Lawrence Berkeley National Laboratory

Recent Work

Title

CHEMICAL STUDY OF THE PLATE OF BRASS

Permalink

<https://escholarship.org/uc/item/31t2c8wk>

Author

Michel, Helen V.

Publication Date

1977-07-01

W W W W 44 78 03 03 03 03

UC-13 and UC-4

To be submitted for publication

LBL-6338
Preprint ^{c-1}

RECEIVED
LIBRARY
BERKELEY LABORATORY
MAR 30 1978
LIBRARY AND
DOCUMENTS SECTION

For Reference
Not to be taken from this room

Energy and Environment Division

Chemical Study Of The Plate Of Brass

Helen V. Michel and Frank Asaro

July 27, 1977

Lawrence Berkeley Laboratory University of California/Berkeley
Prepared for the U.S. Energy Research and Development Administration under Contract No. W-7405-ENG-48

LBL-6338
c-1

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

00004700304

To be published as LBL-6338

Chemical Study of the
Plate of Brass

Helen V. Michel and Frank Asaro

Abstract

The Plate of Brass is an inscribed brass artifact which has been attributed to the landing of Francis Drake on the California coast in 1579 A.D. In the present study the chemical abundances of the major and trace constituents in the Plate of Brass were quantitatively measured. These values were compared with measurements on both medieval and modern brasses and with the levels of impurities expected in brass making processes from medieval times to the present. This study indicates the Plate of Brass was made in the XVIII to XX centuries and suggests the most probable period was the early part of the XX or the latter part of the XIX centuries.

This work was done with support from the U.S.
Energy Research and Development Administration.

Chemical Study of the Plate of Brass

Helen V. Michel and Frank Asaro

I. Introduction

As part of a reevaluation of the authenticity of the Plate of Brass, which is in the custody of the Bancroft Library, at the University of California, Berkeley, its chemical composition has been reexamined. The Director of the Bancroft Library, Professor James D. Hart, requested that the University of California, Lawrence Berkeley Laboratory (LBL) drill three samples from the Plate to be analyzed by both the Research Laboratory for Archaeology and the History of Art at Oxford University and LBL. This paper discusses the sampling procedure, the measurements made at LBL and their interpretation. It was hoped that precise and sensitive measurements of the abundance of impurities likely to occur in brass or its component elements would lead to a method of dating brass artifacts by determining the method of manufacture of the brass and its constituents. These data could be correlated with historical records of brass making procedures and copper and zinc metallurgy to give chronological information on the artifact. A short description of the history of the Plate of Brass is given in Appendix D.

II. Sampling Procedures

Three sites were selected for sampling to check on the uniformity of the brass. The edges of the plate were examined with 36X and 72X magnification to avoid any cracks which might be in the brass. The three sites selected were chosen to give the most information about

uniformity of composition, a direct comparison with previous spectrographic analysis¹ and to avoid defacing the plate. The amount of sample needed for both the Oxford and LBL analyses was approximately 100 mg. A standard tool steel drill (1/16" dia.) was used. The resulting holes were approximately 1/16" x 9/32" deep.

The surface of the Plate at each site was scraped, while viewed under the microscope, to remove the soft black surface contamination which appears to be at least partially organic. The site was then center-punched to guide the drill. One drill was used to remove the surface layer of brass about 1/32" deep, then a clean drill was used to remove the sample. Care was taken that the tools were cleaned thoroughly before use. The samples were collected on clean paper and transferred to clean plastic vials.

The first hole was located on the bottom left edge of the plate 0.85" from the left side of the bottom notch. The second hole was on the left edge of the plate 0.89" from the top. The third sample was taken from the edge cut for the previous analysis in the area which is thought to have held the coin. The plate was held at an 8° angle from vertical to clear the drill chuck which had an extended drill bit. Figures 1, 2, and 3 are photographs of the sample holes 1, 2, and 3 respectively.

The turnings were examined under a 12X magnification and no evidence of patina contamination was observed. The 3 samples were divided in half and one set was sent to Oxford for analysis. Figures 4-6 are photographs of the turnings at 8.5 magnification. X-rays were taken of the Plate of Brass and one of these (Fig. 7) shows the position of the drill holes.

III. Lawrence Berkeley Laboratory Studies

The measurements chosen for this study were those which might be expected to shed some light on the authenticity of the Plate of Brass as an Elizabethan artifact. Measurements of the major constituents and the impurities likely to be in medieval brass were made on the Plate of Brass, medieval brasses and modern brasses. In addition the variation in effective thickness of the Plate of Brass in random areas was also determined.

A. Dependence of brass composition on manufacturing processes.

1. Brass making procedures

Brass is primarily an alloy of copper and zinc, although it may contain other elements that were deliberately or accidentally added. The Romans made considerable brass from metallic copper and zinc oxide.

Brass coins from 45 B.C.² were found to contain nearly 28% zinc although the abundance of the zinc decreased rather monotonically over the next two hundred years.³ In the later years of the republic, brass was made from metallic copper and calamine (zinc carbonate) and that procedure was used in Europe until the XIX century.⁴ In the late XVIII century^{4,5} brass was also prepared by the fusion of metallic zinc and copper, but there was a preference for calamine brass until the XIX century.⁶ Therefore at the time of Drake's voyage, brass should have been made by the calamine procedure.

2. The calamine process

In this procedure, calamine, native zinc carbonate, was mixed with finely divided charcoal or coal and heated with copper metal. Besides copper and zinc, tin, lead and antimony were common constituents added accidentally or deliberately.⁷ In addition, other impurities could arise from the copper, calamine, or scrap used in the brass making procedure. In one description⁸ of the calamine process in 1672, 46 pounds of calamine were mixed with coal and divided into 8 pots. Then 8 pounds of metallic copper were added to each pot. The zinc content should have been much smaller than the 27% indicated by these relations as the calamine probably contained substantial masses of impurities and zinc vapor would be lost in the brass making process. The zinc content could be increased by fusing the brass with an additional calamine-charcoal or coal mixture.⁹

3. Impurities in copper

English copper ore in the late XVI century contained arsenic, sulfur, antimony, iron and other impurities. These were removed by melting and refining to some extent but only by very laborious methods prior to 1582.¹⁰ Even by 1858 most refined copper, excluding that from Russian and some American sources, was considered to be impure and contain lead, iron, and antimony.¹¹ Impurities found in some twentieth century blister copper of 98-99% purity¹² range as high as ~1% oxygen, 0.1% As, 0.2% Sb, .25% Fe, .15% Pb, 0.4% Ni, 0.35% Ag, and .25% S. Modern copper is further refined electrolytically, whereas in the late XVII century copper refining was done with reverberatory furnaces;^{12,13} but neither of the processes was known before Drake's voyage. In the XIX and early XX centuries, American copper of high purity (lake copper) was produced in great quantity. Electrolytic refining of this copper was not necessary.¹⁴ By the middle of the XX century, however, nearly all copper produced would have been electrolytically refined¹⁵ and typically the silver content would be at the 1 ppm level and arsenic and antimony would be below 10 ppm.¹⁶

4. Impurities in calamine

The calamine used for brass making was usually impure¹⁷ and contained $MgCO_3$, $FeCO_3$, and $CaCO_3$. Zinc ores are also usually associated with lead and with cadmium. Commercial metallic zinc prepared

by the horizontal retort process contained copper, antimony, and arsenic, in addition to lead, iron and cadmium.¹⁸ Without redistillation, this spelter contained a percent or so of lead and smaller amounts of cadmium and iron in the first part of the XX century.¹⁹

Indium is an element found principally in zinc ores and its abundance is sometimes 0.1% of the zinc.²⁰ Some calamine ores are rich in indium.²¹

5. Brass compositions

The brass or latten of medieval England was harder and of different composition than common early XX century brass.²² Three examples²³ of English Memorial Brasses of the XV-XVI century contained 24-30% zinc, 1.2-3.0% tin, and 2-7% lead. These contrast with the nominal specifications for commercial high brass of the early XX century which were 35.0% zinc and 65.0% copper.²⁴ It was pointed out earlier that medieval recipes for brass manufacture should generally give lower zinc abundances than this value. Four examples²⁵ of cast, plate and sheet brasses of the XIX century contained 38.8-35.3% zinc, 0.2-0.4% tin and 1.4-2.9% lead.

It is doubtful, during the XVI century, before Drake's voyage, that brass was made or hammered in England on a commercial basis. One company (The Governors, Assistants and Society of the Mineral and Battery Works) had exclusive rights²⁶ to make brass and

hammer metal. That company had not completed²⁷ its battery works by 1582 and may have made brass only on an experimental basis before then. Even by 1596 the "art" of commercial brass making in England may have been known to only one man (John Brode).²⁸

Thus, if the Plate of Brass was made in Elizabethan times prior to Drake's voyage, it would probably have been imported into England. It also should contain lower levels of zinc than modern brass, contain lead in the percent region, tin in the percent or fraction of a percent region, and may contain cadmium, iron, arsenic, antimony, nickel, magnesium, sulfur, calcium, silver, gold, and indium in measurable amounts. If the Plate of Brass is modern brass made from high purity copper (electrolytic or American lake copper) and zinc metal (especially if it is redistilled), all impurities, except indium and cadmium, which are associated with zinc, should be in lower abundance. Lake copper, however, may contain substantial silver. Artifacts made from brass manufactured in the middle of the XX century or later could have very little silver, cadmium, or indium. Reuse of old brass scrap, however, could yield higher abundances of impurities than would be expected from production methods for copper and zinc current at a given time.

The abundances of all of the elements discussed above with the exception of calcium, sulfur, and oxygen were studied in this work. In order to study the homogeneity of the Plate most of the measurements were made as precisely as possible.

B. Measurements made at the Lawrence Berkeley Laboratory

1. Neutron Activation Analysis

The neutron activation analysis techniques are described in Appendix

A. The abundances of zinc (Zn) and copper (Cu) as measured by these methods are shown in Table I. Three determinations of zinc were made on each sample and two of copper. The errors are the uncertainties in counting radioactivity and the variations between the different standards. Additional errors of about 1% are due to uncertainties in the weights of the metal samples, and comparable errors are due to self-absorption of the gamma rays in the metal. The Zn abundance is 35.0% with a root-mean-square deviation of 0.50 or 1.4% of the value. Thus, the Zn is homogeneous within 1.4% for the three areas studied.

The copper abundance is 64.6% and this is homogeneous within 1.8% of the value. Each of these variations, however, is over twice the listed error, and these could be caused by the uncertainties in weight and self-absorption. If the ratios of the Zn to Cu abundances are considered, any errors in weight would cancel out completely and the absorption errors would cancel to a large extent. As seen in Table I the ratios are constant to within 0.45% of the average. This is somewhat smaller than the listed error as the latter includes variations in the measurements of the standards. Thus, the chemical composition of the major constituents of the Plate of Brass is homogeneous within 0.45% in the 3 areas studied.

-9-

Table I

Zinc abundance (%)

Isotope γ Energy Detector	Hole #	DRPL-	^{69}Zn 349 KeV 7cc Ge	^{65}Zn 1115 KeV 7cc Ge	^{65}Zn 1115 KeV 6cc Ge-Li	Best Value
	1	1	$35.4 \pm .7^{(a)}$	$33.6 \pm .6$	$34.8 \pm .2$	$34.8 \pm .2$
	1	2	$34.4 \pm .7$	$34.4 \pm .4$	$34.9 \pm .2$	$34.8 \pm .2$
	2	3	$35.6 \pm .7$	$35.9 \pm .3$	$35.8 \pm .2$	$35.8 \pm .2$
	2	4	$35.2 \pm .7$	$35.2 \pm .3$	$35.3 \pm .3$	$35.2 \pm .2$
	3	5	$34.3 \pm .6$	$34.9 \pm .3$	$35.3 \pm .3$	$35.0 \pm .2$
	3	6	$33.7 \pm .6$	$34.6 \pm .3$	$34.2 \pm .3$	$34.3 \pm .2$
Best Value						35.0
RMSD						.5

Copper Abundance (%)

Isotope γ Energy	Hole #	DRPL-	^{66}Cu 1039 KeV	^{66}Cu 511 KeV	Best Value	Zn/Cu ^(b)
	1	1	62.2 ± 1.2	$64.5 \pm .4$	$64.3 \pm .4$	$.541 \pm .005$
	1	2	63.4 ± 1.2	$64.5 \pm .4$	$64.4 \pm .4$	$.540 \pm .005$
	2	3	64.5 ± 1.1	$66.7 \pm .4$	$66.4 \pm .4$	$.539 \pm .005$
	2	4	65.8 ± 1.2	$64.6 \pm .6$	$65.0 \pm .5$	$.542 \pm .005$
	3	5	64.7 ± 1.1	$64.7 \pm .6$	$64.5 \pm .5$	$.543 \pm .005$
	3	6	62.2 ± 1.0	$63.0 \pm .6$	$62.8 \pm .5$	$.546 \pm .005$
Average					64.6	.5418
RMSD					1.2	.0025

(a) The entries after the $\pm$ signs are the (1σ) errors in measurement but do not include weighing or absorption uncertainties.

(b) Taking the ratio of Zn/Cu cancels any weight errors and cancels most of the absorption errors.

XBL 775-8838

In Table II are shown the abundances of the six elements for which abundance values (in contrast to limits) were determined by neutron activation analysis. For each element the average abundance for the 6 samples is given along with the root-mean-square deviation from the average (RMSD), and the average counting error. As the RMSD is never appreciably higher than the average counting error, the Plate of Brass is homogeneous, for the six trace elements, in the areas studied within the precision of the measurements.

2. X-ray Fluorescence (measurements by Robert D. Giaque)

Measurements for lead and iron abundances were made on one sample from each of the three drillings of the Plate of Brass. The reference standard was NBS 37d and the abundance of Cu in each sample was used as an internal standard. The results are shown in Table III. The lead level is about 0.10% in the Plate of Brass and is homogeneous within the precision of measurement.

3. Emission Spectroscopy (measurements by George V. Shalimoff)

The techniques used for iron and magnesium measurements are described in Appendix B. The results are shown in Table III.

The Mg abundance is 13 ppm and the variation between the areas sampled is comparable to the experimental uncertainty. The iron abundance is 0.027% and the variation is within the experimental uncertainty.

-11-

Table II

Trace elements detected by
neutron activation analysis

DRPL-	Samples from Hole #	Abundance (parts-per-million)						
		Cd	Sn	Ag	Sb	Co	In	Au
1	1	1360 ± 160	83 ± 26	48 ± 9	8.3 ± .6	6.7 ± .7	1.36 ± .20	.27 ± .09
2	1	1160 ± 150	85 ± 25	41 ± 9	8.0 ± .6	6.6 ± .7	1.62 ± .22	.31 ± .09
3	2	1390 ± 150	47 ± 24	33 ± 8	8.6 ± .7	5.1 ± .7	1.53 ± .21	.18 ± .09
4	2	1020 ± 160	81 ± 24	45 ± 8	7.6 ± .6	4.4 ± .6	1.22 ± .16	.19 ± .09
5	3	1210 ± 150	70 ± 24	41 ± 8	9.4 ± .7	5.4 ± .7	1.61 ± .18	.20 ± .09
6	3	1210 ± 130	82 ± 22	58 ± 7	7.7 ± .6	6.1 ± .6	1.57 ± .16	.17 ± .09
Average		1230	75	47.8	8.3	5.4	1.48	.22
RMSD		140	15	6.7	.7	0.9	.16	.06
Ave. error		150	24	8	.6	0.7	.19	.09

XBL 775-8839

Table III

Other measurements on the Plate of Brass

Samples from
Hole #

Element Abundances

X-ray Fluorescence (R. D. Giaque)

	<u>Pb(%)</u>	<u>Fe(%)</u>
1	$\sim 0.11 \pm .03$	< 0.2
2	$\sim 0.10 \pm .03$	< 0.2
3	$\sim 0.08 \pm .02$	< 0.2
Average	~ 0.10	< 0.2
Ave. Error	.03	
RMSD	.02	

Emission spectroscopy (G.V. Shalimoff)

	<u>Mg(ppm)</u>	<u>Fe(%)</u>
1	10 ± 5	$0.027 \pm .003$
2	20 ± 5	$0.027 \pm .003$
3	10 ± 5	$0.028 \pm .003$
Average	13	.027
Ave. Error	5	.003
RMSD	6	.001

Atomic Absorption (R.D. McLaughlin)

	<u>Pb(%)</u>	<u>Cd(%)</u>	<u>Ag(ppm)</u>
1	.04	.06	20
2	.15	.09	55
3	.06	.10	32
Average	.08	.08	36
Ave. error	-	-	-
RMSD	.06	.04	15

XBL 775-8837

4. Atomic Absorption (measurements by Ralph D. McLaughlin)

Lead, cadmium and silver abundances were measured with a newly installed atomic absorption spectrometer before the dependence of AA signal on concentration was measured. These determinations assumed a linear relationship between the AA signal and the concentration of dissolved samples of the Plate. As the concentrations varied considerably, the values are only roughly indicative of the abundance level and not at all indicative of the sample homogeneity. The results are also shown in Table III.

5. Measurements on other brasses.

We are indebted to Mrs. Ruth Eis, Curator of the Magnus Memorial Museum, who generously gave permission for sampling some brass Hanukkah lamps of XIV-XVIII century European origin. These and samples of more modern brass were measured by some of the techniques previously described. In addition some crude x-ray fluorescence measurements were made of the surfaces of the artifacts by the authors. The results are summarized in Table IV.

6. Variation in thickness of the Plate of Brass

The measurement of variation in thickness is described in Appendix C, and the results are summarized in the Discussion.

IV. Discussion of LBL Results

A. Old Brass

The elemental abundances of XVI and XVII century Italian brass shown in Table IV conform roughly to the general expectations for old

Table IV

Comparison of elemental abundances of the Plate of Brass with those of old and recent brasses^a

			Per Cent										Parts-per-million				
	Designation	Century (A.D.)	Cu	Zn	Pb ^b	Fe ^b	Cd ^b	Sn	Sb	As	Ni	Ag	Au	Co	In		
<u>Old Brass</u>																	
France, Spain?			C/1	XIV	75	15.6	6	< 1.2 ^c	< .03 ^c	1.07	.76	.22	.19	.11	5.6	230	17
Italy			C/3	XVI	84	9.1	2.7	.5	< .02	1.45	.71	.33	.63	.23	67	93	3.6
Italy			C/4	XVI ^b	80	12	5.5	.5	< .03	1.5							
Italy			C/7	XVII	72	22	3.1	.3	< .02	1.41	.83	.41	.33	.06	18	90	2.0
Italy			C/8	XVII	83	9.4	3.5 ^d	.5 ^d	< .02	2.5	.55	.41	.42	.12	35	166	3.8
Italy			C/10	XVII	76	15.4	4.3	.5	< .04	2.25	.43	.24	.34	.21	72	82	4.3
Rhineland?			C/26	XVIII	67	27.8	2.8 ^d	1.0 ^d	.02 ^c	1.40	.033 ^e	.036 ^e	.09	.020	2.0	23 ^e	14
Typical errors (1σ)						.8	.7	.2	.01	.11	.02	.02	.02	20%	20%	10	20%
<u>Recent Yellow Brass</u>																	
England			XIX-XX ^b	65	31	3.0	< .4	.03	.4	< .02							
U.S.		No.2	XX	60 ^d	37 ^d	1.40 ^{d,i}	< .35	.001 ^f	.02 ^b	< .002	< .002		.007 ^f	< 2		< .15	
		No.1	XX ^b	60	40	< .2	< .14	< .03	.05	< .01							
U.S. N.B.S.		37D	XX	70.78 ^g	26.67 ^g	.94 ^g	.076 ^g	.001 ^f	.97 ^g	.0002		.58 ^g	.0004 ^f	< .3	47	< .6	
<u>Plate of Brass</u>																	
				64.6	35.0	.10 ^d	.027 ^h	.12 ^c	.006	.0008	< .006	< .06	.0046	~.2	5.7	1.5	

^aAll measurements were by neutron activation analyses unless otherwise indicated by superscripts in the row of chemical symbols, the Century column or on the abundance values. All limits are two standard deviations.

^bx-ray fluorescence (Michel & Asaro)

^fatomic absorption

^cneutron activation

^gvalue certified by National Bureau of Standards

^dx-ray fluorescence (R. D. Giaque)

^hemission spectroscopy

^eprecision of measurements is about 8%

ⁱprecision is about 4%

brass. The zinc abundances are lower than in modern yellow brass and the lead and tin abundances are in the percent region. Iron, antimony, arsenic, nickel and silver are detected at the fraction of a percent level and gold, indium and cobalt are prominent but at lower levels. The XIV century brass of uncertain provenience (possibly French or Spanish) is comparable to the XVI and XVII century brasses in abundance patterns. The XVIII century brass however, has a noticeably higher zinc content than the older brasses, lower abundances of Sb, As, Ni, Ag, Au, and Co and comparable abundances of lead and iron. Although lead or tin might have been added to (or left in) the brass deliberately, iron was considered injurious to the brass making process.²⁹ It would more likely come from impurities in the calamine or old scrap brass. The lead and iron abundances may reflect the use of the calamine process, and the lower abundances of the other elements reflect improvements in copper metallurgy.

The XX century U.S. brass sample has nearly an order of magnitude less antimony, arsenic, cadmium, and indium than that from the XVIII century. The Sb and As abundances probably reflect improved metallurgy of Cu and those of Cd and In the use of electrolytically purified zinc or zinc spelter purified by other means.

B. Plate of Brass

The measurements on the Plate of Brass are summarized in Table V. It has a zinc content (35.0 percent) which is substantially higher than found for XIV to XVIII century brasses studied in this work and is

Table V

Summary of LBL chemical measurements on the Plate of Brass

	Neutron activation ¹		X-ray fluorescence ²		Emission Spectroscopy ³		Atomic absorption ⁴		Best value	Larger of calibration uncertainty or root-mean-square deviation	Deviation in mean
	6 samples		3 samples		3 samples		3 samples				
	abund.	RMSD ⁷	abund.	RMSD ⁷	abund.	RMSD ⁷	abund.	RMSD ⁷			
Cu%	64.6	1.2							64.6	1.2	0.49
Zn%	35.0	0.5							35.0	0.5	0.20
Zn/Cu	.5418	.0025							.542	.005	
Cd ⁵	0.123	.015					.08	.02	.12	.03	
Pb%			.10	.03			.08	.06	.10	.03	
Fe%	<.1		<.2		0.027	.003			0.027	.003	
Parts-per-million											
Sn	60	25							60	30	
Ag ⁵	48	8					56	18	48	10	
Sb	8.3	.9							8.3	.9	
Co	5.6	.9							5.6	.9	
In ⁵	1.5	.2							1.5	.3	
Au ^{5,6}	.21	.09							.2		
Mg					13	6			13	6	
Total Mass									99.9%		.5%
Limits on Abundances (ppm) by NAA											
As	55	La	100	Ta	.06						
Ba	135	Lu	.4	Th	4						
Cl	3000	Mn	6	U	1.4						
Cr	50	Mo	12	W	32						
Ga	65	Na	500	V	300						
Hf	2.1	Ni	600								
K	1000	Sc	1.9								
		Sm	.4								

Legend:

(1) measurement made by Helen V. Michel and F. Asaro

(2) measurement made by Robert D. Giauque

(3) measurement made by George V. Shalimoff

(4) measurement made by Ralph D. McLaughlin

(5) There is about a 20% uncertainty in the neutron activation measurement as this element was not calibrated in the Plate of Brass irradiation

(6) Au is only accurate to about a factor of 2 as it is a contaminant in the high purity Al used for pill

Legend:

- (1) measurement made by Helen V. Michel and F. Asaro
- (2) measurement made by Robert D. Giaque
- (3) measurement made by George V. Shalimoff
- (4) measurement made by Ralph D. McLaughlin
- (5) There is about a 20% uncertainty in the neutron activation measurement as this element was not calibrated in the Plate of Brass irradiation
- (6) Au is only accurate to about a factor of 2 as it is a contaminant in the high purity Al used for pill wrapping.
- (7) RMSD is the larger of the root-mean-square deviation in the values or the experimental error except for the Zn/Cu ratio where it is the former.

XBL 775-8840

comparable to the modern brass or commercial high brass. The levels of lead, tin, iron, antimony, arsenic, nickel, and gold are much lower than found for these old brasses and are also comparable to modern samples of brass.

The low levels of lead and iron strongly suggest the brass was made from zinc which was purer than that generally used in the calamine process. This would probably indicate the Plate of Brass was made after the early part of the XIX century as the manufacture of brass with zinc metal was not generally accepted until then.

The level of cadmium is significantly higher in the Plate of Brass than in a modern brass sample. The limits on impurities in modern yellow brass used for sheet work are shown in Table VI. The Plate of Brass is consistent with these limits, although just barely so. In the 1930's, however, cadmium was one of the impurities in commercial zinc which determined the grade and cost of the material. The maximum cadmium levels in specifications³⁰ for three grades of slab zinc spelter as of 1936 are shown in Table VI. It is seen that the category whose maximum impurity levels conform most closely with the Plate of Brass is the one called Brass Special. Thus, although the cadmium abundance of the Plate of Brass is almost too high for current brass, it is quite consistent with a grade of zinc used for brass in 1936.

The abundance of indium is also substantially higher in the Plate of Brass than a modern brass sample or NBS37d Standard Brass. In 1876,

Table VI

Comparison of Composition of Plate of Brass with Commercial Specifications for XX Century Brass and Zinc (expressed in percent)

Year	Plate of Brass	Yellow Brass 1973 ^a , 1968 ^b	Zinc Spelter ^c 1936		
Grade		Alloy No. 268	Intermediate	Brass Special	Selected
Cu	64.6 ± 0.5	66 + 2.5 - 2.0			
Zn	35.0 ± 0.2	Remainder			
Pb	.10 ± .03	< .15	Sum < 0.18 { < .07	Sum < 0.35 { < .21	Sum < .39 { < .28
Fe	.027 ± .003	< .05	< .011	< .011	< .014
Cd	.12 ± .03	{ < .15	< .18	< .18	< .26
Sn	.006				
Others					

^aCopper Development Association Standards Handbook; copper, brass, bronze; wrought mill products; alloy data part 2, page 89. (1973)

^bCopper Development Association Standards Handbook; copper, brass, bronze; wrought mill products; specifications index part 6, page 4. (1968)

^cReference 30; values have been multiplied by a factor of .35 to compare directly with the Plate of Brass

XBL 775-8841

however, the abundance of indium in metallic zinc was measured as ~ 5 ppm³¹. This zinc would have been produced by the horizontal retort process in which roasted zinc ores are first reduced and then distilled. The zinc could be further purified by redistillation from the horizontal retort,¹⁸ but this does not necessarily separate the indium. Thus, the indium abundance in late 19th century metallic zinc is consistent with the level of the indium in the Plate of Brass, 1.5 ppm. High purity zinc currently is produced in large quantities electrolytically and by other commercial methods first developed¹⁸ in 1934. Thus, modern brass made from these types of zinc could have low abundances of indium (and cadmium) but this is not necessarily true for brass produced before 1934.

In 1936, commercial copper was divided into four categories: low resistance lake copper (from the northern peninsula of Michigan) and electrolytic copper, both used for electrical purposes; high resistance lake copper (fire refined) which could be used for wrought alloys; and fire refined copper (other than lake) which was used for rolling into sheets and shapes and was not intended for wrought alloys or electrical purposes.¹⁴ Among the specifications of maximum abundances in the last category are 0.1% arsenic, 120 ppm antimony, and .05% tin. The Plate of Brass is about an order of magnitude (or better) purer than these limits, and this suggests it was not made of fire refined copper (other than lake). It follows that the Plate of Brass was probably made after the development of the high purity copper

deposits in the Great Lakes region of the U.S. in the XIX or XX century. Electrolytic copper could also have been used to make the Plate of Brass, but electrolytic refining of copper was not done commercially until the late XIX century.³²

C. Homogeneity of the Plate of Brass

The Plate of Brass was homogeneous in all elements measured within the precision of the measurements. The most precise was the copper to zinc ratio and this was constant within 0.45% for six samples. Old artifacts of precious metals or other alloys can be homogeneous but this is less likely for base metal alloys.³³ Corrosion is the most important cause of heterogeneity in chemical composition, and it can occur internally and erratically.³⁴ In particular brass of the composition of the Plate of Brass (35.0% zinc) is especially susceptible to corrosion and weathering.²⁴ In the present work some marked changes in zinc content were observed for a XVII century brass between large (10 mgm) and small (~ 1 mgm) drilled samples (22% and 12% zinc respectively), and between the surface layer (12%) and the large drilled sample. There is no chemical evidence for weathering or other corrosive action in the samples of the three drillings made on the Plate of Brass.

The variation (root-mean-square deviation) in the effective thickness of the Plate of Brass is about 0.001 inches for 20 measurements in which the edges and two dents are excluded. The hammering of the inscription on the Plate of Brass, might account for this variation. The thickness of the Plate of Brass, $.129 \pm .002$ inches, conforms most closely

to the specification³⁵ of gage No. 8 of the American Wire Gage which was commonly used for brass plates in 1936. The nominal thickness for this gage was .1285 inches. The tolerances are not known but modern tolerances³⁶ are .004 inches.

D. Comparisons with earlier work

Fink and Polushkin deduced that the brass plate examined by them was the genuine Drake Plate referred to in the book, The World Encompassed by Sir Francis Drake. Their conclusions are shown in Table VI and the present work relates to their findings 4, 5, and 6. In the present work there was no evidence for an excessive amount of impurities in the Plate of Brass. On the contrary the levels were quite consistent with early XX century brass. There was no evidence for inhomogeneity, in fact the major elements were consistent in their ratios within 0.45%. The magnesium level found in the Plate of Brass is an order of magnitude smaller than reported by Fink and Polushkin and is consistent with their requirements for modern brass.

The measurements reported in the earlier work were mostly qualitative and were made by emission spectroscopy. The quantitative previous measurements for Ag and Mg (3.6 ppm and 102 ppm respectively), also made by emission spectroscopy, differ by an order of magnitude from the present work. It is difficult to make present day measurements by this technique to better than 10%. Forty years ago these difficulties would have been much compounded, especially when working with small samples. The zinc abundance measured in this work,

Table VII
Conclusions of Fink and Polushkin

- 1) There is no doubt whatsoever that the dark coating on the surface of the plate is a natural patina formed slowly over a period of many years.
- 2) Numerous surface defects and imperfections usually associated with old brass were found on the plate.
- 3) Particles of mineralized plant tissue are firmly imbedded in the surface of the plate. This is likewise a very positive proof of the age of the plate.
- 4) Cross sections of the brass plate show (a) an excessive amount of impurities; and (b) chemical inhomogeneity; as well as (c) variation in grain size. All three of these characteristics indicate a brass of old origin.
- 5) Among the impurities found in the brass of the plate there is magnesium, which is present far in excess of the amount occurring in modern brass.
- 6) There are numerous indications that the plate was not made by rolling but was made by hammering, as was the common practice in Drake's time.

35.0% is in good agreement with that determined previously,¹ 34-39%, from a microscope examination of both alpha and beta fields in the brass.

E. Conclusions

The low level of lead and iron in the Plate of Brass indicates it was made from zinc metal which had probably been produced by the retort process and possibly redistilled. This indicates a date of the XIX or XX century although a late XVIII century date might be possible. The low level of antimony, arsenic, nickel, cobalt, silver, and gold in the Plate of Brass indicates it was made from high purity copper which would not have been generally available until about the middle of the XIX century although an XVIII century date is possible. The high degree of chemical uniformity of the Plate of Brass, better than 0.45% from the zinc to copper ratio, and the small variations in thickness in the areas away from the edges, 0.001 inch, are consistent with XX century rolled brass. The average measured thickness of the Plate of Brass away from the edges, 0.129 ± 0.002 inches, is consistent with the specifications for No. 8 gage brass of the American Wire Gage standard used in the 1930's. The Plate of Brass therefore was made in the XVIII to the XX centuries. The most probable period is the late XIX and early XX centuries.

Acknowledgments

The breadth of measurements at LBL was only possible through the generous cooperation of many people. Among these were George V. Shalimoff who did the emission spectroscopy measurements; Robert D. Giauque who did the accurate x-ray fluorescence measurements which helped calibrate the thickness measurements of the plate and our own less accurate XRF measurements; Ralph D. McLaughlin who did the sensitive atomic absorption measurements; Bob Bigelow and Bill Love, photographers, and Alberta Proteau of the Medical Services Dept. who took the x-rays of the Plate.

A great measure of appreciation must go to Duane F. Mosier for many stimulating discussions and his supervision of our electronic system. We express our appreciation to Tek Lim, Supervisor of the Berkeley Triga Reactor, for the irradiations used in this work and to Dr. John Apps of LBL for sharing his knowledge of copper.

We are grateful to Prof. G.T. Seaborg and B.G. Harvey of the Nuclear Science Division and Dr. Robert J. Budnitz of the Energy and Environment Division for their support and encouragement. Prof. Hart and Dr. Arthur Norberg of the Bancroft Library were a continual source of inspiration.

This work was done with support from the U.S. Energy Research and Development Administration.

1. C.G. Fink and E.P. Polushkin Report on the Plate of Brass in Plate of Brass: Evidence of the visit of Francis Drake to California in the year 1579; special publication 14 by the California Historical Society 1938.
2. M. Bahrfeldt. Die Munzen der Flottenpräfekten des Marcus Antonius, Numismatische Zeitschrift 27, 9-33 (1905) (quoted in reference 3 page 121)
3. E.R. Caley. Analysis of Ancient Metals. The Macmillan Company, New York (1964) page 163.
4. Copper Development Association. Copper Through the Ages. C.D.A. Publication No. 3, 1934, page 35.
5. Bridgeport Brass Co. Seven Centuries of Brass Making Bridgeport, Connecticut, 1920. page 15.
6. William Gowland. Copper and its Alloys in Early Times. The Journal of the Institute of Metals VII, 44 (1912).
7. A.S. Piggot. Chemistry and Metallurgy of Copper. Lindsay and Blakiston, Philidelphia, PA. 1858. page 351.
8. Echer "Untererdische Hofhaltung" page 261, 1672, reported in reference 5, page 9.
9. Piggot, page 357.
10. Grant Francis. The Smelting of Copper in the Swansea District of South Wales from the Time of Elizabeth to the Present Day. Henry Sotheran and Co. (1881) page 27.
11. Piggot. page 28.
12. D.M. Liddell. Handbook of Nonferrous Metallurgy. Recovery of the Metals. 1945. page 248.
13. Copper Development Association. page 38.
14. O.W. Eshbach. Handbook of Engineering Fundamentals. John Wiley and Sons, Inc., New York. 1936. page 11-39.
15. J.W. Laist, Copper, Silver and Gold, Vol. 2 of Comprehensive Inorganic Chemistry ed. Sneed, Maynard and Brasted; D. Van Nostrand Co., Inc. New York. page 35.
16. IBID. page 54.

17. Fink and Polushkin. page 60.
18. H.M. Cyr, M.C. Sneed and R.C. Brasted. Vol 4 of Comprehensive Inorganic Chemistry. edited by M.C. Sneed and R.C. Brasted. D. Van Nostrand Company, Inc. Princeton, New Jersey. 1955. page 17.
19. W.M. Latimer and J.H. Hildebrand. Reference Book of Inorganic Chemistry. The Macmillan Co., New York. 1940. page 127.
20. IBID. page 145.
21. A. and D. De Negri. J. Chem. Soc. 34, 708 (1878)
22. J.S.M. Ward. Brasses. Cambridge University Press, (1912) page 108.
23. Gowland. page 47.
24. Esbach. page 11-44.
25. Piggot. page 352.
26. Henry Hamilton. The English Brass and Copper Industries to 1800. Frank Cass and Co. Ltd. (1967) page 20.
27. IBID. page 34.
28. IBID. page 35
29. Piggot. page 351.
30. Esbach. page 11-54.
31. Delachanal & Mermet. Bull. soc. Chim. 25, 197 (1876). Referred to by M.T. Ludwick in Indium p. 77; Indium Corp. of America (1950).
32. Titus Olke, Modern Electrolytic Copper Refining. John Wiley and Sons, New York (1903) page 2.
33. Caley. page 1.
34. IBID. page 4.
35. Pender, Del Mar and McIlwain. Electrical Engineers Handbook. John Wiley and Sons, Inc. New York. page 1-16. Third Edition. 1936.

36. Standards Handbook; Copper, Brass, Bronze; Wrought Mill Products; Tolerances Part I, Copper Development Association, 1968.
37. I. Perlman and F. Asaro. Pottery Analysis by Neutron Activation Archaeometry 11 21 (1969); Science and Archaeology edited by R.H. Brill, Page 182, MIT Press (1971).
38. Herbert E. Bolton. Francis Drake's Plate of Brass. California Historical Society Quarterly Vol. 16, No. 1, Part 2, Page 11 (1937).
39. IBID. Page 1.
40. D.S. Watson. Drake and California. California Historical Society Quarterly Vol. 16, No. 1, Part 2, Page 19 (1937).
41. R.B. Haselden. Is The Drake Plate of Brass Genuine? California Historical Society Quarterly Vol. 16, No. 3, Page 271 (1937).
42. Allen L. Chickering. Some Notes with Regard to Drake's Plate of Brass. California Historical Society Quarterly Vol. 16, Page 275 (1937).

Figure captions

- Fig. 1 Left edge of Plate and hole #1.
- Fig. 2 Bottom edge of Plate and hole #2.
- Fig. 3 Hole #3 and vicinity of the coin hole.
- Fig. 4 Turnings from hole #1 8.5X
- Fig. 5 Turnings from hole #2 8.5X
- Fig. 6 Turnings from hole #3 8.5X
- Fig. 7 X-ray of Plate
- Fig. 8 Effective thickness of the Plate of Brass

Appendix A

Neutron Activation Analysis Techniques

As the general methods of neutron activation analysis used at the Lawrence Berkeley Laboratory have been previously described,³⁷ only the differences between the earlier description and the procedures used in the Plate of Brass study will be discussed.

Neutron activation analyses were made of duplicate samples from each of the three areas of the Plate of Brass which were sampled. Each sample was about 10 mgm in weight and was first mixed with 90 mgm of high purity silicon metal and 50 mgms of cellulose binder. Then the mixture was pressed into a pill 0.394" in diameter and about 0.050" thick with a tool steel die. In the process of pill pressing small contaminants of iron, manganese, chromium, and tungsten are introduced into the sample and interfere with low level measurements of these elements. These pills were encapsulated in polyethylene foil and irradiated in the Berkeley Triga Reactor at a flux of 2×10^{11} neutron/sec-cm² for 18 min. Also included in the irradiation were 4 standards of Standard Sample 37D (National Bureau of Standards Sheet Brass), and 4 of Standard Sample 52C (National Bureau of Standards Cast Bronze) to calibrate the copper, zinc and tin abundances. Four standards of Standard Pottery were included to calibrate the other elements. All samples were placed in a radial array and rotated in the reactor flux so that all samples and standards were exposed to the same flux. About an hour after irradiation the gamma radioactivity of each sample was analyzed for 6 minutes with a 7cc intrinsic Germanium detector coupled to a pulse height analyzer system. All pills were

then turned upside down and reanalyzed. This was necessary as the metal samples and standards were not distributed uniformly within the silicon-cellulose pills. Reversing the pills and averaging the results compensated for this effect in the vertical axis. The detector system is much less sensitive to variations in position on the horizontal plane. The pill thicknesses were each measured and appropriate corrections were made to the counting rates of the gamma rays. In this analysis copper was determined from the counting rate of the 1.346 MeV gamma ray of 12.7 hr ^{64}Cu and also from the 0.511 MeV annihilation radiation of the same isotope. Zinc was determined from the 0.439 MeV gamma ray of 13.8 hr $^{69\text{m}}\text{Zn}$ and indium was determined from the 0.417, 1.107 and 1.293 MeV gamma rays of 54 min $^{116\text{m1}}\text{In}$. Small contributions to the indium peaks due to n,p reactions on tin in the samples were subtracted. From this analysis upper limits were also placed on the Ba, Ga, K and Na abundances. A one minute analysis had been previously performed on each sample about 10 minutes after the irradiation and limits on Cl and V were obtained from those measurements.

The samples were rewrapped with 99.999% pure Al foil and irradiated again in the reactor for 8 hours at a flux of 2×10^{13} n/sec-cm². Over a period of 11 to 70 days after the end of the irradiation, the samples and standards were analyzed 8 times with 3 different gamma ray detector systems. In these measurements the zinc abundance was remeasured with better precision with the 1.116 MeV gamma ray of 244 day ^{65}Zn . Cadmium was measured with the 0.336 MeV gamma ray of 4.5 hour $^{115\text{m}}\text{In}$ formed

by the decay of 53 hr ^{115}Cd . Tin was measured with the 0.1584 MeV gamma ray of 14 day $^{117\text{m}}\text{Sn}$ whose energy could be distinguished from the .1594 MeV gamma ray of ^{47}Sc . Silver was measured with the 0.658 MeV gamma ray of 253 day $^{110\text{m}}\text{Ag}$. Antimony was measured both with the 0.564 MeV gamma ray of 2.7 day ^{122}Sb and the 1.691 MeV gamma ray of 60 day ^{124}Sb . Gold was measured with the 0.412 MeV gamma ray of 2.7 day ^{198}Au and cobalt with the 1.332 MeV gamma ray of 5.3 year ^{60}Co . There were no standards used in these irradiations which contained useful amounts of cadmium, silver, or gold. Previously calibrated flux monitors were used to determine the abundances of these elements, and those abundances are therefore assumed to have a 20% uncertainty. Gold is an impurity in the high purity aluminum foil used to wrap the pills and this causes an uncertainty of a factor of two in the gold value of the Plate of Brass.

A short irradiation was made of new samples, which weighed about one mgm each, to obtain a better limit on the manganese value. These samples were encapsulated in polyethylene. In order to avoid the problem of tool steel contamination they were not mixed with silicon metal or cellulose nor pressed into pills. From these experiments, a limit of 6ppm could be set on the manganese abundance. In the earlier runs the samples of the Plate of Brass with the least iron ($0.13 \pm .04\%$) contained 14 ± 2 ppm of Mn. As the tool steel has 0.5% manganese relative to iron, the iron content of the Plate of Brass should be smaller than 0.1%. Each of the six samples of the Plate of Brass which had been made into pills had an upper limit of 0.1% for the iron abundance when treated in this fashion.

Appendix B

I. SUMMARY OF THE SPECTROGRAPHIC DETERMINATION OF MAGNESIUM IN PLATE OF BRASS

The analysis of magnesium in brass in the range of 100 ppm or less is difficult in this case because of three factors. One, only milligram samples are available, two, no reference brass standards are available with analyzed magnesium content, and three, magnesium is a common contamination element in spectrographic analysis.

A spark emission spectrographic method whereby portions of a brass solution are evaporated on electrodes was chosen to get replicate analyses from the available samples. High density graphite electrodes were chosen because the solutions contain nitric acid.

To prepare a working curve of magnesium content versus intensity of magnesium the addition method was used. To a solution of ordinary sheet brass which spectrographically showed low amounts of magnesium, known amount of magnesium were added in the range of 10 - 300 ppm. The magnesium was added as a solution of magnesium oxide dissolved in nitric acid. Lanthanum equal to 10% of the weight of brass was added as a solution of lanthanum trichloride for an internal standard. The intensity ratio of Mg II 2795.53 angstroms and La II 2791.51 angstroms was measured for the various concentrations of magnesium

Magnesium contamination is critical. The small amounts of magnesium which can be easily introduced into the sampling procedures will give measureable intensities on the photographic plates which would yield high

The three samples supplied were carefully weighed, dissolved, lanthanum added and made to appropriate volumes. For these analyses each sample was run in triplicate. The magnesium - lanthanum intensity ratio was measured and the concentration determined from the working curve taking the blank into account.

Sample	Mg ppm
DRPL - 1 E	10 ± 5
DRPL - 3 F	20 ± 5
DRPL - 5 G	10 ± 5

II. SUMMARY OF THE SPECTROGRAPHIC DETERMINATION OF IRON IN PLATE OF BRASS

The emission spectrum of iron is very rich in lines which allows one to choose a useful analytical line for the analysis of iron in brass over a wide concentration range. The iron present in these samples is in a concentration range where iron contamination in the sampling procedures for spectrographic analysis would have an insignificant effect. This is unlike the magnesium analyses on the same samples where the most sensitive emission line of magnesium had to be used and the analysis could be influenced by contamination and residual magnesium in the electrodes.

The iron was determined in the same exposures made for the magnesium analyses with the spark emission spectrographic method. The sample preparation is described in the summary of the magnesium determination.

A working curve of iron content versus intensity of iron was prepared using synthetic standards. A copper solution made from reagent copper oxide dissolved in nitric acid was used as the matrix material. Lanthanum equal to 10% of the weight of copper was added as a solution of lanthanum trichloride as the internal standard. Iron was added as a solution of reagent iron wire dissolved in dilute nitric acid. The intensity ratio of Fe II 2755.74 angstroms and La II 2791.51 angstroms was measured for various concentrations of iron in the range 0.01 to 0.1% Fe.

The measured intensity of the lanthanum line in the copper matrix was comparable to the intensity measured in the brass matrix which was used for the magnesium determination. This indicated that any matrix effect on the internal standard lanthanum and the iron during the excitation was essentially the same for copper and brass. This reinforced our confidence in using synthetic standards to create a working curve of iron concentration versus intensity. No iron was detected in the blanks.

The averages of the triplicate runs for the three brass samples are given below:

Sample		% Fe
DRPL - 1	E	0.027 ± 0.003
DRPL - 3	F	0.027 ± 0.003
DRPL - 5	G	0.028 ± 0.003

Appendix C

Thickness of the Plate of Brass

The variation in thickness of the Plate of Brass was measured by the variation in absorption of a gamma ray beam of ^{57}Co . The gamma ray beam was homogeneous over a 9.5 mm diameter and tapered to zero intensity at a diameter of 14.5 mm. The general uncertainties (one sigma) due to counting error was equivalent to 0.0006 inches. There was an additional uncertainty of $0.0 \rightarrow -.0014$ inches due to drifting of electronic equipment in 4 measurements made at the top of the Plate at its extreme right. A traverse was made across the top of the plate, a perpendicular traverse was made on the left half of the plate, several other measurements were made in randomly selected areas and a measurement was made of an obvious dent in the lower left section of the plate. The top edge of the plate, especially the right side, appeared to be thinner than the other areas sampled. The obvious dent was thin as was another spot which later inspection of x-rays indicated was on or close to a dent. These results are shown in Fig. 8. If the edges of the plate and dents are ignored, the root-mean-square deviation in thickness for 20 measurements was .0012 inches. The measurement uncertainties contribute .0006 inches which leaves 0.0010 inches due to variation in thickness. To determine the thickness of the plate, two calibration systems were used. In the first the thickness of the upper edge was measured at several places with a micrometer (with one rounded surface). This data together with the gamma ray data on the same areas served to cali-

brate the other measurements. These are the values shown in the figure and the average thickness was 0.1309 inches. Imperfections in the calibration areas caused by hammering or bending could lead to a ficticiously large value of the thickness. The gamma ray measurements were also calibrated with a flat plate of modern brass of about the same dimensions and composition. The lead content of this plate as well as the copper and zinc were carefully measured by Robert D. Giaque by x-ray fluorescence. Gamma ray absorption data from this plate (U.S. yellow brass #2) could be used to calibrate the Plate of Brass whose composition was known, and these gave an average thickness of 0.127 inches. The best value is probably the mean of the two calibrations, 0.129 inches with an uncertainty of 0.002 inches.

Appendix D

Description of the Plate of Brass

The Plate of Brass is an eighth inch thick piece of brass which is about 8 inches in length and 5½ inches in width. One side is inscribed with a message which claims title to the land in the name of Elizabeth, Queen of England and indicates the Plate was left by Francis Drake in 1579. The inscription as published³⁸ reads as follows:

BEE IT KNOWNE VNTO ALL MEN BY THESE PRESENTS

IVNE 17 1579

BY THE GRACE OF GOD AND IN THE NAME OF HERR
MAIESTY QVEEN ELIZABETH OF ENGLAND AND HERR
SVCCCESSORS FOREVER I TAKE POSSESSION OF THIS
KINGDOME WHOSE KING AND PEOPLE FREELY RESIGNE
THEIR RIGHT AND TITLE IN THE WHOLE LAND VNTO HERR
MAIESTIES KEEPEING NOW NAMED BY ME AN TO BEE
KNOWNE VNTO ALL MEN AS NOVA ALBION.

FRANCIS DRAKE

The Plate of Brass was found in 1936 in Marin County in the San Francisco Bay Area by Beryle Shinn. It was attributed to the voyage of Francis Drake³⁹ in 1937 and was thought to be the same brass plate that was described in World Encompassed by Sir Francis Drake. There has been considerable discussion and some controversy on the authenticity of the Plate.⁴⁰⁻⁴²

The Plate of Brass has been in the custody of the University of California at Berkeley since 1937. In 1938 a chemical study by Fink and Polushkin was published and their conclusions attested to the authenticity of the Plate. In 1974 Professor James D. Hart, Director of the Bancroft Library, instituted a reevaluation of the authenticity of the Plate of Brass and the present work is part of that study.

XBB 775-5063

Fig. 1

XBB 775-5064

Fig. 2

XBB 775-5065

Fig. 3

XBB 775-5062

Fig. 4

XBB 775-5199

Fig. 5

XBB 775-5066

Fig. 6

Effective thickness* of Plate of Brass

*Values assume constant density and homogeneous chemical composition

Add 100.0 mils to all values

1 σ precision from counting error = 0.6 mils

XBL775-1011

Fig. 8

00000000-87000/00009

This report was done with support from the United States Energy Research and Development Administration. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the United States Energy Research and Development Administration.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720