San Salvador buckle looks like a semi-oval, with a straight bar placed across the ends of it and extending beyond the ends. All the buckles from Llinars look instead like semi-ovals with rounded ends extending beyond a straight bar joining them inside the ends.

Professor Barrachina's information is encouraging, in that it establishes that small buckles, possibly shoe buckles, similar (although not identical) to the San Salvador specimen were in use in Cataluna towards the end of the 15th century. Much further research must be done to see what small buckles from other places were like at that time. For all we know at present, similar buckles might have been used in many other parts of Europe.

Barrachina also shows examples of D-rings from Llinars.[21] However, his finds were made of iron, whereas that from San Salvador (4691) is made of bronze.

Bernardo Vega[22] illustrates two buckles similar to those found at Long Bay. Vega, then director of the *Museo del Hombre Dominicano in Santo Domingo*, Dominican Republic, reported finding 29 metal artifacts of European origin, together with stone and amber objects of Taino origin. Twelve croissant-shaped metal pieces were analyzed and turned out to be brasses containing about 85% copper and 13% zinc. We have not examined the buckles Vega illustrates. However, the two illustrated closely resemble Barrachina's in that the rounded ends project beyond the straight bar joining them inside the ends. The composition of the metal of the buckles is not given.

Chemical analyses of the San Salvador buckles are shown in Table 4. The analysis of the small buckle (4692) yielded only a surface composition because it was done by x-ray fluorescence.[23] Nevertheless, the results are sufficient to establish that the alloy is a lightly-leaded bronze. The D-ring (4691) was analyzed by a combination of atomic absorption and emission spectrography, because it was possible to obtain a sample without disfiguring the object. This alloy is also a lightly leaded bronze. The D-ring could have served any number of purposes, although the fact that it is bronze might suggest it also had a partially decorative function, or had been used for maritime purposes, where resistance to corrosion was required.

The Pottery and Pottery Glazes

Small samples of the glazes of two of the pottery sherds from San Salvador (Figure 9) were analyzed qualitatively with the electron microprobe by one of the authors (SSCT).[24] The analyses established that both are lead glazes. The *melado* ware (4697) contains only lead in substantial proportions, but the white-glazed ware (4698) contains tin in addition. The fragment of white-glazed ware, which is too small to tell whether its parent object was decorated or undecorated, could be from a piece of Columbia plain ware. This type of pottery, thought to have been made in Triana (a suburb of Seville), is common on 15th- and 16th-century Spanish Colonial sites in The New World.[25] The one example of Columbia plain we have analyzed so far is a broken plate similar in color and fabric to the tiny white-glazed sherd from San Salvador. This plate, now in the collection of The Hispanic Society of America, was excavated at the Convent of San Nicolas near Santo Domingo. It is our sample 4699. The plate is identical, or nearly so, to one excavated at La Vega Vieja and illustrated by Goggin.[26]

X-ray diffraction by one of the authors (MJM) established that Quartz, Calcite, Augite and the clay mineral Chlorite are the major mineral constituents in the *melado* sherd (4697) and the white-glazed sherd from San Salvador (4698), and also in the Columbia plain sherd from Santo Domingo (4699). Thin-section analysis (by MJM and John F. Wosinski of Corning Glass Works) established that the non-matrix constituents consist of well-sorted quartz silts, larger fragments of quartz sand, randomly dispersed books of Biotite, some amphiboles and pyroxene (Augite) in a fine-grained matrix of Calcite and clay. The only difference among the three sherds is a slight color difference between samples 4697 and 4699. This is due simply to the sherds having been fired under somewhat different redox conditions. In light of present knowledge it seems unlikely that the sampled wares could have been made in the New World. These findings are consistent with the literature of Spanish Colonial majolica ceramics.[27]

The above analysis indicates that all three sherds were made from very similar clay sediments, and suggests that they could have been made in the same general region. Because the Columbia plain ware is thought to have been made near Seville, the evidence further suggests — but does not prove — that the San Salvador sherds might have come from some place not far from Seville. In support of this, one can look at those geological environments where the principle clay mineral, Chlorite, can occur. Chlorite will form as a secondary mineral phase in low-grade metamorphism, often associated with the formation of talc via a retrograde metamorphic sequence. With these particular samples such is not the case; the presence of amphiboles, pyroxene (Augite) and mica (Biotite) indicates a plutonic origin for the clay sediments, an origin in which Chlorite is the weathered by-product of amphiboles and mica. Large clay deposits of Chloritic clays will occur via detrital processes, i.e., alluvial processes. Based on our present knowledge, the mineral assemblage of the three sherds is compatible with the geo-environment of southern Spain.

A *Blanca* of Henry IV

The most useful find of the excavation, as far as dating is concerned, is a billon coin (Figures 5 and 6). The coin is in very poor condition, being heavily corroded, fragmentary, and possibly partially defaced. It is so thin that it must have been badly worn before having been buried. The corrosion has produced an overall green patina with microscopic bead-like protrusions containing cores of cuprite. A segment of the coin had been broken away in the distant past as evidenced by the presence of corrosion products on the broken edges. Dr. Doty (see below) is of the opinion that it was probably broken accidentally because billon, a copper-based alloy containing varying amounts of silver, is often very brittle. On the other hand, part of the coin also appears to have been scratched before burial with a pointed tool, perhaps an iron nail, and possibly had been hammered before burial. If this had been in an attempt to puncture it, with the intention of stringing it as a bead, then the breakage also might have been deliberate.

In order to identify the coin, the authors examined it with Richard G. Doty (then of the American Numismatic Society) and three experts in Madrid who are specialists in Spanish coins of the period in question. They are: Antonio Orol Pernas, Juan J. Rodriguez Lorente, and Carlos Castan.

The corrosion is so heavy that at first it was thought an identification would be impossible. Under the microscope, however, several features can be discerned which match features on *blancas* of Henry IV of Castile (1454-74). For comparison, uncorroded specimens of the same coin are illustrated in Figures 7 through 8. Fortunately, certain of the preserved features are unique to *blancas* of Henry's reign, thereby making the identification conclusive. Among these features are squared-off corners of the castle in the upper left quadrant of the coin; a floret near the perimeter at 5 o'clock; the ground line of the castle running horizontally near the bottom; and on the reverse, parts of the lion. In addition, parts of the beaded circular outline on the obverse and straight lines of the lozenge enclosing the lion on the reverse are preserved. Most definitively, traces of some of the lettering on each side are visible, although in some cases only faintly so. Mr. Orol Pernas was able to decipher parts of the legend, which would have read *"ENRICUS DEI GRACIA REX"*, when complete.

The part of the coin where the mint mark should appear (just below the center of the castle) is badly corroded. There is a faint suggestion, however, of the corner of a feature below the ground line. This might be part of a stylized aqueduct, the mint mark for Segovia.

When excavated, a small piece of the coin preserving no diagnostic elements was almost ready to separate from the coin itself. This piece was removed for chemical analysis and lead-isotope determinations. Where it was snipped away, the exposed uncorroded metal has a bright, somewhat brassy, color. The sample was so small that after a portion had been removed for lead isotope analysis, the remaining portion could only be analyzed by the electron microprobe.

An electron microprobe analysis of the coin was carried out by one of the authors (SSCT). Small samples removed from four known billon coins of Henry IV were used as reference standards (4676-79). These had been purchased from the trade for this purpose. Although all came from Henry's reign and all bear known mint marks, none are dated. They were analyzed by a combination of atomic absorption and emission spectrography. The microprobe analysis of the San Salvador coin (4693) is reported in Table 4. For comparison, analyses of ten other *blancas*, and three Henry IV billon coins of higher denominations, all from known mints, were carried out by atomic absorption and emission spectrography (Table 4). It was hoped that the chemical analyses of the additional specimens could be used for identifying the mint in which the San Salvador coin had been struck, but there is only partial correlation between the alloy compositions and mint locations. Nos. 4643 and 4647 both struck in Toledo, have significantly lower silver than the others; 4644 and 4650 (Cuenca) have higher lead; 4646 and 4649 (Segovia and Avila) have higher gold; 4642 and 4648 (Segovia and Burgos) have lower lead; 4645 (Seville) has higher silver. Unfortunately, the gold content of the San Salvador coin is below the limit of detection for the microprobe, so no gold content was available for comparison. Although the data are sparse, the analysis of the San Salvador coin seems to resemble those of the two coins from Segovia and Burgos more closely than the others, mainly on the basis of its rather low lead value.

The analysis confirmed that the San Salvador coin is made of billon and contains 3.97% silver. The silver contents of the comparative *blancas* range from 2.51 to 4.71%. Henry's reign was plagued by severe economic difficulties, but the variability in silver contents does not seem great enough to have come from deliberate debasement. It is more likely to have come from random sources.

The reign of Henry IV extended from 1454 to 1474. He was succeeded by his half sister, Isabella, who married Ferdinand. Because Henry's reign ended eighteen years before Columbus's first landing in 1492, the finding of one of his coins on San Salvador — or anywhere in The New World, for that matter — is at first quite surprising. The coin seems almost too early. However, the *blanca* was a coin of low value and circulated widely for many years, as small change of the times. This particular *blanca* is known to have been issued only between 1471 and 1474. Following Isabella's succession in 1474, no other copper-based coins were issued until the coinage reform of 1497. (Those are much larger in size and cannot be confused with Henry's *blanca.*) Mr. Orol Pernas remarked, "The copper-based coins in the pockets of Christopher Columbus and his crew would be expected to have been *blancas* of Henry IV, just like this one, or else Portuguese *ceities*".

LEAD-ISOTOPE ANALYSES

Isotope analyses of lead extracted from archaeological objects can be used to identify the mining regions from which the lead could or could not have come. The determinations are made by high-accuracy, high-precision mass spectrometry. The resulting ratios can be compared with those for other objects, or galena (lead sulfide) ores from known mining regions.

This, in turn, allows one to learn more about where the objects themselves might have been made.

The method has found widespread and growing application.[28] Its advantages are that only very minute samples need be sacrificed and that the isotope ratios measured for a sample today, regardless of its chemical form or physical condition, are exactly the same as they were when the object was made. The two disadvantages are that while the ratios determined are characteristic of a given mine or mining region, they are not necessarily unique to that region, and also, when leads from different sources are mixed together, the resulting ratios will be somewhere intermediate between those of the starting leads. These two difficulties are called, respectively, overlapping and mixing.

As shown by our preceding chemical analyses, the glass beads from San Salvador, the buckle, the D-ring, the two pottery glazes, and the *blanca* all contain lead. In some cases, for example the glass beads and glazes, the lead was a deliberate addition. In the case of the alloys from which the two buckles were made, we are not sure whether the lead is present as a deliberate addition or as an accidental impurity. The lead in the *blanca*, however, because it is at such a low level (0.09%), must be from an impurity in either the silver (produced by cupellation of lead) or, less likely, the copper, from which the billon was made.

Lead-isotope analyses for all seven San Salvador objects, and for several related objects, were carried out at the National Bureau of Standards by two of the authors (ILB and ECJ). The three specific objectives were:

1. To identify artifacts which were made nearby one another,
2. To verify (based on preceding chemical analyses and examinations) the suspected Spanish origins of the artifacts, and
3. Depending upon the above, to locate, eventually, the regions within Spain where the artifacts are most likely to have been made.

An *a priori* decision was made that if the results for the artifacts turned out to be consistent with the results for the Spanish coins (which certainly contain Iberian lead), then overlapping with other countries on The Continent should not be considered a serious complication.

The data are reported in Table 4. Previous research at the Bureau of Standards, done largely in collaboration with The Corning Museum of Glass, has yielded data on approximately a thousand samples of lead from ancient objects and ores.[29] Figure 10 summarizes the results on several hundred early objects and illustrates that isotope ratios vary widely among objects of different dates and places of manufacture. All the samples analyzed in this study lie close to Group S which contains Spanish lead.[30] That part of the graph is expanded in Figures 11-14. The isotope ratios of the San Salvador and related specimens spread out somewhat, but are clustered together in small groups. These are the kinds of results expected for samples of different materials, made over some period of time, in one general area, but drawing on leads from various mines within that area.

The interpretation of the data is not only complicated in itself, but also very difficult to explain. One of the most salient points, however, can be simply stated: The data are consistent with the hypothesis that all seven of the objects from The Long Bay Site were made in Spain.

In all, 38 samples are involved: 8 from San Salvador, 6 from other New World sites, one from West Africa, 12 Spanish coins, and 11 ores or miscellaneous samples from the Iberian Peninsula. Figure 11 contains the data for the artifacts; Figure 12 the billon coins; Figure 13 the ores and miscellaneous materials. In Figure 14, the data have been divided, somewhat arbitrarily, into groups of samples containing similar leads. These are enclosed in loops labeled I-V. For convenience, the samples are also listed in Table 6 grouped according to their isotope ratios. Proximity in the table corresponds to proximity on the graphs, so that objects close to one another in the listing might very well contain lead from the same mining regions.

Unfortunately, we have at present only a few analyses of Spanish ores for comparison, so it is not yet possible to identify the sources of the lead in the objects very specifically or unambiguously. Nonetheless, it is entirely possible that in some instances those mining regions represented by the few ores already at hand could have provided the lead in certain of the objects.

Some Artifacts: Group II (Figures 11 and 14)

Considering first the artifacts, one group of six forms a rather tight cluster near the lower left of the graph (Group II). All were probably made with lead from a single source. The group includes the two green glass beads from San Salvador (Pb-1485 and 1486), the D-ring (Pb-1493), the excavated *blanca* (Pb-1494), and two of the beads from other sites — a green one from Nueva Cadiz (Pb-1487) and a yellow opaque from Sinu (Pb-1489). Mixed in are three *blancas* and a silver from Almeria (NBS-691). It seems reasonable to infer that in all likelihood these objects were also all manufactured in the same region as one another. Considering that the *blancas* must almost certainly have been made from metals mined in the Iberian Peninsula, we conclude that all of the artifacts were made in Spain. These isotope ratios do not match any of the few Spanish ores we have so far analyzed. They are a very close match, however, for a galena ore from Albergaria-a-Velha, near Aveiro in Portugal (NBS-707). Similar ores must also occur somewhere in Spain, but only future analyses will reveal where.

Some Artifacts: Groups III and IV A (Figures 11 and 14)

Near the center of the graph is another cluster of four artifacts, including the San Salvador bronze buckle (Pb-1492), the green glass bead said to have been found in Peru (Pb-1490). and two *blancas*. These samples resemble two lead ores (one from the Los Belgas Mine) from the Sierra de Gador, just west of the city of Almeria (NBS-681 and 676, Figure 13). It may be significant that the Sierra de Gador is not far from the location of 15th-century glass factories lying somewhat to the north. Close to these samples on the graph is Pb-1491, from a lead pistol ball. This was excavated by Mary Jane Berman at the Three-Dog Site, about 2.7 km south of where the other San Salvador objects were excavated. We conclude that all these excavated objects are of Spanish origin, and could have come from a region making use of lead from the Sierra de Gador. Two other galenas, from Posadas and Granada (NBS-708 and 677, Figure 13) are also quite similar to these objects, but are not quite as close a match as those from the Sierra de Gador. (In particular, it should be added that the isotope analysis proves that the lead in the pistol ball definitely is not an English lead.)

Some Artifacts: Group IV B (Figures 11 and 14)

The leads in the two pottery glazes from San Salvador (Pb-1495 and 1496) are virtually identical to one another, but differ from those in the other San Salvador artifacts. They are quite similar to a galena ore, a metallic lead, and two earthy mineral samples (possibly litharge or jarosite) from the Rio Tinto mining area, and also to a galena ore from the Centenillo Mine, near Linares in the Sierra Morena. Consequently, lacking any further evidence, the sherds might tentatively be attributed to either of these regions. (There may be complications, however, as explained below.) Even though the ratios of these two samples are at the upper range of the ratios for the artifacts in Fig. 11, it can be seen in Fig. 14 that there are three coins having still greater ratios, thus the two San Salvador glazes are bracketed by leads known to have been mined in Spain.

The most significant point concerning the glazes is that these two sherds, which are so different in their outward appearances (one being a honey-glazed terra cotta and the other a lead-tin glazed whitish ware) contain exactly the same kind of lead. This amounts to near-proof that they came from workshops nearby one another, as would be expected for wares taken on board an outgoing vessel just before embarkation. If the lead actually came from the Rio Tinto, located only 70 km from Palos de la Frontera, Columbus's port of embarkation, it is precisely what one would expect to find in the glazed pottery wares with which his ships would have been fitted out. Because this lead is different from that in the glass beads, the beads were possibly not made close to Seville, but came from elsewhere in Spain.

A third pottery sherd, Pb-1499, the Columbia plain ware from Santo Domingo, differs markedly from the two Long Bay sherds, in its lead-isotope composition and, hence, was glazed with lead from some other mine. At present, however, we have no way of telling how close or how far away that other mine might have been. The difference is somewhat surprising. Because the fabric of the Columbia plain ware is so similar to that of the San

Salvador white-glaze ware it had been surmised that they had been made nearby one another. Remarkably, the Columbia plain lead glaze is a near-perfect isotopic match for the two beads, the D-ring, and the *blanca* from Long Bay, all of which lie in Group II. It seems probable that this sherd was glazed with lead from the same source as the leads in those four artifacts. Clearly, it is important that more pieces of Columbia plain ware be analyzed, a project we hope to continue soon.

Another truly intriguing isotopic match is found in the upper right of the graphs. We have begun, but not yet completed, a search for archaeological parallels to the San Salvador beads. To date, aside from the four New World specimens, the only near parallel uncovered is a bead from Igbo-Ukwu in Nigeria.[31] This is a single, very small, wire-wound specimen found among several hundred drawn beads (and much larger wound beads) submitted by Thurstan Shaw for analysis. The date of this bead is uncertain, but it could be from the 15th century. It is yellow opaque and virtually identical in size and appearance to the San Salvador beads. However, it does not have the same unusual high-lead chemical composition. (The bead was not chemically analyzed, but its specific gravity is only 2.6, too low for a PbO content in the 70% range.)[32] Nevertheless, it does contain lead in its yellow opacifier. That lead (Pb-1062) is a very close match for the two San Salvador pottery glaze samples. It is thus reasonable to infer, at least as a working hypothesis, that this yellow opaque bead, traded down the coast of Africa, was probably made in Spain or Portugal, possibly near Seville or the coastal regions to the south, or possibly near the Sierra Morena mountains.

Some Artifacts: Group I (Figures 11 and 14)

The one bead which is out of line with the others, Pb-1488, the green bead said to be from Sinu, falls well to the left of the graph. We had not previously seen leads with these lower ratios in objects or ores from Spain. However, the leads in three *blancas* are close matches to that in the bead. Calling again upon the argument that Spanish coins should be made of metals occurring in the Iberian Peninsula, we should anticipate that future studies will turn up ores with these same isotope ratios somewhere in Spain.

Pb-2220, a small fragment of "*latticinio*" glass excavated at En Bas Saline, also falls in *Group I.* The fragment measures only 1.6 cm in greatest dimension. There is reason to believe that the site is the location of El Navidad, the settlement founded by Columbus after the *Santa Maria* was wrecked on Christmas Eve, 1492. It is extremely difficult to distinguish between complete *latticinio* glasses made in Venice, the Tyrol, the Lowlands, and Spain — and all but impossible (within the framework of our present knowledge) to make a confident attribution for as small a fragment of glass as this, on a stylistic basis. Therefore, the sample was analyzed chemically and for lead-isotope ratios at the request of Kathleen Deagan, the excavator, who will publish a final interpretation.

The lead in the glass matches those in three *blancas*. Thus, the lead-isotope data are consistent with a Spanish attribution for the glass. That, along with the general similarity of its lead-isotope ratios to those of four of the samples from Long Bay (Group II), tends to strengthen the case for the identification of En Bas Saline as the location of El Navidad. Also, the chemical analysis of the glass gives some reason to believe that it differs from the few Venetian *latticinio* glasses we have so far analyzed.

The Coins (Figures 12, 14, and Group V)

In order to understand better the lead-isotope results for the *blanca* excavated at Long Bay (Pb-1494), lead-isotope analyses were also made for twelve of the other billon coins of Henry IV which had been analyzed chemically. Of these, nine are *blancas* struck at known mints and three are of higher-denominations. The results verify again that Spanish leads spread out over a considerable isotopic range. Unfortunately, the ratios do not seem to correlate well with the locations of the six different mints represented, although it is noteworthy that the three higher-denomination coins form a group of their own in the upper right of Figures 12 and 14 (Group V).

The spread in the coin data may have a ready explanation. To begin with, the isotope ratios really serve more as an indicator of the sources of the bullion from which the coins were struck, rather than the mints. Also, as was pointed out above, the lead in the billon coins probably came in as an impurity of the silver component of that alloy. Because it is a precious metal, silver was rarely discarded, as base metals sometimes were, but has always been saved and melted down for reuse. Thus it is to be expected that the interpretation of isotope ratios of lead extracted from silver objects may be subject to mixing complications. Probably the leads at the higher and lower limits of the range are relatively free of mixing and represent ores from specific mining regions, but some of the intermediate ratios could be the results of mixing. Nonetheless, some of the intermediate ratios probably do represent specific mining regions, particularly where they are found to match the lead in other artifacts. The lead in the glasses and bronzes should have been less susceptible to mixing complications because lead would not have been hoarded as scrupulously, and is less likely than silver to have been transported over long distances for reuse.

Concerning Pb-1494, the *blanca* from San Salvador, the lead-isotope data for the other *blancas* do not seem to be very helpful. Its lead is a close match for individual coins struck in Cuenca, Seville, and Segovia (Pb-1450, 1445, and 1442), which are widely separated geographically. However, all could have been struck from alloys prepared with silver bullion from a common source. (As noted above, the chemical analyses suggested a common source with coins struck in Segovia and Burgos.)

What is most significant is that the San Salvador *blanca* is a very close match for the two beads and the D-rings from San Salvador. Find the source for the lead in any one of these, and you might well have found the source for all of them.

Ores (Figures 13 and 14)

As shown in Figure 13, the few Spanish ores and other minerals analyzed so far vary in their isotopic compositions. While sufficient to establish that the San Salvador artifacts were made in Spain, they fall far short of enabling one to pin down reliably locations of the mines which might have supplied the leads in the artifacts. Many more data are needed. Even so, there are some promising prospects. For example, the Sierra de Gador ores resemble the buckle and a bead from Peru, and the Centenillo Mine ore resembles the glazes and the bead from Igbo-Ukwu. However, the latter ore also illustrates the complications of overlapping within Spain, because its ratios are very similar to those of samples from the Rio Tinto, lying, more-or-less, at the other end of the Sierra Morena.

The situation in the Rio Tinto is particularly confusing.[33] There is said not to be much native galena there. It is believed that in Roman times lead used for cupellation had to be brought into the region. For the present, therefore, we have used the term *Rio Tinto* loosely, with the understanding that it refers to the type of lead *in use* at Rio Tinto. If brought in from elsewhere, however, that source was probably not very far away, possibly even as close as Nerva, only a few km away from the main mining, smelting, and cupellation remains at Rio Tinto.

Relationships with Other Leads from the Continent (Table 5)

Up to this point, the interpretation of the data, although complicated, does lead to some very useful results. We are well satisfied that all the San Salvador objects and the other glass beads must have been made in Spain. However, there are other interesting aspects of overlapping which should not be overlooked. Objects from other European contexts are already known which contain leads isotopically similar to those in the San Salvador objects, and still others will undoubtedly come to light. These include some white lead pigments from Italian, Dutch, and Flemish paintings of the 15th century and a few Benin bronzes reported in the literature.[34] At first, these might seem rather startling companions for the San Salvador artifacts, but a moment's reflection suggests plausible explanations.

In the opinion of one of the authors (RHB), many of the Benin bronzes — perhaps more than usually recognized — were made from metals imported into West Africa by Portuguese traders. Hence, the isotope ratios of the lead in those bronzes (and brasses) should match those in ores from Portugal or neighboring Spain. Concerning the Dutch and Flemish white lead pigments, realizing that there are no lead deposits in the Low Countries, it is apparent that either the pigments themselves or the lead to make them must have been imported. Since there were well-established trade and political connections between the Low Countries and Spain at this time, some of that lead could well have come from Spain even though there is evidence that some also came from England.[35] English leads, however, are easily distinguished by their isotope ratios which are different from those discussed here. Interestingly, the two leads in the present study which overlap Group E (the bead from Sinu and the *blanca* minted in Seville) are almost identical to the white lead pigments from six paintings[36] (one Flemish, one Dutch and four Italian.) The Italian paintings date from 1450, 1482, and 1492, while the others are from 1587 and 1651. Taken together, the eight objects constitute a tight cluster lying isolated among a few dozen unrelated ancient objects. We fully expect to locate someday an Iberian lead matching those ratios.

We know there are some ores occurring in Italy which have ratios similar to some of those occurring in Spain. For example, there are ores from Bottino much like those from the Sierra de Gador (Table 5) and we suspect that region might be the source of the white leads in the Italian paintings. As far as the San Salvador artifacts are concerned, the overlapping effect can be disregarded because of a obvious fact stressed previously. The lead in the Spanish coins — whatever the mechanism by which it found its way into the alloys of the coins — is virtually certain to have been mined in Spain. Hence, the close proximity on the graph of the *blanca* Pb-1494 to the other San Salvador objects — the glass beads and the D-ring — points to Spain with equal certainly as being the source of the lead in those San Salvador objects.

Concerning the possibility of mixing, we are inclined to believe it is not a major problem here, because matches with ores have been found for the intermediate groups of three samples; furthermore the group of six samples including the four San Salvador objects are too diverse in character for their isotopic matches to be explained by fortuitous mixing.

CONCLUSIONS

Stylistically, all the artifact evidence seems consistent with Spanish origins and consistent with late-15th or very early 16th-century dates. It is surely significant, too, that the artifacts were found in rather high concentration, archaeologically. The main outcome of the lead-isotope determinations is that the isotopic types of lead found in all seven of the San Salvador artifacts, and in the four beads from Spanish Colonial sites in The New World, are consistent with the hypothesis that these objects were all made in Spain, although possibly in two or three different regions.

Archaeologically, stylistically, and archaeometrically, the San Salvador artifacts form a coherent group — coherent in the sense that there is nothing among them which does not plausibly belong there. This, particularly when coupled with the similarities of the isotope data among such diverse types of objects, suggests that they all found their way to San Salvador on a single voyage. Moreover, the resemblance of the leads in the pottery glazes to Rio Tinto lead suggests the likelihood of that voyage having embarked from southern Spain. Further research on the lead-isotope ratios of Spanish ores and artifacts in the future is likely to allow the wording above to be strengthened into more definitive statements and to specify particular regions of manufacture.

The glass beads are of an unusual type, being wire-wound, in contrast to the more ubiquitous drawn beads of the time. They have a distinctive appearance and an extremely unusual chemical composition, employed for an easily-explained technological reason. Consequently, there is a good chance that further research will reveal just where in the Iberian Peninsula they were made.

The identification of the excavated coin as a *blanca* of Henry IV seems definite. Struck between 1471 and 1474, preceding a hiatus lasting until 1497 during which no other small, low-denomination copper-based coins were minted in Spain, it appears to be precisely one of the types of small change which would have been "carried in the pockets of Columbus or his crew."

The artifacts clearly represent a very early Spanish contact with The New World. Turning to the question of a possible association between the artifacts excavated at The Long Bay Site and the verification of the contention that Columbus's first landing was at San Salvador, it will not have escaped the reader's attention that the objects uncovered correspond very closely to what Columbus is said to have recorded in his journal. The little green and yellow beads fit his descriptions, as do the D-ring and the buckle — at least if a shoe buckle without a tongue is regarded as having been made to serve as a trinket and not to fasten a shoe. (It would be interesting to know if the translation of the rings as being "brass" is strictly accurate — or whether brass and bronze might not then sometimes have been confused for one another in everyday speech — just as they frequently are today by the general public.) The coin, too, is not only of an interesting date, but fits in very well with the *ceitis* and *blancas* mentioned in the journal. Even the small pottery sherds were mentioned — "broken platters and glass." In fact, if an archaeologist started out with a shopping list of what they would hope to find to confirm evidence of Columbus's landing, it would pretty much match what was found at Long Bay. Only the hawk's bell and the red cloth cap are missing.

Until now, the San Salvador artifacts appear to be the only objects excavated anywhere which seem to have a chance of being associated with Columbus's first landing on his first voyage.

It is also worth noting that no records have yet been uncovered of other early visitors to the present San Salvador, except possibly for Ponce de Leon who, in 1513, reported the island to be uninhabited. However, other visitors there must have been — the slavers responsible for the depopulation.[37] Whether or not their visits would have left behind artifact evidence of the sort excavated is open to speculation.

It can be argued that Columbus left similar trinkets on other islands he visited; in fact, he *says* he did. The present day San Salvador could then have been one of his later stops although that would raise objections from other quarters.

Archaeological evidence of the sort discussed here cannot, in itself, be taken as proof that this site was visited by Columbus, because there are other means by which such artifacts as these could have reached Long Bay. Suffice it to mention only one, namely, that even if they had been given by Columbus or his crew to Indians elsewhere, the Indians themselves could have brought the artifacts to Long Bay. Afterall, only three days after his landfall Columbus encountered on open water, an Indian carrying some of the beads and *blancas* he had traded them on Guanahani. The Indians probably moved around a lot more often and more widely than is ordinarily appreciated.

The argument is far stronger, however, in the other direction. To whatever extent one believes, for whatever *independent* reasons, that Columbus made his first landfall on San Salvador, then, to that same extent, one should be entitled to believe that these artifacts probably were actually given or traded to the Indians on that occasion. The archaeological evidence is extremely persuasive as corraborative evidence.

Presumably debate as to where the landfall occurred will continue for some time. For the present, some will choose to base their opinion upon computations of extraordinary precision applied to data of dubious accuracy, some on observational aspects, and others upon archaeological evidence, the interpretation of which is subject to vagaries of its own. Future excavations throughout the Bahamas, whether the results be positive or negative, will surely cast further light on the subject. In any event, no one should lose sight of the fact that after all is said and done, it is *Columbus* who made a great discovery — not those who merely seek to identify where it occurred.

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SAMPLE DESCRIPTIONS

- • indicates chemical analysis completed
- + indicates lead isotope analysis completed
- p indicates some physical properties measured

Glass Beads (San Salvador)

• + p 5710 San Salvador, fragment of glass bead. Bright green transparent glass, heavily pitted, cordy with some spherical seed. Wire-wound, perforation straight-sided. Contains single flake of yellow colorant opacifier. Fragment represents approx. 30% of complete bead, apparently from thinner part. Excavated 6/84. (Same as Pb-1485.)

• + p 5711 San Salvador, fragment of glass bead. Bright green transparent glass, heavily pitted, cordy with some spherical seed. Wire-wound, perforation straight-sided, cords following winding pattern. Fragment represents approx. 40% complete bead. Distorted ring shape; apparent maximum original o.d. 3.5 mm, i.d. 2.5 mm, thickness 1.8 mm. N10 E6, 20-30 cm (27 cm). Excavated 7/83. (Same as Pb-1486.)

5712 San Salvador, glass bead. Bright green transparent glass, heavily pitted, cordy with some spherical seed. Wire-wound, two sharp winding-thread pull-offs, perforation straight-sided, cords following winding pattern. Distorted ring shape; o.d. 2.7-3.3 mm, i.d. 1.5-2.1 mm, thickness 1.2-1.5 mm, N4 E6, 20-30 cm, 7/5/83; SS9, no. 884.

5713 San Salvador, glass bead. Bright green transparent glass, heavily pitted, very cordy with many spherical seed and flake-shaped stone. Wire-wound, one sharp winding-thread pull-off and one firepolished, perforation straight-sided, cords following winding pattern. One large elliptical bubble trapped at original interface with wire and oriented in direction of winding. Nearly circular ring shape; o.d. 2.9-3.1 mm, i.d. 1.6-1.8 mm, thickness 1.0-1.5 mm. N10 E10 10-20 cm, SS-9, no. 318.

5714 San Salvador, glass bead. Bright green transparent glass (stronger but slightly more yellowish than 5712 and 5713), heavily pitted, cordy with some spherical seed, a batch or refractory stone, and three black inclusions, possibly from a metal tool or wire. Wire-wound, two sharp winding-thread pull-offs, perforation straight-sided, cords following winding pattern. Nearly circular ring shape; o.d. 2.4-2.5 mm, i.d. 1.5-1.6 mm, thickness 0.8-1.5 mm, N8 E8 10-20 cm, 6/22/84. Found with shell bead.

5715 San Salvador, glass bead. Bright green transparent glass (more nearly emerald green than others), heavily pitted with some weathering products remaining, cordy with some spherical seeds. Wire-wound, no winding-thread pull-offs evident, perforation straight-sided, cords following winding pattern. One large elliptical bubble trapped at original interface with wire and oriented in direction of winding. Distorted ring shape; o.d. 3.3-3.6 mm, i.d. 2.1-2.3 mm, thickness 1.1-1.3 mm. Ring was broken in distant past, possibly just after manufacture. (Fractured surfaces are weathered.) N6 W12 0-1- cm, 6/20/84; SS-9, no. 292.)

5716 San Salvador, glass bead. Pale yellowish amber transparent glass, heavily pitted, cordy. Wire-wound, cords following winding pattern. Nearly circular ring shape; o.d. 3.2-3.5 mm, i.d. 2.7, thickness 1.0 mm. N8 E6, 20-30 cm, south end, 7/4/83.

Glass Beads (Other)

+ p 5550 Igbo-Ukwu, Nigeria, very small glass bead. Yellow opaque glass, moderately weathered, cordy with many spherical seeds. Wire-wound. o.d. 3.2 mm, i.d. 1.7 mm, thickness 1.5 mm, sp. gr. 2.55. Excavated by Thurstan Shaw; location I-362-R. His type L-3; See: Thurstan Shaw, *Igbo-Ukwu*, vol. 1, Northwestern University Press, Evanston, 1970, plate 5. (Same as Pb-1062.)

• + p 5700 Nueva Cadiz, glass bead, 1515-45. Emerald green glass, little or no weathering, some spherical seed. Wire-wound, one sharp winding-thread pull-off and one firepolished, perforation straight-sided. Somewhat distorted ring shape, o.d. 4.0 mm, i.d. 1.7-2.1, thickness 2.0 mm. Excavated by John Goggin and Jose M. Cruxent in 1954; submitted for analysis by Charles Fairbanks of the University of Florida on Oct. 10, 1972. From Trench 9, section 4-6 m, 0-15 cm depth. (Same as Pb-1487.)

• + 5720 Sinu area, Colombia, fragment of glass bead. Bright green-transparent glass, little or no weathering, some spherical seed. Wire-wound, perforation straight-sided. Fragment represents 40% of complete bead, from a thickened part. Ring-shaped, approximately same size as 5700. Purchased from a dealer, submitted for analysis by Marvin T. Smith (then of the University of Florida) on Dec. 30, 1983. His no. 187. (Same as Pb-1488.)

• + p 5721 Sinu area, Colombia, glass bead. Yellow opaque glass, little or no weathering, large flakes of yellow opacifier. Wire-wound, one winding-thread pull-off lightly ground down, *5721 (cont.)* and one firepolished, perforation straight-sided. Nearly circular ring shape; o.d. 4.0 mm, i.d. 2.0 mm, thickness 1.5-2.0 mm; weight 0.0774 g. Purchased from a dealer, submitted for analysis by Marvin T. Smith (then of the University of Florida) on December 30, 1983. His no. 187. (Same as Pb-1489.)

• + p 5730 Peru, glass bead. Emerald green glass, little or no weathering. Wire-wound, two sharp winding-thread pull-offs, perforation straight-sided. Nearly circular ring shape; o.d. 4.0-4.2 mm, i.d. 2.0 mm, thickness 2.0-3.0 mm; weight 0.1064 g. Purchased from a dealer, submitted for analysis by Marvin T. Smith (then of the University of Florida) on Dec. 30, 1983. His no. 197-3. (Same as Pb-1490.)

Metals, Glass, Ceramics (San Salvador and Elsewhere)

• + 4092 En Bas Saline, near Cap Hatien, Haiti, fragment of "*latticinio*" glass. Colorless glass vessel wall with colorless glass rib containing white opaque (SnO_2) threads, moderately weathered. Excavated by Kathleen Deagan at what might have been the location of Navidad. EBS 1984/Unit 7. 7162/FS #3771. Wall glass is non-lead, but rib glass contains 20.4% PbO. (Same as Pb-2220.)

• + p 4691 San Salvador, bronze "D-ring". Bronze, with greenish gray corrosion patina. Rounded with straight shank. Beveled corners formed by mold seams create diamond-shape cross-sections in most parts; possibly finished by filing. Maximum diameter across rounded portion 3.9 cm, length of straight shank 2.7 cm, thickness varies from 2.5-4.0 mm. (Same as Pb-1493.)

• + p 4692 San Salvador, bronze shoe (?) buckle. Bronze with dark greenish gray corrosion patina. Rounded with single straight overlapping shank and triangular slot. No keep attached, and no wear where it would have been attached at shank. Appears to have been molded and possibly finished by filing. Length across shank 2.0 cm. (Same as Pb-1492.)

• + 4693 San Salvador, coin. Billon *blanca* of Henry IV of Castile (1454-74). Heavily corroded on all surfaces, original struck impressions barely legible in places, possibly deliberately defaced. Segment broken or snipped out before burial. (Same as Pb-1494.)

• 4694 San Salvador, Indian pottery sherd. Rim fragment, reddish-brown, friable, coarse-textured ware with many white inclusions. N4 E6, 20-30 cm.

4695 San Salvador, Indian pottery sherd. Similar to 4694.

4696 San Salvador, Indian pottery sherd. Similar to 4694.

• + 4697 San Salvador, European pottery sherd. Example of *melado* ware. Wall fragment, salmon-colored with honey-colored glaze on one side. Found in same context as Indian wares. N4 E6, 10-20 cm, 6/6/83. (Same as Pb-1495.)

• + 4698 San Salvador, European pottery sherd. White-glazed ware ("majolica"). Small sherd, grayish with thick dull white glaze. Found in same context as Indian wares. N6 E6, 10-20 cm, 6/13/83.(Same as Pb-1496.)

• + 4699 Convent of San Nicolas, Santo Domingo, Dominican Republic, European pottery sherd. Example of Columbia Plain ware. Large fragment of a plate, cream-colored with white enamel glaze. Similar in appearance to 4698. From The Hispanic Society of America, no. LE 1036; Cruxent Donation, 1974. Submitted by Dr. Isadora Rose-de Viejo. An identical plate is illustrated by Goggin, *loc. cit.*, pp. 117-126 and Plate 3. (Same as Pb-1499.)

Castilian Coins

• + 4676 *Cuartillo* (= 4 *dineros*), Enrique IV (1454-74) Castilla y Leon, Toledo mint. Castle in sexfoil; lion in sexfoil. Billon. Purchased from Henry Christensen, Inc., who identified the coin. (Same as Pb-1476.)

• + 4677 Half *cuartillo* (= 2 *dineros*), Enrique IV (1454-74) Castilla y Leon, Toledo mint. Castle in sexfoil; lion in sexfoil. Billon. Purchased as above. (Same as Pb-1477.)

• + 4678 Half *cuartillo* (= 2 *dineros*). Enrique IV (1454-74) Castilla y Leon, Cuenca mint. Castle in sexfoil; lion in sexfoil. Billon. Purchased as above. (Same as Pb-1478.)

• + 4679 *Blanca*, Enrique IV, 1471-74, Castilla y Leon, Seville. Castle in lozenge; lion in lozenge. Billon. Purchased as above. (Same as Pb-1479.)

• + 4742 Same, Segovia. Donated by Antonio Orol Pernas. (Same as Pb-1442.)

• + 4743 Same, Toledo. Donated as above. (Same as Pb-1443.)

• + 4744 Same, Cuenca (?). Donated as above. (Same as Pb-1444.)

• + 4745 Same, Seville. Donated by Carlos Castan. (Same as Pb-1445.)

• + 4746 Same, Segovia. Donated as above. (Same as Pb-1446.)

• + 4747 Same, Toledo. Donated as above. (Same as Pb-1447.)

• + 4748 Same, Burgos. Donated as above. (Same as Pb-1448.)

• + 4749 Same, Avila. Donated as above. (Same as Pb-1449.)

• + 4750 Same, Cuenca. Donated as above. (Same as Pb-1450.)

LEAD ISOTOPE SAMPLES

From San Salvador:	8
Other New World Sites:	6
Spanish Coins:	12
West Africa:	1
Spanish Ores and Slags:	12
S:	denotes San Salvador

	Lead No.	Analytical Sample No.	Brief Description
	Pb-1442	4742	Billon *blanca*, Segovia mint
	Pb-1443	4743	Billon *blanca*, Toledo mint
	Pb-1444	4744	Billon *blanca*, Cuenca mint
	Pb-1445	4745	Billon *blanca*, Seville mint
	Pb-1447	4747	Billon *blanca*, Toledo mint
	Pb-1448	4748	Billon *blanca*, Burgos mint
	Pb-1449	4749	Billon *blanca*, Avila mint
	Pb-1450	4750	Billon *blanca*, Cuenca mint
	Pb-1476	4676	Billon *cuartillo*, Toledo mint
	Pb-1477	4677	Billon half-*cuartillo*, Toledo mint
	Pb-1478	4678	Billon half-*cuartillo*, Cuenca mint
	Pb-1479	4679	Billon *blanca*, Seville mint
S	Pb-1485	5710	Green bead, San Salvador
S	Pb-1486	5711	Green bead, San Salvador
	Pb-1487	5700	Green bead, Nueva Cadiz
	Pb-1488	5720	Green bead, Sinu
	Pb-1489	5721	Yellow bead, Sinu
	Pb-1490	5730	Green bead, Peru
S	Pb-1491	—	Lead pistol ball, San Salvador From Three Dog Site, not Long Bay. Excavated by Mary Jane Berman
S	Pb-1492	4692	Bronze shoe (?) buckle, San Salvador
S	Pb-1493	4691	Bronze D-ring, San Salvador
S	Pb-1494	4693	Billon *blanca*, San Salvador
S	Pb-1495	4697	Honey-glazed ware, San Salvador
S	Pb-1496	4698	White-glazed ware, San Salvador
	Pb-1499	4699	Columbia Plain ware, Santo Domingo
	Pb-1062	5550	Yellow bead, Igbo-Ukwu
	Pb-2220	4092	*Latticinio* glass, En Bas Saline
	Pb-89	—	Rio Tinto, galena
	Pb-847	—	Rio Tinto, metallic lead
	Pb-848	—	Rio Tinto, earthy material
	Pb-849	—	Rio Tinto, earthy material

Lead No.	Analytical Sample No.	Brief Description
NBS-676	—	Almeria, Sierra de Gador, galena
NBS-681	—	Almeria, Los Belgas Mine. Laujar (?). Sierra de Gador, galena
NBS-691	—	Almeria, Frederick Julian Mine, Sierra de Gador, silver
NBS-677	—	Granada, galena
NBS-679	—	Centenillo Mine, Sierra Morena, north of Linares, galena
NBS-708	—	Posadas, Santa Barbara Mine, Cordova, galena
NBS-707	—	Albergaria-a-Velha, nr. Averio, Portugal, galena

NOTES

1. Joseph Judge and James L. Stanfield, "The Island of Landfall," *National Geographic*, 170, 5 (November, 1986), 566-97.

2. Bartolome de Las Casas, *El Libro de la Primera Navegacion*. The manuscript is in the collection of the Biblioteca Nacional, Madrid. Throughout we have quoted English passages as they appear in Samuel Eliot Morison, *Journals and Other Documents on the Life and Voyages of Christopher Columbus*, The Heritage Press, New York, 1963. Morison worked from a photographic copy of the Las Casa manuscript (his p. 47, note 3).

3. There are further entries describing the articles. On October 16th, having proceeded to *Fernandina* he presented each man who visited him with strings of ten or a dozen glass beads, plates of brass, and thongs of leather. On October 21st he mentions trading hawk's bells and glass beads for water, and again on October 22nd hawk's bells and glass beads — this time for gold. On December 12th the Spaniards captured a young woman. He presented her with glass beads, hawk's bells and rings of brass. Again, on December 16th, they met an Indian crossing the open water alone in a canoe. They presented him with glass beads, hawk's bells and brass rings. On December 17th, in Hispaniola, they bought pieces of gold beaten into thin plates, for strings of beads, and on December 21st, gave presents of the same three items, glass beads, hawk's bells, and brass rings, in appreciation of a gift of parrots and other things. On December 22nd, Columbus criticized the greed of his Spanish crew and praised the generosity of the Indians. He mentions the barter of a piece of gold for half a dozen strings of beads. On January 14th, shortly before departing for home, they still had some trinkets left, for he recorded presenting an Indian with a red cap, some beads, and red cloth. References in Columbus's later voyages indicate that the hawk's bells were much more highly prized by the Indians than glass beads. On his fourth voyage, while stranded in Jamaica (July 1503), it is remarked "...if they brought rounds of the bread which they call *cassava*, made with the grated roots of a plant, we gave them two or three green or yellow rosary beads; if they brought a large quantity of anything, they got a hawk's bell;..."

4. Van Wyck Brooks, *Christopher Columbus, Journal of First Voyage to America*. New York: Albert and Charles Boni, 1924, p. vi.

5. Apparently Columbus was on one or two Portuguese voyages to Sao Jorge da Mina between 1482 and 1484. Samuel Eliot Morison, *Admiral of the Ocean Sea, A Life of Christopher Columbus*. Boston: Little, Brown and Co., 1942, pp. 40-42. Portuguese trade, including reference to glass beads, is described in A. F. C. Ryder, *Benin and the Europeans 1848-1897*, New York: Humanities Press, 1969, pp. 37, 40, *passim*.

6. See also: Charles A. Hoffman, "Bahama Prehistory: Cultural Adaptation to an Island Environment," (Ph.D. dissertation, University of Arizona, 1967); also, Charles A. Hoffman, "The Palmetto Grove Site on San Salvador,

Bahamas," *Contributions of the Florida State Museum, Social Sciences*, no. 19, Gainesville: Florida State Museum, 1970. The site bears the designation SS-9 and has sometimes also been called The John Winter Site. The excavation was conducted under the auspices of the College Center of the Finger Lakes Bahamian Field Station in cooperation with the Ministry of Education and Culture of the Bahamas.

7. John Winter, *Archaeological Site Reconnaissance on San Salvador, 1980. Bahamas Archaeology Project Report*, San Salvador, Bahamas: College Center of the Finger Lakes' Bahamian Field Station, 1980. See also similar reports for 1981 and 1982 surveys.

8. A preliminary account of some of the laboratory investigations was presented at the Tenth Congress of The International Association for the History of Glass, in Madrid, September 24, 1985.

9. Marvin T. Smith and Mary Elizabeth Good, *Early Sixteenth Century Glass Beads in the Spanish Colonial Trade*, Greenwood, Mississippi: Cottonlandia Museum Publications, 1982.

10. There is a typographical error in Chapter III, on page 3, where these varieties are discussed in connection with Columbus's journal. Variety VI is clearly intended where the text says variety IV.

11. We dislike using *perforation*, which seems to imply a drilling operation, but that term appears to have become standard useage among many bead people.

12. There are exceptions, a group of Islamic cameo glasses and some deep-cut glasses from Serce Liman. All date probably from the 11th and 12th centuries. This group of glasses, numbering fewer than a dozen at present, are probably not related to the beads under study here. However, there might have been an indirect technological relationship. See: I. Lynus Barnes, Robert H. Brill, Emile C. Deal, and G. Venetia Piercy, "Lead Isotope Studies of Some of the Finds from the Serce Liman Shipwreck." (In press). Justine Bailey, by personal communication, has told us she has found a similarly high lead content in a Viking bead excavated at York. In his *L'Arte Vetraria*, published in Florence in 1612, Antonio Neri gives batches for several emerald green glasses for use as artificial gems. They are lead-silicas with high lead contents colored with calcined brass.

13. J. W. H. Schreurs and R. H. Brill, "Iron and sulfur related colors in ancient glasses," *Archaeometry*, 26, 2 (1984), pp. 199-209. The high-lead copper green has been duplicated in the laboratory of The Corning Museum of Glass.

14. Robert H. Brill, "The Scientific Investigation of Ancient Glasses," *Proceedings of the VIIIth International Congress on Glass, London,* Sheffield, England: The Society of Glass Technology, 1968, pp. 47-68.

15. Unpublished analyses by The Corning Museum of Glass.

16. For a similar calculation see: Robert H. Brill, "Scientific Investigations of the Jalame Glass and Related Finds," in G. D. Weinberg's forthcoming book on the Jalame excavations.

17. In Roman times, we believe volume measurements were often used. See preceding note.

18. For example, see the following, which report compositions for brasses from elsewhere in Europe: H. K. Cameron, "Technical Aspects of Medieaval Monumental Brasses," *The Archaeological Journal*, 131, 1974, pp. 215-237 and O. Werner, "Analysen Mittelalterlicher Bronzen und Messinge, II and III," *Archaologie und Naturwissenschaften*, 2, 1981.

19. Luis Monreal and Jaume Barrachina, *El Castell De Llinars Del Valles*, Publicacions de l'Abadia de Montserrat, 1983.

20. *Ibid.*, p. 259, no. 4, and object 1058 in Plate 115.

21. *D-ring* might not be a legitimate historical term, but it conveys the shape of the object very well.

22. Bernardo Vega, "Metals and the Aborigenes (sic) of Hispaniola." *Proceedings of the Eighth International Congress for the Study of The Pre-Columbian Cultures of the Lesser Antilles*, Anthropological Research Papers No. 22, Arizona State University, Tempe, 1980, pp. 488-497.

23. George Reilly and Janice Carlson of the Winterthur Museum Laboratory carried out this completely nondestructive, nonsampling analysis.

24. A sample of the local Indian palmetto ware (4694) was analyzed by atomic absorption and emission spectrography. The analysis showed that the fabric contains an extraordinarily high lime content (43.2% as $CaCO_3$) owing to the presence of shell temper. Thermoluminescence dating was attempted for four sherds of this pottery, and one of the *melado* ware, but the results were erratic and must be checked.

25. John M. Goggin, *Spanish Majolica in The New World*, Yale University Publications in Anthropology, No. 72, New Haven, 1968, pp. 117-126.

26. Goggin, *op. cit.*, plate 3 a & b.

27. J. S. Olin, G. Harbottle, and E. V. Sayre, "Elemental Compositions of Spanish and Spanish-Colonial Majolica Ceramics in the Identification of Provenience" in *Archaeological Chemistry II*, Advances in Chemistry Series 171. Edited by Giles F. Carter. Washington: American Chemical Society, 1978, pp. 200-229; M. Maggetti, H. Westly, and J. S. Olin, "Provenance and Technical Studies of Mexican Majolica Using Elemental and Phase Analysis" in *Acbaeological Chemistry III*, Advances in Chemistry Series 205. Edited by J. B. Lambert. Washington: American Chemical Society, 1984, pp. 151-191.

28. For example, see: Robert H. Brill and J. M. Wampler, "Isotope Ratios in Archaeological Objects of Lead," *Application of Science in Examination of Works of Art*, Boston: Museum of Fine Arts, 1965, pp. 155-166. Robert H. Brill, "Lead Isotopes in Ancient Glass," *Proceedings of the IVth International Congress on Glass, Ravenne-Venise,* Liege: International Congress on Glass, 1969, pp. 255-261. Robert H. Brill, "Lead and Oxygen Isotopes in Ancient Objects," *The Impact of the Natural Sciences on Archaeology*, London: The British Academy, 1970, pp. 143-164, and Robert H. Brill and William R. Shields, "Lead Isotopes in Ancient Coins," *Special Publication No. 8*, Royal Numismatic Society, Oxford: University Press, 1972, pp. 279-303.

29. The program is currently funded in part by the Conservation Analytical Laboratory of the Smithsonian Institution.

30. For convenience lead-isotope data were summarized in our earlier publications as Groups L, X, E, and S. Group S contained leads from Spain, Wales, and Sardinia; Group E from England, Italy, and Turkey; Group L from Laurion in Greece.

31. Thurstan Shaw, *Igbo-Ukwu*, vol. 1, Evanston: Northwestern University Press, 1970.

32. Note added in proof: An electron microprobe analysis shows that the bead is made of a soda-lime glass, made with plant ash, colored with lead antimonate, and contains 4.05% PbO.

33. Beno Rothenberg, personal communication.

34. Candice L. Goucher, Jehanne H. Teilhet, Kent R. Wilson, Tsaihwa J. Chow, "Lead isotope studies of metal sources for ancient Nigerian 'bronzes'," *Nature*, 262, no. 5564, 1976, pp. 130-131.

35. Unpublished analyses of the National Bureau of Standards and The Corning Museum of Glass. Isabella herself was a patron of Dutch and Flemish painters, who might have either painted in Spain or used white lead pigments prepared from Spanish lead.

36. Unpublished analyses from the National Bureau of Standards and The Corning Museum of Glass.

37. The heaviest slaving raids took place in 1509-1512 throughout the Lucayas in general. See C. O. Sauer, *The Early Spanish Main*, Berkeley: University of California Press, 1966, pp. 159-60. Ponce de Leon must have been one of the last of the earlier explorers to visit San Salvador itself. He was there in 1513, at which time the island is generally thought to have been uninhabited.

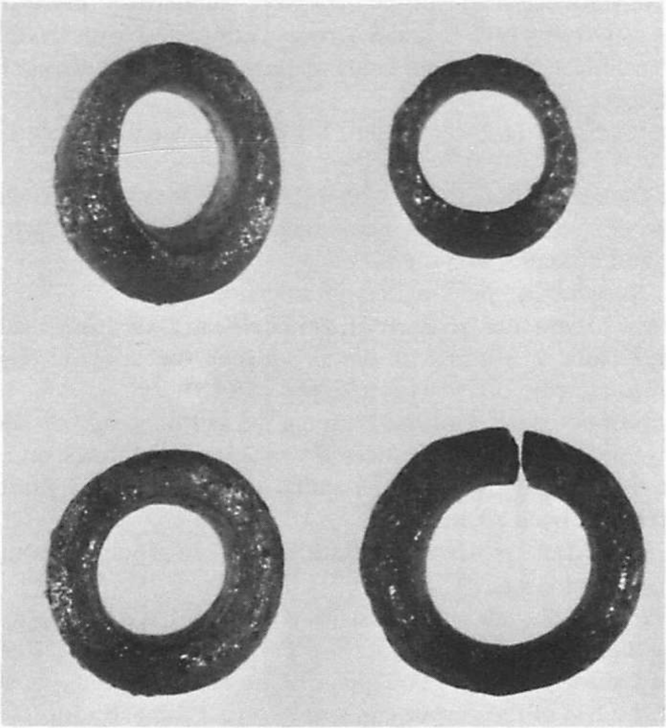

Fig. 1. Four bright green transparent glass beads from San Salvador. From top left to lower right: nos. 5712, 5714, 5713, and 5715. Diameter (horizontal) of 5715 is 3.6 mm.

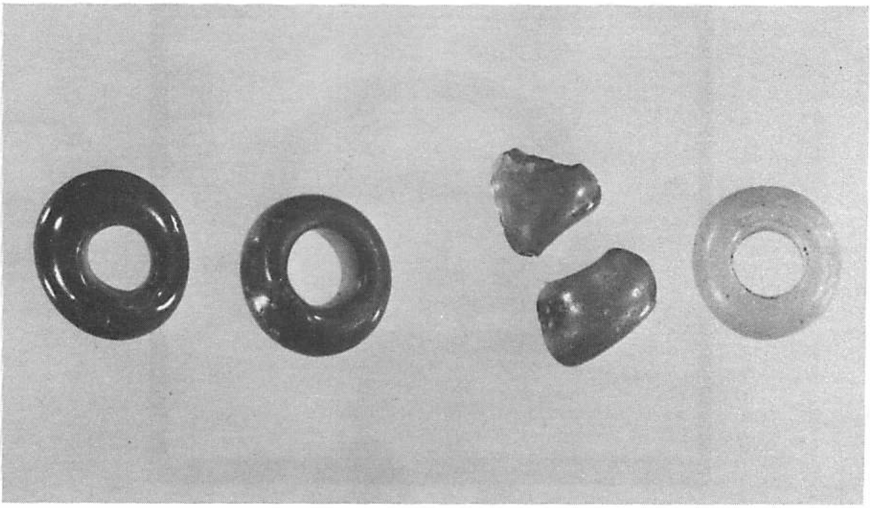

Fig. 2. Glass beads from various sources. From left to right: no. 5700 (Nueva Cadiz, emerald green), 5730 (Peru, emerald green), 5720 (Sinu, bright green transparent, two fragments), and 5721 (Sinu, yellow opaque). Diameter of 5700 is 4.0 mm.

Fig. 3. Bronze buckle from San Salvador. No. 4692 (Pb-1492). Length of shank 2.0 cm.

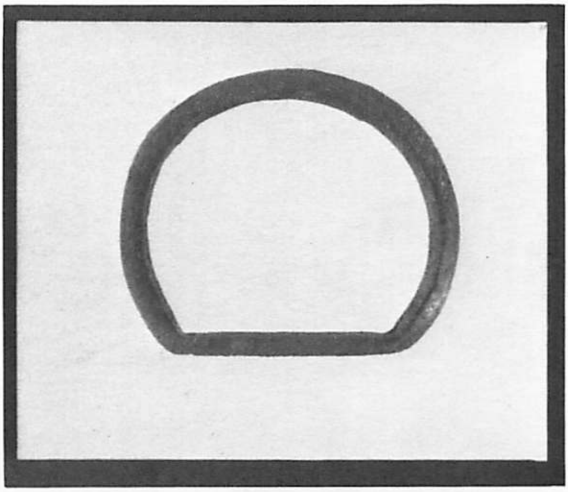

Fig. 4. Bronze D-ring from San Salvador. No. 4691 (Pb-1493). Length of shank 2.7 cm.

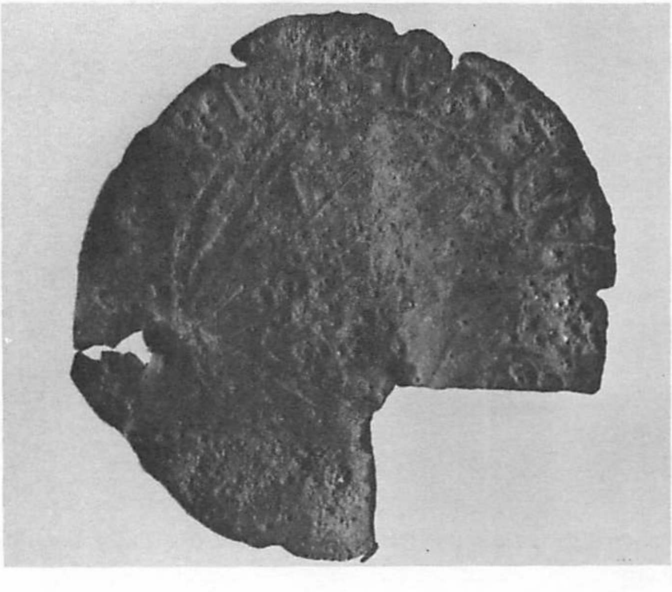

Fig. 5. *Blanca* of Henry IV of Castile (1454-1474) from San Salvador. No. 4693 (Pb-1494). Obverse. Diameter 2.3 cm., thickness (near apex of breakage) 0.20-0.25 mm.

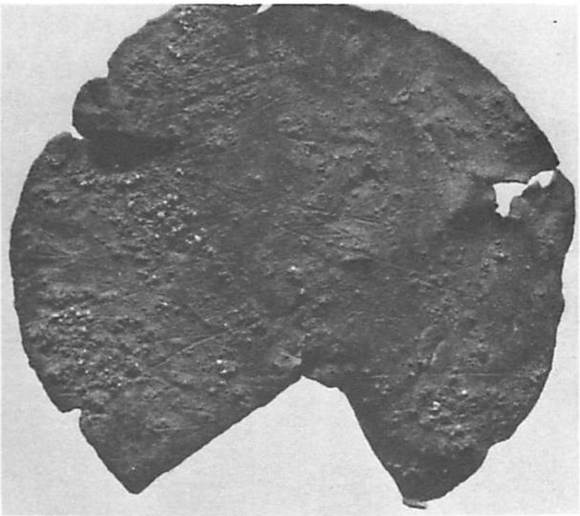

Fig. 6. Same as Figure 5. Reverse.

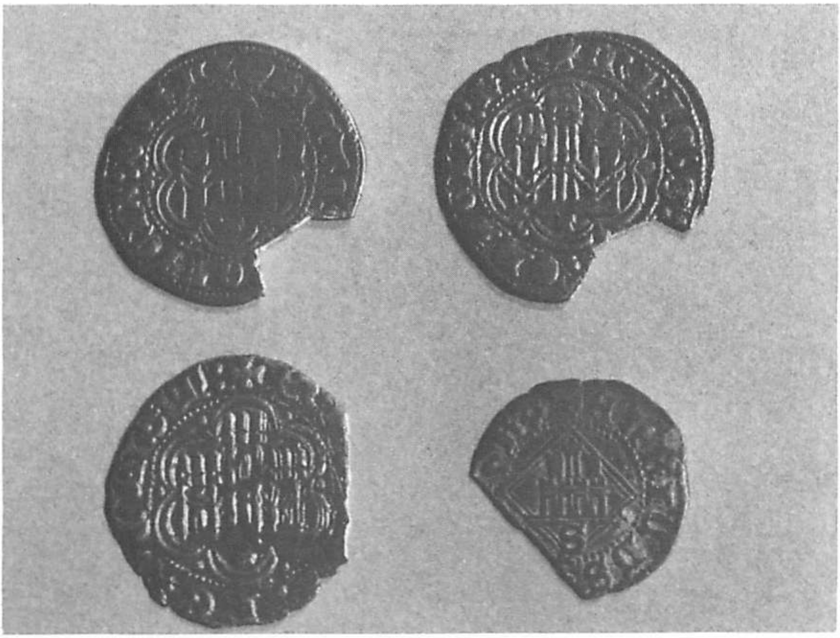

Fig. 7. Group of billon coins of Henry IV purchased for comparison with No. 4693. From top left to lower right: nos. 4676 (*cuartillo*, Toledo), 4677 (half-*cuartillo*, Toledo), 4678 (half-*cuartillo* Cuenca), and 4679 (Pb-1479) (*blanca*, Seville). Obverse.

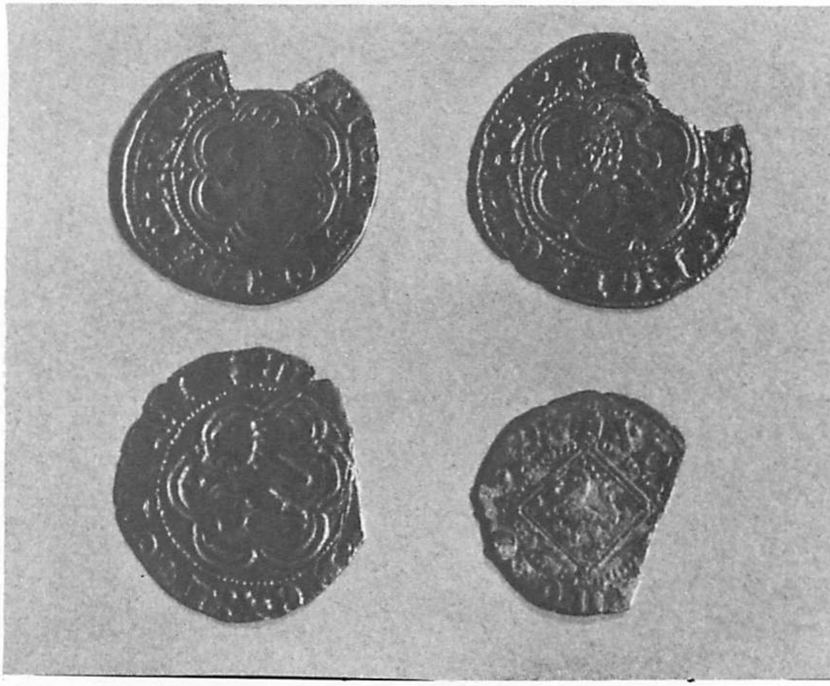

Fig. 8. Same as Figure 7. Reverse.

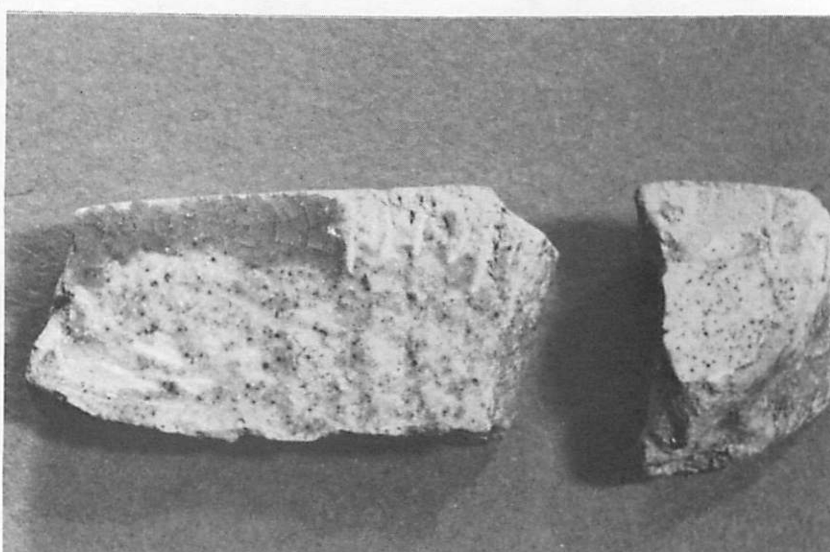

Fig. 9. Two pottery sherds from San Salvador. Left: no. 4697, *melado* ware, with some lead glaze chipped away. Right: no. 4698, white-glazed or "majolica" (?) ware. (Left edge of 4698 measures 1.1 cm.)

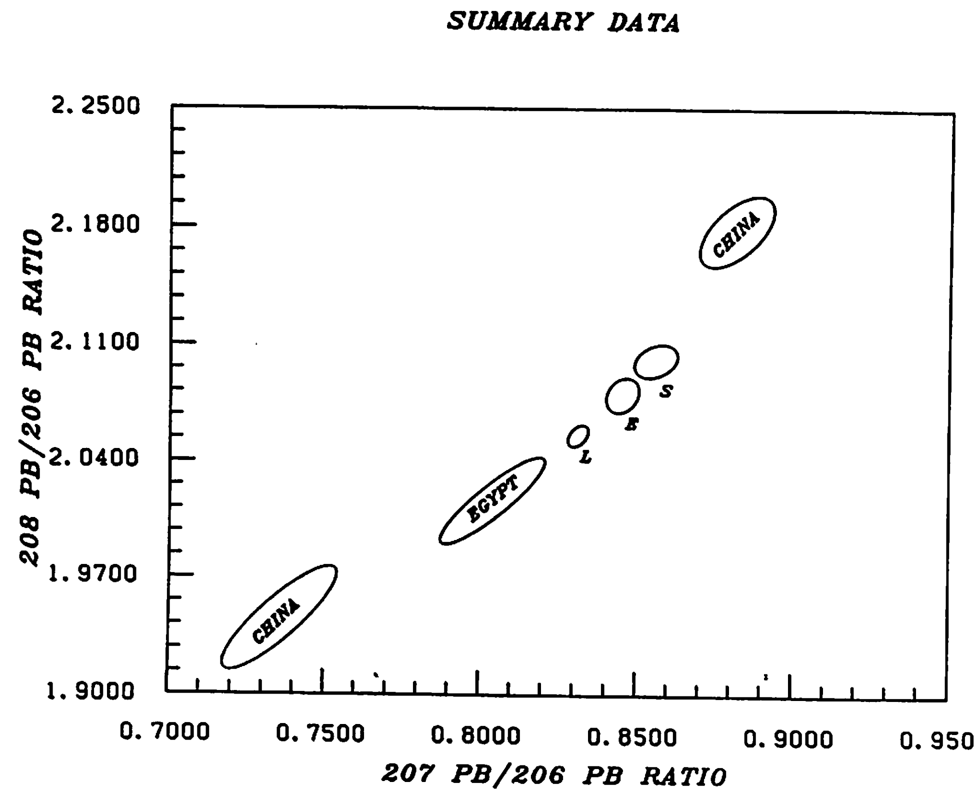

Fig. 10. Summary of lead-isotope ratios for several hundred objects of diverse materials, dates, and proveniences. The leads from the seven San Salvador artifacts all fall in Group S, which is known to contain leads from Spain.

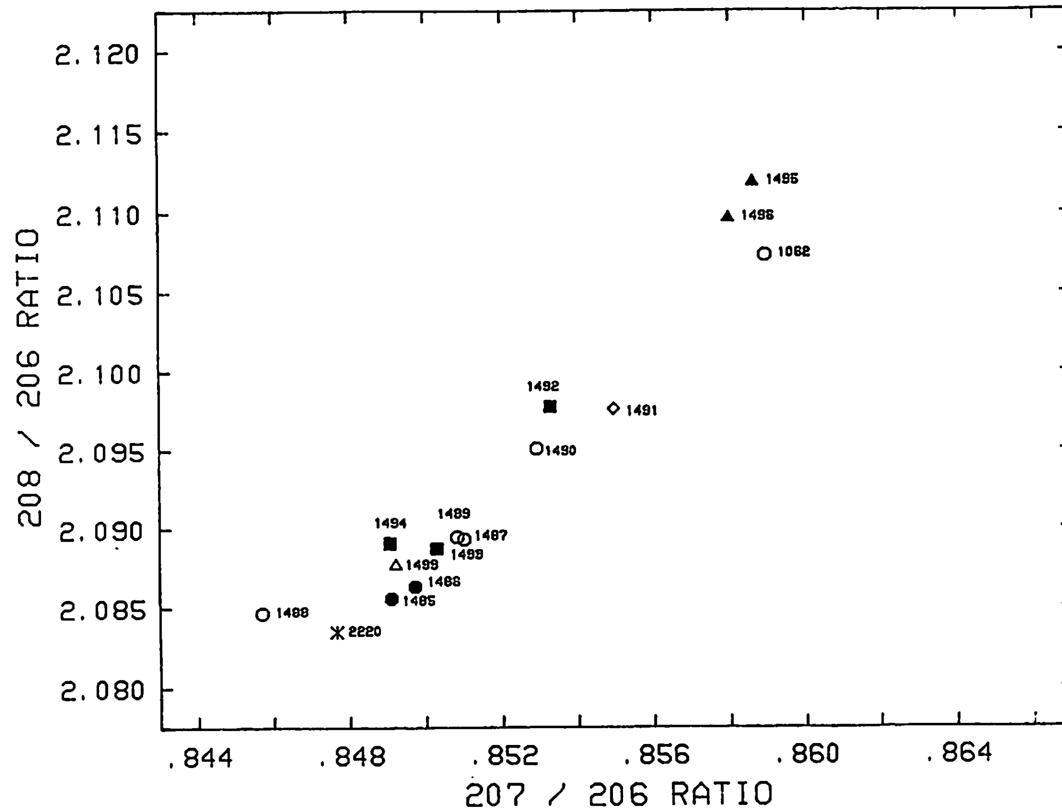

Fig. 11. Lead-isotope ratios of artifacts in this study. Solid symbols are from San Salvador, open symbols from elsewhere. Circles indicate glass; squares metals; triangles glazes; diamond lead metal; * *latticinio* glass.

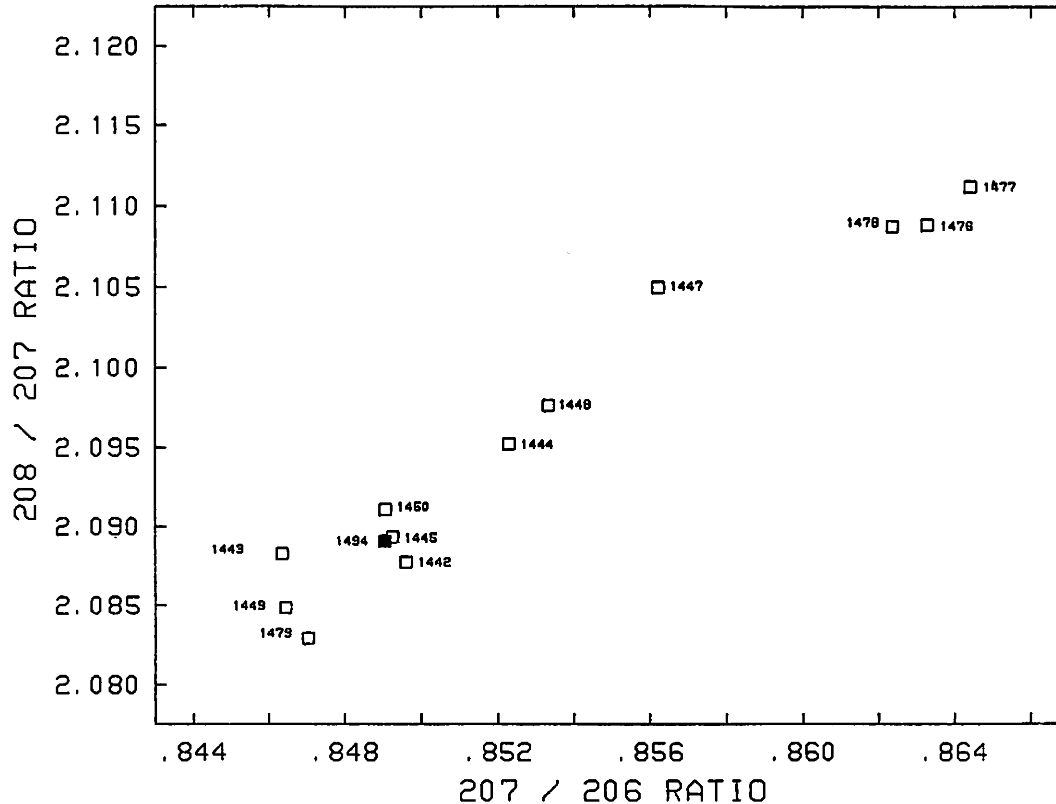

Fig. 12. Lead-isotope ratios of Spanish billon coins of Henry IV of Castile. All except three in upper right are *blancas* minted between 1471-74. Three in upper right are higher denominations. Shaded square is *blanca* from San Salvador.

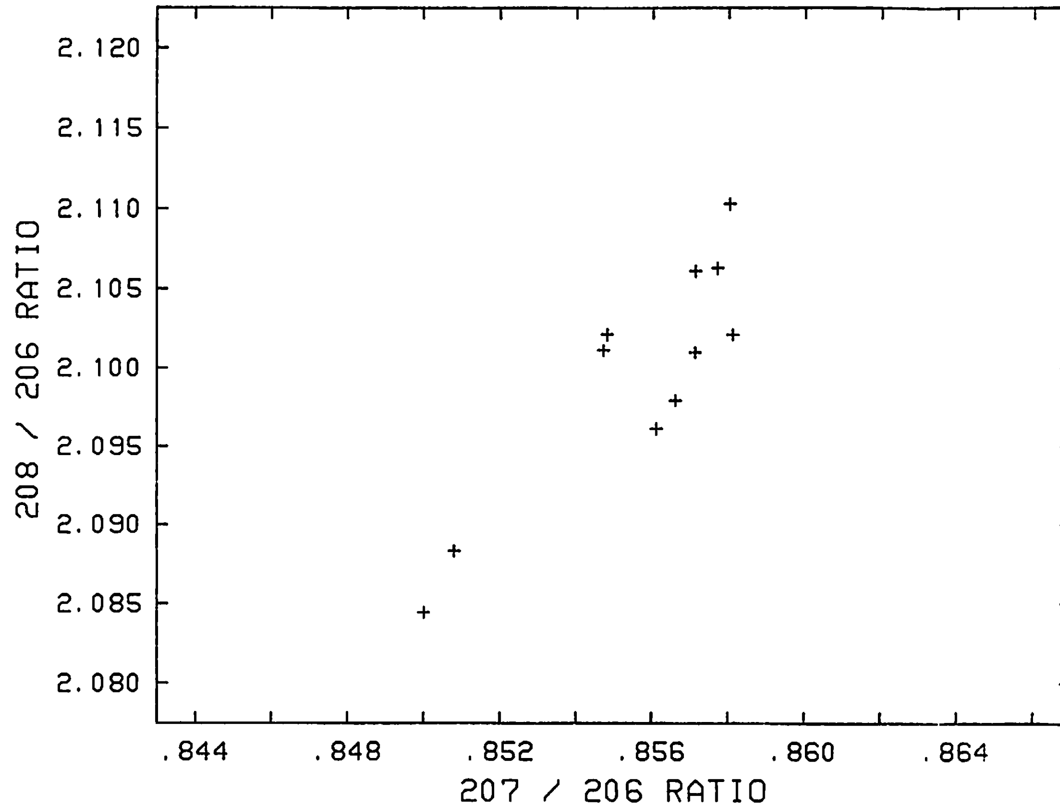

Fig. 13. Lead-isotope ratios of ores and miscellaneous minerals from Spain.

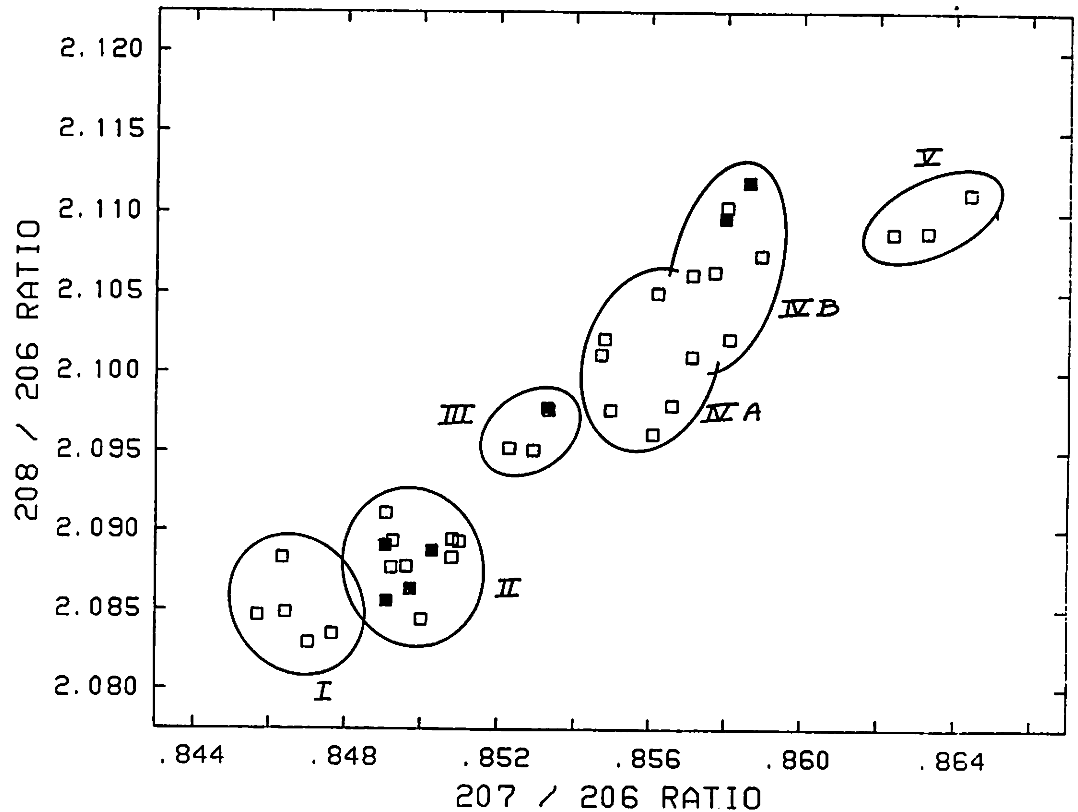

Fig. 14. Groupings of all samples in this study irrespective of materials, dates, and origins. Samples within each group might contain lead from a single mine or mining region.

Table 1
Summary of Artifact Analyses

Sample Numbers	Material	Source	Chemical Analysis and Method	Lead Isotope Determination	Physical Properties
5710, Pb-1485	grn. glass	San Sal.	e	+	n
5711, Pb-1486	grn. glass	San Sal.	e	+	n
5700, Pb-1487	grn. glass	Nueva Cadiz	a	+	s
5730, Pb-1490	grn. glass	Peru	a	+	s
5720, Pb-1488	grn. glass	Sinu	a	+	
5721, Pb-1489	ylw. opq. glass	Sinu	a	+	s
5550, Pb-1062	ylw. opq. glass	Igbo-Ukwu		+	s
4092, Pb-2220	latticinio glass	En Bas Saline	e	+	
4692, Pb-1492	bronze	San Sal.	x	+	s
4691, Pb-1493	bronze	San Sal.	a	+	s
4693, Pb-1494	blanca	San Sal.	e	+	
4697, Pb-1495	glaze	San Sal.	e	+	p
4698, Pb-1496	glaze	San Sal.	e	+	p
4699, Pb-1499	glaze	Santo Domingo	x	+	p
— Pb-1491	lead	3-dog		+	
4694 —	pottery	San Sal.	a		
4676-79, Pb-1476-79	4 coins	Toledo, Cuenca	a	+	
4742-50, Pb-1442-50	9 blancas	Various mints	a	+	(except Pb-1446)

e - electron microprobe
a - atomic absorption and emission spectrography
x - x-ray fluorescence
+ - completed
s - specific gravity
n - refractive index
p - petrography

Table 2
Chemical Analyses of Glass Beads

	San Salvador* br. green 5710	San Salvador* br. green 5711	Nueva Cadiz** em. green 5700	Peru** em. green 5730	Sinu** br. green 5720	Sinu** ylw. opq. 5721
SiO_2	26.7	27.4	19.5	27.5	27.2	20.6
Na_2O	0.01	0.01	1.85	1.32	1.09	2.27
CaO	0.05	0.09	0.063	0.50	0.12	0.12
K_2O	0.14	0.19	0.26	1.15	0.21	0.96
MgO	0.05	0.02	0.50	0.53	0.28	0.61
Al_2O_3	0.40	0.42	1.76	0.60	0.98	1.64
Fe_2O_3	0.47	0.67	0.30	0.21	0.24	0.36
TiO_2	0.05	0.06	0.03	0.03	0.03	0.03
Sb_2O_5	0.05	0.05	0.05	nf	0.03	0.08
MnO	—	—	0.001	0.005	0.005	0.001
CuO	0.51	0.53	0.60	0.60	0.50	0.10
CoO	—	—	nf	nf	nf	nf
SnO_2	—	—	0.03	0.01	0.01	0.77
Ag_2O	—	—	0.008	0.005	0.001	0.001
PbO	72.6	70.9	74.9	67.4	69.2	72.3
B_2O_3	—	—	nf	nf	nf	nf
V_2O_5	—	—	nf	nf	nf	nf
Cr_2O_3	—	—	0.01	0.01	0.01	0.01
NiO	—	—	nf	nf	nf	nf
ZnO	0.07	0.18	0.20	0.17	0.12	0.019
ZrO_2	—	—	nf	nf	nf	nf
Bi_2O_3	—	—	nf	nf	nf	0.15
Sum	101.0	100.5	—	—	—	—
Specific gravity	—	—	5.30	4.77	—	4.96
Refractive index	1.80	1.80	—	—	—	—

* Electron microprobe analyses by Stephen S.C. Tong of Corning Glass Works.

** Combined atomic absorption and emission spectrographic analyses by Brant Rising and Rolando Gonzales of Lucius Pitkin, Inc., New York City. SiO_2 estimated by difference from 100% on these samples.

Na_2O values probably low on microprobe analyses.

nf Sought but not found.

— Not sought.

Physical properties by Joseph Giardina and Dirk Sears of Corning Glass Works.

Table 3
Chemical Analyses of Metallic Objects

	San Salvador			Castilian Coins of Henry IV					
	D-ring* 4691	Buckle** 4692	Blanca† 4693	Ten blancas* mean ± 90% conf. limits			Three higher denominations* mean ± 90% conf. limits		
Copper	∿90	94	95.7 ± 0.59	--	95.4	--	∿86	89.0	∿92
Silver	nf	0.2	3.78 ± 0.79	2.3	3.41	4.5	6.8	10.1	13.3
Lead	4.98	1.5	0.13 ± 0.08	0.28	0.76	1.2	0.26	0.36	0.46
Tin	2.5	2.5	<0.01	--	0.015	0.04	0.08	0.09	0.10
Antimony	1.34	0.2	0.15 ± 0.04	0.02	0.12	0.22	0.22	0.30	0.38
Nickel	0.26	nf	0.09 ± 0.06	0.002	0.11	0.22	0.01	0.093	0.17
Manganese	--	trace	--	--	0.005	--	--	--	--
Iron	0.58	trace	0.05 ± 0.04	0.004	0.014	0.02	0.01	0.02	0.03
Bismuth	--	--	--	0.006	0.016	0.03	--	0.06	--
Arsenic	--	0.3	--	--	--	--	--	--	--
Magnesium	--	--	--	--	<0.01	--	--	--	--
Gold	--	--	--	0.01	0.03	0.05	--	0.01	--
Silicon	--	--	--	0.02	0.12	0.20	--	--	--
Sum	99.7	98.7	99.90	--	100.0	--			
Sp. gravity	8.20	8.43	--		--			--	

-- Not sought.
* Atomic absorption and emission spectrography by Brant Rising and Rolando Gonzales, Lucius Pitkin, Inc.
** X-ray fluorescence by George J. Reilly and Janice H. Carlson, the Winterthur Museum Laboratory.
† Electron microprobe by Stephen S.C. Tong, Corning Glass Works.
Also sought but not found: Zn, V, Cr, Mo, Cd, In, Be, Ga, Ge, Co, P, B.
90% confidence limits = ± 1.69 x std. dev.

Table 4
Lead-Isotope Ratios

Sample No.	NBS No.	$^{208}Pb/^{206}Pb$	$^{207}Pb/^{206}Pb$	$^{204}Pb/^{206}Pb$
Pb- 89	401	2.1021	0.8581	0.05484
Pb- 847	1701	2.10611	0.85712	0.054862
Pb- 848	1702	2.11032	0.85802	0.055019
Pb- 849	1703	2.10097	0.85711	0.054932
Pb-1062	1528	2.10733	0.85892	0.055106
Pb-1442	1674	2.08773	0.84960	0.054433
Pb-1443	1675	2.08827	0.84634	0.054043
Pb-1444	1676	2.09520	0.85228	0.054478
Pb-1445	1677	2.08932	0.84924	0.054329
Pb-1447	1679	2.10496	0.85621	0.054822
Pb-1448	1680	2.09761	0.85331	0.054515
Pb-1449	1681	2.08483	0.84643	0.054122
Pb-1450	1682	2.09106	0.84906	0.054278
Pb-1476	1522	2.10880	0.86328	0.055269
Pb-1477	1523	2.11115	0.86440	0.055312
Pb-1478	1524	2.10870	0.86237	0.055133
Pb-1479	1525	2.08290	0.84703	0.054150
Pb-1485	1387	2.08556	0.84909	0.054402
Pb-1486	1380	2.08632	0.84971	0.054440
Pb-1487	1381	2.08930	0.85099	0.054443
Pb-1488	1382	2.08464	0.84569	0.054030
Pb-1489	1383	2.08944	0.85081	0.054344
Pb-1490	1384	2.09508	0.85291	0.054515
Pb-1491	1385	2.09761	0.85497	0.054639
Pb-1492	1264	2.09776	0.85327	0.054530
Pb-1493	1521	2.08872	0.85028	0.054422
Pb-1494	1386	2.08906	0.84905	0.054201
Pb-1495	1526	2.11184	0.85860	0.055040
Pb-1496	1527	2.10963	0.85797	0.055084
Pb-1499	1683	2.08766	0.84920	0.054368
Pb-2220	1725	2.08346	0.84765	0.054271
--	676	2.1021	0.8548	0.05458
--	677	2.0979	0.8566	0.05496
--	679	2.1063	0.8577	0.05482
--	681	2.1011	0.8547	0.05453
--	691	2.0844	0.8500	0.05673
--	707	2.0883	0.8508	0.05440
--	708	2.0961	0.8561	0.05491

Table 5
Nearest Neighbors in Lead-Isotope Ratios
(Listed in approximate order of increasing values)

Group in Figure	Sample No.	Descriptions, sources	Other leads
I	Pb-1488	Bead, Sinu	Borderline English leads
	1443	Blanca, Toledo	7 Italian, Dutch, and
	1449	Blanca, Avila	Flemish paintings
	1479	Blanca, Seville	
	2220	Latticinio, En Bas Saline	
	*		
II	Pb-1450	Blanca, Cuenca	
	1445	Blanca, Seville	
	1494	Blanca, San Salvador	
	1499	Glaze, Santo Domingo	
	1485	Bead, San Salvador	
	1486	Bead, San Salvador	
	1442	Blanca, Segovia	
	NBS-691	Silver, Almeria	
	1493	D-ring, San Salvador	
	1489	Bead, Sinu	
	1487	Bead, Nueva Cadiz	
	NBS-707	Galena, Albergaria (Port.)	
	*		Lead, Roman, Carteia
III	Pb-1444	Blanca, Cuenca	Italian painting
	1490	Bead, Peru	Jarosite, Rio Tinto
	1492	Buckle, San Salvador	(Ref. .)
	1448	Blanca, Burgos	Lead, Roman, Majorca
	*(?)		
	Pb-1491	Pistol ball, Three-Dog	Italian painting
	*(?)		Italian painting
IV A	NBS-681	Galena, nr. Almeria, Sierra de Gador	Galena, Bottino (Italy)
	NBS-676	Galena, Sierra de Gador	Lead, Roman, Carteia
	NBS-708	Galena, Posadas, Cordova	
	NBS-677	Galena, nr. Granada	
	849	Earthy material, Rio Tinto	3 leads, Roman, Coimbriga
	89	Galena, Rio Tinto	
IV B	1447	Blanca, Toledo	
	847	Lead, Rio Tinto	
	NBS-679	Galena, nr. Linares, Sierra Morena	
	848	Earthy material, Rio Tinto	
	1496	Glaze, San Salvador	
	1495	Glaze, San Salvador	
	1062	Bead, Igbo-Ukwu	
	——		
V	Pb-1478	Half cuartillo, Cuenca	
	1476	Cuartillo, Toledo	
	1477	Half cuartillo, Toledo	

* Small, but significant difference
—— Distinct difference

Note: Other leads include unpublished NBS-CMG analyses some of which were run several years ago and therefore are not known for certain to be in calibration with current analyses. These samples are not plotted in Figure 13.