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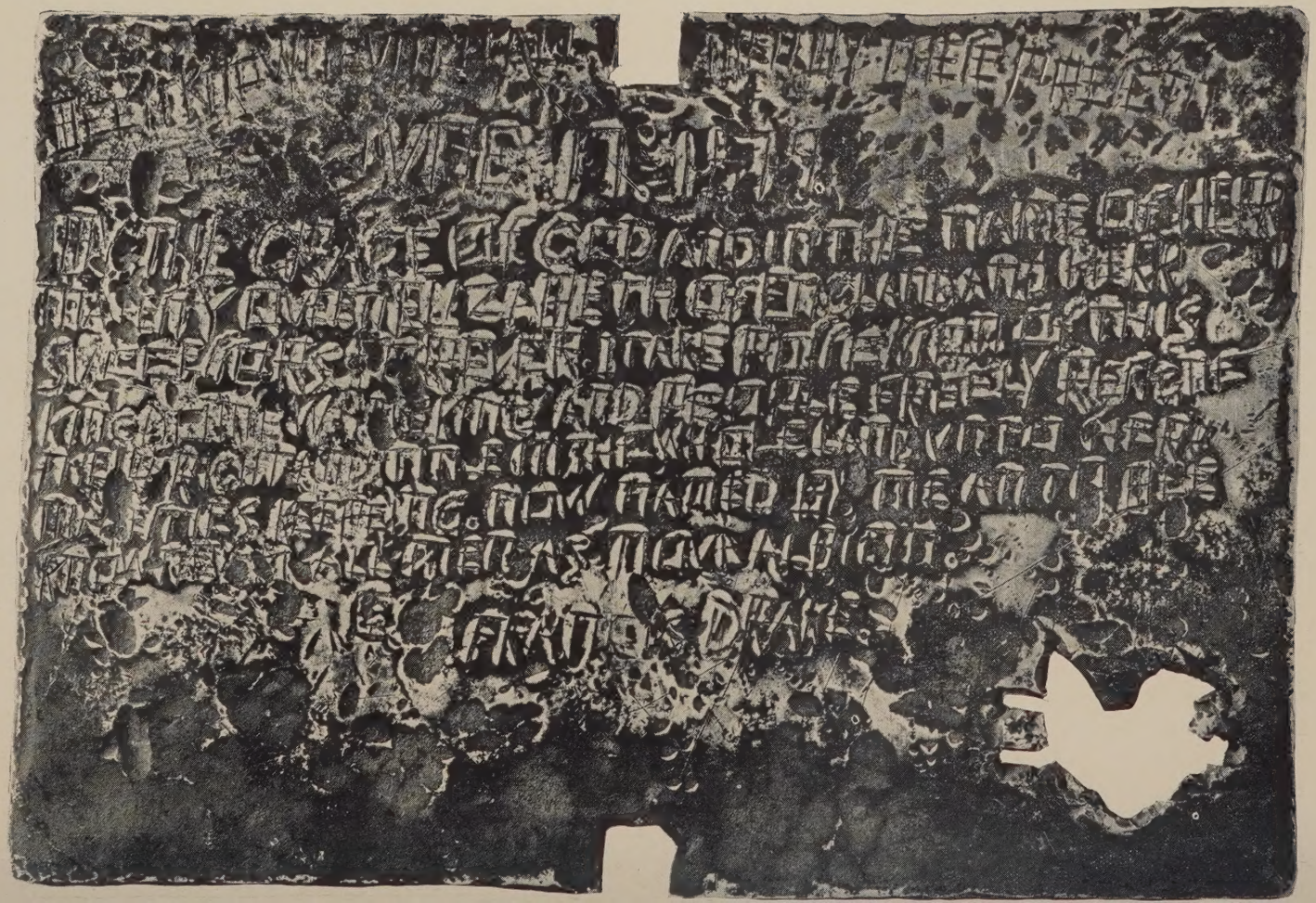

DRAKE'S PLATE OF BRASS AUTHENTICATED

The Report on the Plate of Brass

by COLIN G. FINK, Ph. D., D. Sc., Head of the Division of Electrochemistry, Columbia University, and E. P. Polushkin, Consulting Metallurgical Engineer

With a foreword by Allen L. Chickering, President of California Historical Society, and a Biographical Note on Professor Fink by Joel H. Hildebrand, Ph. D., Professor of Chemistry, University of California.

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SAN FRANCISCO: CALIFORNIA HISTORICAL SOCIETY

Special Publication No. 14

Attention is called to Special Publication No. 13, issued April, 1937, under the title, "Drake's Plate of Brass," to which the present volume is a sequel.

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Drake's Plate of Brass

ITS PAST AND PRESENT BRIEFLY TOLD

By Allen L. Chickering

In June, 1579, Francis Drake landed in California to recondition his vessel, the *Golden Hinde*. He remained for about six weeks. When he left he set up a post on which was nailed a plate bearing an inscription. According to *The World Encompassed by Sir Francis Drake*, published in 1628, this Plate was of brass and was accompanied by a sixpence of current English money bearing the picture of Queen Elizabeth, showing itself "through a hole made of purpose" through the Plate.

On a day in the latter part of June or the early part of July, 1936, a young Oaklander named Beryle W. Shinn, while picnicking, picked up a piece of metal on a ridge at the head of San Quentin Bay, an arm of San Francisco Bay, and carried it home, believing that it was a piece of iron and might serve to cover a hole on the inside of his automobile. Some months later, when he started to make use of it for that purpose, he discovered that it seemed to bear some inscription, so he took it into the house and scrubbed it but was able to make nothing of the inscription. Being curious, he showed it to some friends, among them a former pupil of Dr. Herbert E. Bolton of the University of California, who advised that Mr. Shinn show it to Dr. Bolton. Dr. Bolton at once recognized it and believed it to be the Plate set up by Francis Drake in 1579. He consulted with Mr. Allen L. Chickering, President of the California Historical Society, who organized a group of members of that Society to acquire the Plate from the finder and present it to the University of California.

Announcement of the finding of the Plate was made at a meeting of the California Historical Society held April 6, 1937, at the Sir Francis Drake Hotel in San Francisco, and an account of the Plate, its discovery, the speech of Dr. Bolton announcing its discovery, and the historical accounts relative to setting it up, were published by the California Historical Society under the title of "Drake's Plate of Brass" in 1937.

Upon the announcement of its discovery, Mr. William Caldeira, a chauffeur employed by Mr. J. B. Metcalf, in Piedmont, came forward and announced that he had more than three years theretofore found the same Plate on the Laguna Ranch owned by Mr. Leland S. Murphy. This

ranch is in Marin County and borders on Drake's Bay. At the time he found it, he had driven his then employer, Mr. Leon Bocqueraz, Vice-Chairman of the Bank of America National Trust & Savings Association, to the Laguna Ranch to hunt. While Mr. Bocqueraz was engaged in hunting, Mr. Caldeira passed the time in walking around. While doing so, he saw and picked up a plate in the Y between two intersecting roads near the Laguna Ranch house at a point about one and a half miles interior from Drake's Bay. He states that he washed the plate in a creek and that he was able to make out the letters "Drake" in the signature at the foot of the plate, but could not make out any other words. He thought that the printing was foreign writing of some kind. He showed it to Mr. Bocqueraz when he returned from hunting, which Mr. Bocqueraz remembers. However, Mr. Bocqueraz was very tired and remarked that it was probably something off a ship and that he did not care to look at it. Mr. Bocqueraz stated later that he had intended to ask Caldeira to show him the plate when he got back to the Club at which he was staying, but that the matter slipped his mind. Caldeira kept it for several weeks and then, according to his story, threw it out of his automobile on the right hand side of the road from San Quentin to Kentfield in the first meadow after one leaves the intersection of the San Francisco-San Rafael road and the San Quentin-Kentfield road. It should be noted that Caldeira could not have thrown it far enough so that it could have fallen at the place where Shinn found it. Accordingly, some other agency than Caldeira must have intervened between the time he threw it away and the time that Shinn picked it up. On being shown the plate, Caldeira stated that he was sure that it was the same plate as the one he had picked up because he remembered the hole in it and because of the name "Drake" on it. He did not remember the notches at the top and bottom of the plate. He stated that at the time he found it, it was very dirty and not nearly as clear to read as when it was shown to him for identification.

Following the announcement of its discovery, the Plate on or about April 12, 1937, was physically delivered to the University of California, together with a sum of money for the purpose, among others, of being used for such test or tests as to the genuineness of the Plate as might seem desirable.

As was to be expected, the announcement of the discovery of the Plate was attended with great interest and some expressions of doubt as to its authenticity.

Dr. Robert G. Sproul, President of the University of California, accordingly appointed a committee, consisting of Professors Herbert E. Bolton, J. M. Cline and Joel H. Hildebrand and Mr. Allen L. Chickering, to determine upon and have made such tests as to the authenticity of the Plate as in its judgment seemed proper. At its first meeting the Committee decided unanimously that any tests of the Plate itself should not be made by anyone connected with the University of California on account of the interest of the University in the Plate. It was the Committee's belief that the matter should be submitted only to an expert of the highest quality, not connected with the University of California and entirely impartial. The selection of such an individual was a matter of great difficulty and required much correspondence, study and thought.

The public generally, especially those who were but little informed, believed that if this or that chemist or metallurgist could have a small piece of the metal of the Plate, he would be able to determine in a few minutes whether it was ancient brass or not. This view was not shared by the best informed gentlemen who were consulted, all of whom believed that it was a question to be submitted only to an expert of the highest standing. In spite of constant pressure and suggestions, however, the Committee decided not to be hurried but first to make sure that it was right and then proceed. Finally it was decided to refer the matter to Dr. Colin G. Fink of Columbia University, New York, he being in the opinion of the Committee the best qualified man in the United States to make the investigation. Dr. Fink was indeed fortunate to be able to enlist the services of George R. Harrison of Massachusetts Institute of Technology, a recognized expert in spectroscopy. He also had the assistance and collaboration of other eminent scientists, who are mentioned in his report which is printed herewith. The Plate itself was in the hands of Dr. Fink and his associate, Dr. Polushkin, for more than seven months. Information submitted to them at their request included a report on the climate and temperatures of the region in which the Plate was found or in which it might have been set up, by Prof. John Leighly of the University of California; a report on the geology of these regions by Dr. O. P. Jenkins, Chief Geologist of the California State Mining Bureau, and samples of soil from the place where Shinn found the Plate, the place where Caldeira found it, and from the site of the Francis Drake Monument at Point Reyes. No one taking the trouble to read Dr. Fink's report can doubt the care, thought and industry of which it is the result. Also it will be apparent to anyone reading his report that the determination of the factors

surrounding the authenticity of the Plate was by no means the easy matter which so many people in good faith believed.

It is submitted that the time taken in selecting the proper expert to make the investigation, and the time consumed in making the investigation, have been fully justified. The results of Dr. Fink's investigation speak for themselves.

The report herewith appended on the examination of the Drake Plate is respectfully submitted to the owners of the Plate by:

Colin G. Fink,
Ph. D., D. Sc.

E. P. Polushkin

E. P. Polushkin

Electrochemical Laboratories,
Columbia University,
New York City.
Sept. 16, 1938.

The Report on the Plate of Brass*

By Colin G. Fink[1] and E. P. Polushkin[2]

Introduction

Professor H. E. Bolton, of the University of California, submitted to the senior author for examination a metal plate with an engraved inscription, attributed to Sir Francis Drake. The complete text of the inscription is given in the pamphlet, *Drake's Plate of Brass. Evidence of His Visit to California in 1579,* San Francisco, California Historical Society, MCMXXXVII. Professor Bolton advised that this plate had been found on the northern shore of San Francisco Bay in 1936, that the text of the inscription on the plate corresponds closely with the data cited in the book, *The World Encompassed by Sir Francis Drake,* published in London in 1628 and based on the notes of Chaplain Francis Fletcher, one of Drake's party, and that, in all probability, the plate submitted to us for authentication is the one that had been fastened to a post by Drake's order during his stay at California in 1579. We were requested to make a careful study of the plate in order to ascertain whether it was genuine.

Although the text of the inscription closely corresponds with Fletcher's data, it was not considered a sufficient proof of the genuineness of the plate, since anybody could have referred to *The World Encompassed by Sir Francis Drake,* composed an inscription based on data recorded therein, and then engraved it on a brass plate. Objects of art, as well as historical relics, are so often copies or so basely fraudulent that such a critical attitude was fully justifiable. Accordingly, it was decided to undertake an independent, thorough examination of the plate from every possible angle, with the object of uncovering any and all proofs of fact or fraud.

It was necessary to examine under the microscope not only the metal structure but also all details on the surface of the plate, its workmanship and patina. In addition, the metal, patina and soils in which the plate

* Throughout this report the word "plate" invariably refers to the plate or plaque submitted to us as the Drake Plate.

1. Head, Division of Electrochemistry, Columbia University, New York City.

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had lain buried had to be analyzed, aside from many other tests detailed below. The results of certain of these tests had to be compared with data on modern brass as well as with data on well-known old brass of the period to which the Drake Plate would belong. The large number of tests involved in this study and the difficulty and delay experienced in obtaining acceptable specimens for comparison study were chiefly responsible for the prolonged period of this investigation.

The Shape and Dimensions of the Plate

The plate has a rectangular shape,[3] but the length of opposite sides is not exactly the same. The upper side is 201 millimeters; the lower, 204 millimeters; the right, 138 millimeters; and the left, 135 millimeters. This difference in the length and width is easily noticeable even without measurement. In general, the plate exhibits poor workmanship and a hasty execution of the inscription. The upper and the right sides of the plate are markedly curved, the right half of the lower side is not in line with the left half. Two notches, presumably for the spikes used to fasten the plate to the post, are not in the middle of the long sides but 4 or 5 millimeters off toward the left. The crude workmanship is especially evident in the appearance of the hole which, according to Fletcher, was made to hold the sixpence. This hole was very roughly cut by means of a chisel. (Figs. 1 and 2.)

The thickness of the plate varies from 3.15 millimeters to 3.35 millimeters. It should be noted, however, that the presence of numerous dents and other surface irregularities is partly responsible for the variations in the thickness. If the plate is genuine, it was not rolled, since the process of rolling brass had not yet been introduced at the time of Drake. The shaping of large brass plates during that period was done with heavy hammers which, however, produced plates of more or less uniform thickness, and any variations in thickness could be made very small. Brass household objects of the same period which we have examined for comparison were made of sheets of uniform thickness. Consequently it is difficult to draw any definite conclusions as to the method of manufacture of the plate submitted to us merely from variations in thickness of the plate.

3. See Frontispiece.

It appears certain, however, that the plate was cut from a larger plate and with a chisel, since the cut edge still bears chisel marks. (Fig. 3.) The larger plate had apparently been under-cut from both sides, thus producing the uneven and slightly convex edges shown in Fig. 3. Undercutting was largely applied to the back surface, and a burr produced on the opposite or front surface of the plate was later partially flattened out. Traces of the burr are still visible at the edge of the plate. (Fig. 4.)

The shape of the hole for the insertion of the coin is shown in Figs. 1 and 2. The lower edge of the hole was rounded and split with a chisel so as to form a groove in which the coin could rest; three small prongs protruding from the upper edge of the hole and from the sides were slightly bent in opposite directions, presumably in order to support the coin from both sides. Two perpendicular distances between the extreme edges of the hole in horizontal and vertical directions were 22 and 16 millimeters respectively. (Fig. 1.) In order to verify the above assumptions that a hole of the given dimensions could hold a sixpence coin, we placed a sixpence of Elizabeth's time in the hole. We found that the groove and prongs held the coin well in place, as shown in Fig. 5. The particular coin we used was dated 1561. The rose[1] behind the Queen's head is seen in the photograph.

Examination of the Engraved Letters

When we received the plate for examination, its front surface had unfortunately been cleaned and the patina, valuable from the attribution point of view, had largely been removed. The back surface of the plate was, we believe, in the condition in which it was found. A part of the face of the plate and the entire back surface were still covered with a black deposit.

The letters of the inscription, our investigation has shown, were composed of deeply cut grooves which, when we received the plate, were partly or entirely filled with a black coating similar to that found on the back surface of the plate. Each individual groove was examined under the microscope at magnifications of 50 to 200 diameters. The importance of this individual examination is self-evident because in case of fraud there is always the chance of finding a hidden area which would disclose a fresh, corrosion-free surface of the metal or a trace of artificial treatment. In this case, however, most of the grooves were filled with the black deposit or, when the grooves were not filled, their walls were found to be

1. *English Coins*, by George C. Brooke, Lincoln MacVeach. The Dial Press, N. Y., p. 193.

completely coated with the black substance which adhered firmly to the metal. In only a few grooves organic fibers were found lying loosely and not imbedded in the coating. Undoubtedly these fibers were forced into those grooves by rubbing the surface with a cloth during the cleaning operation carried out before the plate was received by us. No indication or clue of artificial patination of any kind was discovered by us in the grooves. The coating appeared black but contained occasional specks of red or brown material.

The majority of the letter grooves have smooth areas bordering on the left sides or edges of the grooves and on the top edge. (See for example the letters in THE, also N, Y, and Q in Fig. 6.) These smooth areas on the plate next to the grooves produced a certain illuminating effect and it is possible that they were purposely made to facilitate reading. They could have been produced by a slanting cut with a chisel so that one side of the metal of the groove was raised and then, subsequently, this raised section was levelled down with a tool.

An interesting detail which we observed in the lettering was the "parallel lines," a series of fine, parallel grooves located near many of the letters. (Figs. 6, 7 and 8.) In most cases these lines were parallel to the letter grooves. Sometimes the lines were so close to each other that two or three of them could be counted in the width of one millimeter. The closeness of these lines to each other and their strict parallelism indicate that they could not have been made by hand one by one. If they had been made with a hand chisel (which is most probable), a special holder for the chisel fastened to a bench might have been used. It seems most plausible that these lines represent a series of marks in the brass surface left by the cutting edge of the tool in its gradual approach to the final position at which the tool edge was driven into the metal. Such parallel marks can be made today with a modern pneumatic tool but not readily with a hand chisel. We were not able to duplicate such parallel lines on a piece of modern brass using a hand chisel and we found no explanation for these parallel lines in an old treatise on methods of engraving as practiced in Drake's time;[5] but upon consulting Mr. S. V. Grancsay, an expert on armor at the Metropolitan Museum of Art, New York City, he stated that parallel lines such as we observed in the plate were occasionally found on old brass armor. It is also possible that, due to limited equipment of the machine shop on board Drake's ship, some unusual, homemade,

5. Abraham Bosse, *Traité des manieres de graver en taille douce sur airain par le moyen des eaux fortes et des vernix durs et mols,* Paris, first edition, 1645.

mechanical device was used in cutting the letters into the plate. The chisel may have been securely fixed over the plate and the plate moved about after each groove had been cut.

It was surprising to us to find that some of the grooves still had sharp, well-preserved edges, but this could be attributed to the energetic cleaning of the surface before we received the plate which removed part of the patina and polished the metal underneath. The surface everywhere else, where not thoroughly cleaned, appeared old.

As in any old brass, the surface of the plate shows numerous defects such as cracks, pits and corroded areas. (Figs. 9-11.) In Fig. 11 two layers of corrosion products can be seen: a lower layer which is in direct contact with the metal, and an outer layer on top of the first. Where the edge of a letter groove is badly pitted, due to corrosion, two layers can also be seen inside the groove. These corrosion layers will be discussed in detail further on in this report.

Indentations

The face or front surface of the plate has many indentations, large and small, scattered all over the plate. (Figs. 12-15.) Examination showed that these are not accidental markings but were made by a tool or weapon: they all show more or less similar deformation lines on the depressed surface. Practically all of the indentations were made *after* the letters had been engraved. This is evident in the frequent distortions of the letter grooves such as in the case of the letter "I," Fig. 8, numeral "9," Fig. 13, and the letter "K" in Fig. 14. The origin of the indentations is of interest. On cursory examination they appear to have been made by scooping out the brass with a sharp tool, perhaps with a round-edged chisel. The presence of deep flow lines in the bottom of the large indentations (see Figs. 6 and 15) and the absence of a corresponding bulge on the back of the plate may easily lead to this conclusion. But when an experiment was made by us with a modern brass sheet by striking its surface with a sharp-pointed steel hammer in oblique, slanting fashion, indentations similar to those on the plate were produced. On account of the low angle of inclination of our strokes, no bulge was produced on the opposite side of the sheet. It is possible that the indentations on the plate were made by the Indians who were afraid of a mysterious or hostile power of the plate and after the departure of Drake tried to destroy the plate by striking its surface with their tomahawks; they were not familiar with the toughness of metals.

This assumption of ours was fully supported by Dr. W. C. Orchard, of the Museum of the American Indian, New York City, whom we consulted in regard to these indentations. He expressed the opinion that indentations of this kind were, most probably, made by stone axes or celts used by the Indians. A typical view of an Indian stone ax is shown in Fig. 16. When the surface of a modern brass sheet was struck with this ax in oblique direction, the indentations produced were very similar to those on the plate, as may be seen in Fig. 17. Small, triple indentations visible in the center of Fig. 8, and on the right side of Fig. 12, may have been made by a stone ax with a blunted edge.

Examination of the Back Surface of the Plate

The typical appearance of the back surface of the plate is shown in Fig. 18, magnified three times, and in Figs. 19 and 20, magnified thirty-five times. With the exception of a few bare areas free from patina, the whole surface is covered with a black deposit. Microscopic examination disclosed that this deposit contains small inclusions of red and brown minerals scattered all over the surface. Upon further microscopic examination we found this deposit to be composed of two layers. The upper layer could easily be detached by scraping with a razor blade, but the underlying layer adhered very firmly to the metal base. The lower layer is usually of a light brown or dark brown color. In some areas on the plate, the lower layer has a smooth surface—see, for instance, the black, circular area located in the center of Fig. 21.

Small amounts of the two-layer coating on the plate were scraped off at different points of the surface and also out of the letter grooves. The scrapings were then placed on a glass slide and examined under the microscope. In order to reveal the natural colors of the components of the scrapings and the actual shape of the individual particles, they were examined under diffuse illumination. We found that the coating of the plate is a conglomerate of a black substance, the real nature of which was not distinct, and several minerals of brownish and red color (Fig. 22). Some of the black particles displayed a fibrous structure and resembled charcoal.

In order to determine the chemical nature of the deposit, the surface of the plate was rubbed with a small wad of cotton soaked in warm water. No visible change in the appearance of the coating was noticed. The

coating, therefore, is not soluble in water. Similar tests were made with benzine, alcohol, and a phenol solution in place of water in order to see if the coating contained a lacquer or a resin. The results were all negative. Although the wad of cotton sometimes became black, its coloring, we found, was caused by the mechanical dislodgment and adhesion of detached dark particles of the coating.

Tests for the presence of chlorine were made by rubbing the surface with a wad of cotton soaked in warm water and then testing the water in the wad with a solution of silver nitrate. This test likewise gave negative results.

A test for sulfur was made by fusing the scrapings with potassium hydroxide, adding water and then silver nitrate. This test gave positive indications of the presence of sulfur, suggesting sulfide minerals as a component of the patina.

Resistance to salt water was tried by placing a small tube with water containing 3 per cent sodium chloride (approximately the sodium chloride content of the Pacific Ocean) on the surface of the coating and keeping it over night. The edge of the tube next the plate was sealed to the surface with paraffin. No change was found in the coating of the plate.

The most important results were obtained when the scrapings were heated on a platinum crucible cover for from two to three minutes. After heating, the color of the scrapings was visibly changed. Examination under the microscope showed a striking difference in the appearance of the particles. Their black color had almost entirely disappeared and the originally homogeneous mass could now be classified into four differently colored minerals. The prevailing mineral had a pale orange color, sometimes varying from pure red to almost brown. Next in abundance was a black mineral, then a white—almost colorless—one, and, finally, a deep blue mineral. Elaborate identification of these minerals could not be made in view of the very small amount of each mineral available for examination. It is certain, however, that the pale-orange and red colors can be attributed to the presence of cuprite (Cu_2O), while the brown, colorless and blue shades are due to calamine ($ZnCO_3$) which will take on these shades if it is contaminated by other metal carbonates.[6]

Fig. 23 shows particles before heating, and Fig. 24 after heating. Unfortunately, the change in color from black to red, brown, blue, etc., could not be reproduced in the monochromatic photomicrographs.

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6. Henry A. Miers, *Mineralogy*, Macmillan Co., New York City (1907).

This experiment was repeated twice with scrapings taken from various parts of the plate and in both cases, again, the same results were obtained as in the first experiment. The appearance of sparks during the first stages of the heating on the platinum cover is to be attributed to the burning-out of carbonaceous matter which is mechanically mixed with the mineral constituents. On this account, the volume of the powder was markedly decreased after the heating. The black color of the coating on the plate we concluded is due chiefly to the presence of finely divided carbon.

A parallel examination of the patina on old museum brass objects of the 16th and 17th centuries was made for comparison. The patina of these objects was found to contain mostly white, brownish, and red minerals closely resembling those found in the scrapings from the plate after heating the scrapings (Fig. 25).

All of the results of the examination of the coating on the plate point to the conclusion that the coating is a genuine patina gradually formed during a long period of time. Indeed, it is highly improbable that such an aggregate of minerals and carbonaceous particles, firmly adhering to the metal, could have been produced artificially. Originally, undoubtedly, the patina covered the whole surface of the plate and thus protected it from further corrosion. The protective quality of the patina readily accounts for the good condition of the plate even after more than three centuries' exposure (whole or partial) on the shore of the Pacific.

In addition to the above study of the patina of the plate, a microscopic study was made of the patina on a small piece of metal cut from the plate. The results of this study will be found further on in this report.

Examination of the Material from the Coin Groove

Material located in the groove (which had presumably been cut into the lower edge of the hole in order to support the sixpence) was removed, and a portion placed on a glass slide and examined under the microscope. Another portion was imbedded in a special cement in order to prepare finely polished sections of the particles composing the material.

Examination of the unpolished material or powder placed on the glass slide disclosed that some of the particles had a distinctly fibrous structure and in their general appearance closely resembled charcoal (Fig. 26); other particles, also black in color, had a decidedly different structure and appearance and occasionally showed small inclusions of brown minerals.

Examination of polished sections of the material out of the coin groove confirmed the presence of the two black substances, organic and mineral. We also found some remnants of plant tissue in the groove material in which the cells seemed to be impregnated with the same black mineral substance which was found everywhere on the surface of the plate. (Fig. 27.) In order to prove that these plant cells were mineralized, the specimen examined was subjected to heating to high temperature by which process any carbonaceous or cellulose cells would have been destroyed. But after the heating the microscope revealed that the mineralized plant tissue had remained intact. In another experiment, particles of the material from the coin groove showing plant cells under the microscope were heated directly on the platinum cover, as it was thought that when the particles were imbedded in the mounting cement, as was done in the first experiment, the cement might have protected the cells against burning. However, the result we obtained in the second experiment was the same as that of the first: The plant cells were undoubtedly mineralized.

Occurrence of this mineralized organic tissue in the coin groove proves without any doubt that the plate had been lying on the ground, or was buried in the surface layer of the soil, for a long time, since impregnation of organic tissue with minerals is a long, slow process. Finding petrified organic remnants in the cavities of ancient metals always provides an unquestionable proof of their authenticity.

The observed results of heating the bulk of the black material taken from the coin groove were, in general, the same as those upon heating the scrapings from the coating of the plate; that is, the black substance of the powder from the coin groove was largely changed into pale orange, red and brown particles with only occasional inclusions of black mineral.

Microstructure of the Metal and Patina of the Plate

For the microscopic examination of the metal of the plate, as well as for spectrographic analysis, it was necessary to cut off a small piece of the plate. The best place for cutting off the specimen was the edge of the hole presumably intended for the coin, because it has an irregular shape and the missing bit of metal would not be noticeable. It was decided to cut off a small, triangular projection of the edge which was in a deep recess and, therefore, was not needed for the support of the coin. The metal specimen is shown at S in Fig. 28 in natural size. Its weight was 225 milli-

grams and the dimensions were 6.5 millimeters long and 3 millimeters wide. Judging from the appearance of the cut to the naked eye, the metal of the plate is dense and normal. The small metal specimen was mounted in a soluble siliceous cement which could easily be removed if the specimen needed to be remounted. The first polished section was prepared parallel to the saw cut. It is marked I in Fig. 29. After examining and photographing the structure, the second section (II) was polished as shown in the sketch, Fig. 29; then the specimen was removed from the cement and part of it (approximately 60 to 70 milligrams) was cut off for spectrographic analysis. The remaining piece of metal was remounted. Two more sections (III and IV) were later prepared, one after another, for microscopic examination. In this manner structural characteristics of the metal were studied in four different sections. In each case our aim was to study: (1) inclusions and cracks; (2) products of corrosion at the edge of the sections; and (3) the structural constituents of the metal.

Inclusions: Under the microscope the metal revealed an excessive amount of inclusions, as may be seen from Figs. 30-32 which show the typical appearance of the polished sections (unetched) at three different magnifications. The inclusions observed represent impurities of different kinds. The large amount of impurities present is very characteristic of all old metals due to the comparatively crude methods employed in their smelting and refining. In the 16th Century or earlier, all brass was made by smelting copper and zinc ore (calamine), together with fine charcoal. Salt was added as a flux.[7] Although the liquid alloy was skimmed before pouring, some foreign substances contained in the calamine, in the copper and in the gangue were only partially eliminated and, accordingly, various impurities passed into the alloy.

The chemical identification of the inclusions in an old metal is even more important than their quantity in determining the genuineness of such old metal. Some of the small inclusions found in the metal of the plate have an unusual color, brown or red. Although the real chemical nature of the compounds of these inclusions could not be established due to the very minute size of the inclusions, still we feel justified in stating that such inclusions do not occur in modern brass. Probably the inclu-

7. Ecker, *Untererdische Hofhaltung*, published in 1672. See also articles by Galon, Swedenborg, Duhamel du Monceau in the *Proceedings of the Royal Academy of Sciences*, Paris, 5, (1764); Swedenborg's Treatise on Copper, translated into English by Arthur Hodson Searle, Brit. Non-ferrous Metals Research Assn., *Miscell. Publ.* #333, (Section II), Chaps. 43-49, "Brass and Its Preparation" (1938).

sions we observed in the plate are traces of calamine, certain varieties of which have these brown and red colors.

Large inclusions were rarely found in the metal sample of the plate. Fig. 33 shows a relatively large inclusion which was identified as a grain of quartz sand.

In regard to the number and nature of inclusions, the metal of the plate showed a close similarity to that of well-known old brass which was examined by us for comparison's sake. See, for example, brass of the 17th Century in Fig. 34. This photomicrograph shows a cold worked sheet of brass, the structure of which was developed by etching. Numerous inclusions appear in the photomicrograph of this old brass as black dots; they are scattered throughout the metal and are mostly of a dark brown color, although some are distinctly red.

In Section I of the metal specimen cut from the plate we found small, globular inclusions arranged not in a straight line but, on the contrary, in a wavy line following a fine wavy crack (Fig. 35). In old brass, the cracks are often caused by the presence of impurities and in this case the peculiar, wavy arrangement of the fine inclusions was very indicative. If the metal had been rolled, the inclusions would be strung out in virtually straight lines parallel to the direction of rolling. The rolling process began to be used in the copper and brass industry at the end of the 17th Century; before that time, all brass objects had been worked by hammer.[8] The use of large hammers might have the same effect on the structure as rolls, but small hammers necessarily produce local irregularities in the structure and particularly in the arrangement of the inclusions. This is illustrated in Fig. 36, which shows inclusions in one of the well-known old brasses examined for comparison. Here inclusions are elongated, but they are not parallel to each other as would necessarily be the case in a rolled sheet.

We could not find even a slight indication that the plate before us had been rolled. On the other hand, we did find evidence that the plate had been hammered. The character of the surface of the plate, as well as the wavy arrangement of the inclusions, point to hammering rather than to rolling as the method used in making the plate.

Cracks: Cracks are very common in old brass. In this specimen we found them in every section examined. Fig. 37 shows a typical one.

Corrosion of the Metal: The original, exposed edge of the cross section

8. *Copper through the Ages,* published by the Copper Development Association, London (1934).

of the polished specimen of the metal of the plate was found to be corroded. Fig. 38 shows a solid layer of corrosion products and also how from this layer the incipient corrosion extended into the body of the metal. This layer was the lower layer of the patina already referred to above.

Fig. 39 shows a cross section of the outer layer of the patina. Here patina is mixed with accidental inclusions such as sand particles.

In some places, streaks of metallic copper were disclosed at the outer edge of the metal. One of these copper streaks is shown in Fig. 40, the color of the copper not being reproduced in the monochromatic photograph. This copper streak is in close contact with a string of mineral particles, products of corrosion. Accumulation of metallic copper as a result of corrosion is very frequently found in corroded specimens of brass and bronze.

All of the results of our microscopic study of the cross section of the patina of the plate confirm our conclusion arrived at after the preliminary examination of the patina, namely, that the coating on the plate is a genuine, old patina, gradually formed during a long period of time.

Structural Constituents of the Metal

To develop the microstructure of the metal, the polished sections of the metal specimen of the plate were etched with ammonium hydroxide plus a few drops of hydrogen peroxide—the usual reagent for copper and brass. In some cases, however, it was found necessary to use ammonium persulfate solution as etching reagent. A light etching with ammonium hydroxide solution brought out the Cu-Zn beta constituent which is present only in very small amount. Fig. 41 shows small areas of beta (darkened by etching) in the alpha background which had not been completely etched. And Fig. 42 shows two streaks of beta constituent in the fully etched background of alpha. A trace of beta was found in all sections examined. This indicates that the composition of the brass of the plate lies at the boundary between the fields of alpha alone and alpha plus beta. This boundary for slowly cooled alloys is at 39 per cent zinc, balance copper, but in rapidly cooled alloys a trace of beta may occur even at 34 or 35 per cent zinc. These per cent values are correct for pure copper-zinc alloys; if other elements are present, the boundary may be displaced. Spectrographic analysis (see below) showed only small amounts of foreign elements in the plate, and it is safe to conclude that the zinc proportion in the metal lies within the range of 34-39 per cent.

Typical views of the microstructure of the metal of the plate are given in Figs. 43 and 44 after etching with ammonium hydroxide, and in Figs. 45 to 47 after etching with ammonium persulfate. The most striking characteristic of the structure revealed is the large variation of grain size. Although the maximum area of the sections examined was less than 18 square millimeters, grain size varied widely, as shown in the photomicrographs. In some areas all grains were fine, as in Fig. 47, which represents the structure at the narrow end of the section I; in other areas all grains were large, or large and small grains were mixed together. (Figs. 43, 44, 45, 46.) The grains were generally polygonal and twinned, and in some of them deformation lines (slip markings) were noticeable (Figs. 45 and 46), caused by cold work, i. e., by working the plate without heating, or working at such a low temperature that the metal was not sufficiently plastic. Judging from the appearance of these grains, the amount of cold work applied was not very great. Compare, for example, Fig. 46 of the plate with Fig. 48 which shows the structure of a typical cold worked brass of the same period, 1500-1600. In the latter, slip markings are much more numerous.

In some sections of the plate the grains were more uniform in size or showed few deformation lines. Obviously the structure of the metal throughout the specimen of the plate was not homogeneous.

Unusual variations in grain size can be accounted for in two ways: First, the annealing of the plate after cold work was at a very low temperature, especially so if the metal was not uniformly heated; and, secondly, the presence of impurities inhibited the grain growth during annealing. This latter effect of impurities has been investigated and described by Maurice Cook and Herbert J. Miller in their paper, "The Effect of Different Elements on the Annealing and Grain Growth Characteristics of Alpha Brass."[9] They found that small additions of iron, manganese, aluminum, silicon, etc., to 70 Cu-30 Zn brass greatly impaired the grain growth. The presence of these four elements in the plate before us was established by spectrographic analysis. (see below). Their distribution throughout the metal is not uniform, as is often the case with impurities in old metals. In those sections of the plate which were especially rich in certain impurities, grain growth could be easily retarded.

It should be noted, however, that such variation in grain size as we observed in the plate is not always found in old brass. We have examined several specimens of well-known old brasses and found it in only one;

9. The Institute of Metals, London (1932).

even in this one, variation was not as pronounced as in the plate before us. This is probably due to the fact that all of the specimens of old brass examined by us for comparison were thin sheets, fabricated more carefully than the plate. But there is no doubt that widely varying grain size and an excessive amount of enclosed impurities, especially of unusual nature, indicate lack of skill in the manufacture of the plate. Some other observations, such as the presence of cracks and chemical inhomogeneity of the metal, point to the same conclusion. Cracks were frequently found in all sections of the metal of the plate. (See Figs. 47 and 49.) The latter photomicrograph, Fig. 49, shows the same crack as Fig. 35, but after etching.

Chemical inhomogeneity of the metal was apparent in all sections of the plate examined which, after etching, displayed reddish streaks. These could be seen distinctly under an ordinary magnifying glass but were not clearly visible under the microscope since the difference in color was too faint. For this same reason they could not be properly photographed. Repeated etching and repolishing proved that this difference in color was not caused by a surface staining of the metal but originated undoubtedly from some chemical inhomogeneity of the metal itself. It is well known that alpha brass in cast condition consists of two different portions of alpha solution, copper-rich and zinc-rich, which have different colors under the microscope. In modern brass this difference in the chemical composition of two portions of alpha is entirely eliminated by subsequent mechanical and thermal treatment, but in old brass, which was worked by crude methods, a trace of the original heterogeneity can always be expected.

Chemical Composition of the Metal

On account of the very small amount of metal available for analysis, the chemical composition of the plate could be determined only by spectrographic analysis. About one-third of the specimen used for microscopic examination (60-70 milligrams) was cut off and sent to Professor George R. Harrison of the Massachusetts Institute of Technology with the request that he make a preliminary qualitative determination of elements present in the metal. The following results were reported by him:

Major constituents: copper and zinc.
Minor constituents: magnesium, iron and cadmium.
Small amount: silver, silicon and tin.
Very small amount: calcium, aluminum, manganese and antimony.

The proportion of the two principal elements, copper and zinc, has already been determined approximately by the microscopic examination which showed that the metal is brass with 34-39 per cent zinc. A more accurate determination of the zinc percentage was of no importance. Of the three minor elements magnesium was the most interesting since it is not as common in modern brass as are iron and cadmium. If it is present in larger amounts than found in modern brass, this will suggest an old origin of the plate because all brass of Drake's time was produced from mixtures of copper and calamine, and the latter mineral always contains magnesium. Although the chemical formula of calamine is $ZnCO_3$, it seldom occurs in the pure state, being usually intermixed with other carbonates such as $MgCO_3$, $FeCO_3$ and $CaCO_3$.

A quantitative estimate of the silver present was also of interest because copper used in the making of brass in Drake's time was not refined and, in case the copper contained silver, the latter should have passed into the brass.

For these reasons it was necessary to analyze the specimen quantitatively for magnesium and silver, and Professor Harrison reported the following proportion of these elements:

Magnesium: 102 parts per million or 0.0102%.

Silver: 3.6 parts per million or 0.00036%.

Contrary to expectations, a much smaller amount of magnesium was found, and the percentage of silver is so insignificant that it can be entirely ignored.

We were not able to find in the literature any indication of the presence of magnesium in modern brass amounting to more than 0.002 per cent. It appears possible, however, that minute quantities of this element can be transferred to molten brass from zinc in which magnesium is sometimes found. E. H. Kelton in his paper, "Wrought Zinc and Zinc Alloys,"[10] refers to a grade of zinc in which magnesium is 0.007-0.02 per cent. Another source of contamination of the brass by magnesium may be the furnace lining, according to Dr. Alan Morris, of the Bridgeport Brass Company. However, since as much as 0.01% magnesium was found in the brass of the plate, this would indicate that the brass is very likely not modern.

One of the interesting results in the preliminary spectographic analysis was the absence of lead. This element is invariably found in modern brass, whereas in old brasses, according to published data, it may some-

10. *Metals Handbook* (1936), p. 1347.

times be entirely absent. In order to check up the results of the preliminary analysis in regard to lead, a new qualitative determination was made on a second small piece of metal cut from the remaining portion of the original metal specimen cut from the plate. The following elements were reported by Professor Harrison:

> In moderate quantities[11]: lead, magnesium, calcium, iron, silicon, tin and silver.
>
> Present as traces: cadmium, aluminum, nickel, chromium, titanium and antimony.

We next compared the results obtained in the first and second qualitative analyses and found that:

(1) Lead was detected only in the second determination. This discrepancy may perhaps be explained by a very small amount of lead being present and its uneven distribution throughout the metal. The results, however, did not justify us in considering lead as an element of differentiation to decide whether the brass is old or modern.

(2) Magnesium and iron were recorded in both reports in the same group of minor constituents or "moderate quantities."

(3) Cadmium is mentioned in the first report as a minor constituent, and in the second as a trace.

(4) Silver, silicon and tin are reported as being in small amount or "in moderate quantities."

(5) Calcium is reported as present in very small amount or "in moderate quantity."

(6) As regards aluminum and antimony, the results are concurrent.

(7) Manganese is mentioned only in the first report as a trace; nickel, chromium and tin only in the second, as a trace.

(8) No bismuth was found in either sample.

Such discrepancies as noted above in the classification of the elements according to their proportionate quantities are natural for the qualitative determination if all impurities are present in minute amounts, or if they are unevenly distributed in the metal.

Summing up the results of the spectrographic analyses, we must admit that they failed to disclose any indication of the antiquity of the plate except in the case of the amount of magnesium found, which does suggest ancient origin.

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11. In grouping the elements according to their magnitude, we used the same terms as were given in the original reports.

Chemical Composition of the Patina

A small amount of patina scraped off the surface of the plate was analyzed qualitatively in Professor Harrison's laboratory. Two specimens were submitted, one after the other, of 2 or 3 milligrams each. The results are arranged in Table I.

Table I

Chemical Elements Found by Spectrographic Analysis of Two Specimens of Patina Removed from the Plate

	1st Specimen	2nd Specimen
Major Constituents	Iron*	Silicon,* copper,* magnesium.*
Minor Constituents	Copper,* lead,* zinc,* calcium,* aluminum,* magnesium,* silicon,* sodium, tin,* silver,* barium, manganese,* chromium.*	Iron,* zinc,* calcium,* aluminum,* silver,* tin,* lead,* barium.
Traces	Boron, bismuth, cadmium,* strontium, nickel.*	Chromium,* sodium, manganese,* cadmium.*

(The asterisk* indicates the elements found also in the metal of the plate.)

It was surprising to find that, in the first specimen of the patina, iron was present as a major element. On account of this unexpected result, the second specimen was submitted for analysis, and silicon, copper and magnesium were found to be the principal elements. Due to the extreme smallness of the specimens, such striking variations in the important elements of the patina are to be expected. These variations are caused by purely local or accidental conditions in the patina. If, for instance, during the process of patination a part of the plate was in contact with an iron-bearing mineral, this part would be enriched in iron. The latter element is very common in nature and is also present in the plate itself. It is generally known that the patina of all objects buried in the ground absorbs some chemical constituents from the surrounding minerals.

From the table it will be noted that there are five elements in the patina, sodium, barium, boron, bismuth and strontium, which were not found in the metal. On the other hand, two elements, antimony and titanium, present in the plate, were not found in the patina. The latter circum-

stance can easily be explained by the fact that both elements are mentioned as "traces" only.

Altogether fourteen elements identified in the plate were also detected in the patina. This constitutes another substantial proof that the patina is not an artificial coating composed of some foreign substance but that the patina had been formed directly on the plate by a patination process. However, the presence of five foreign elements in the patina not found in the plate needs further explanation. As these elements were probably picked up by the plate from local minerals, it was necessary to analyze the soil in the localities where the plate had been lying in the ground. According to information received from Professor Bolton, the plate might have wandered from one place to another. At our request, Mr. Allen L. Chickering sent us four samples of soil collected: (1) at the place where Mr. Shinn found the plate; (2) just above the beach at Drake's Bay, below the monument erected in 1916 by the Sir Francis Drake Association; (3) at the base of the monument, in the premises of the Coast Guard Station on the Drake's Bay side of Pt. Reyes; and (4) at the place where Caldeira found the plate.

These samples were analyzed in Professor Harrison's laboratory and the results are shown in Table II.

TABLE II

Analysis of Soil Samples

Sample	#S.1	#D.2	#P.3	#C.4
Barium	S	S	S	S
Bismuth	O	O	O	O
Boron	O	O	T	O
Chromium	M	M	M	M
Iron	S	S	S	S
Lead	T	T	T	T
Nickel	M	T	O	T
Sodium	M	M	M	M
Strontium	T	T	T	T

In Table II the letter S indicates that the element is present and is a major constituent, M indicates the presence of the element in moderate abundance, T indicates the element is present but only as a trace, and O indicates that the element was not detected.

From Table II we can see that all those elements found in the patina but not in the metal of the plate, except bismuth, namely, barium, sodium, strontium and boron, were found in soil sample P.3 and, except for boron, the other three, barium, sodium and strontium, were found in all soil samples. Bismuth was present in the patina as a trace only and was not found in the soil samples.

Thus, spectrographic analysis of the soil substantiated our assumption that the patina had been formed on the plate as a natural product of chemical changes in the metal caused by atmospheric conditions and by contact of the plate with the minerals of the surrounding soil.

Summary

(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.

Conclusion

On the basis of the above six distinct findings, as well as other data herewith recorded, it is our opinion that the brass plate examined by us is the genuine Drake Plate referred to in the book, *The World Encompassed by Sir Francis Drake,* published in 1628.

ACKNOWLEDGMENTS

In our investigation of the Drake Plate we were very kindly and ably assisted by a host of fellow scientists and engineers, and it is a pleasure and privilege to express our sincere gratitude to:

Herbert E. Bolton, Chairman of the Department of History, University of California, Berkeley, Calif.

Allen L. Chickering, President of the California Historical Society, San Francisco, Calif.

John L. Christie, Bridgeport Brass Company, Bridgeport, Conn.

C. H. Clark, Brigadier, Secretary, Artillery Museum, Rotunda, Woolwich, England.

Carter S. Cole, Copper and Brass Research Association, New York City.

Welton J. Crook, Professor of Metallurgy, Stanford University, California.

William S. Dewey, Librarian-Curator, American Numismatic Association, Mt. Vernon, N. Y.

G. H. Edgell and W. J. Young, Museum of Fine Arts, Boston, Mass.

S. V. Grancsay, A. Hyatt Mayor and A. H. Kopp, Metropolitan Museum of Art, New York City.

George R. Harrison and Rockwell Kent III, Massachusetts Institute of Technology, Cambridge, Mass.

Joel H. Hildebrand, Department of Chemistry, University of California, Berkeley, Calif.

Henry E. Huntington Library and Art Gallery, San Marino, Calif. Leslie E. Bliss, Librarian, and Roland Baughman, Assistant Curator of Rare Books.

Olaf P. Jenkins, Chief Geologist of the California Division of Mines.

John Leighly, Department of Geography, University of California, Berkeley, Calif.

Alan Morris, Chief Metallurgist, Bridgeport Brass Company, Bridgeport, Conn.

W. C. Orchard, Museum of the American Indian, New York City.

George D. Van Arsdale, Pasadena, Calif.

A Word Concerning Professor Colin C. Fink

By Joel H. Hildebrand*

My particular responsibility as a member of the Committee on the Drake Plaque was to give advice regarding the best method of throwing light upon the authenticity of the plaque through physical and chemical examination. Advice was sought from several persons competent in such matters, among whom should be mentioned particularly Dr. T. A. Rickard, of Victoria, British Columbia, Professor Weldon J. Crook, professor of metallurgy at Stanford University, and Professor Colin G. Fink, head of the Department of Electrochemistry of Columbia University. The outcome was that Dr. Fink kindly consented to undertake the difficult and laborious task of making the desired examination.

No one could have been found better equipped professionally for this work. His professional training and experience have included study in this country and in Germany, research work with the General Electric Company, direction of the research laboratory of the Chile Exploration Company, extensive experience in metallurgical and art research. He is a past president and now secretary of the American Electro-chemical Society; a member of numerous scientific organizations, and the originator of the drawn-tungsten filament used throughout the world today in electric lights. He is an authority upon commercial chromium, tin, and aluminum plating. He has been awarded the Acheson Gold Medal for outstanding accomplishments in electrochemistry, as well as the Perkin Medal.

The work on the Drake Plaque has profited from the unusual interest which Dr. Fink has taken in the problem. He has spent an amount of time and effort and gone into detail to an extent far beyond anything that we have a right to expect from so busy a man. In my judgment, the physical evidence has been presented completely and conclusively.

* Professor of Chemistry, University of California.

A Partial Bibliography of Professor Fink's Writings

"Restoration of Ancient Bronzes," by Colin G. Fink and Charles H. Eldridge, Metropolitan Museum of Art *Bulletin* (1925).

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"Electrolytic Restoration of Metals," based on interviews with Colin G. Fink, written by H. D. Keiser, *Engineering & Mining Journal,* Vol. 130, pp. 163-65 (1930); and in *Engineering & Mining World,* August (1930), pp. 419-21.

"Ancient Egyptian Antimony Plating on Copper Objects," by Colin G. Fink and Arthur H. Kopp. Metropolitan Museum *Studies,* Vol. IV, Part 2, 163-67 (1933).

"The Care and Treatment of Outdoor Bronze Statues," by Colin G. Fink. *Technical Studies in the Field of the Fine Arts,* **2**, 34 (1933).

"Incrustations on Porous Pottery. A New Method of Cleaning without Loss of Pigment Particles," by Colin G. Fink, *Technical Studies in the Field of the Fine Arts,* **2**, 58-61 (1933). A paper read at the June, 1933, meeting in Chicago of the American Association of Museums.

"Chemistry and Art," by Colin G. Fink. Address given by Dr. Fink at the presentation to him of the Perkin Medal, published in *Chemistry & Industry* (London), **53**, 191-95, 216-20 (1934); also in *Industrial and Engineering Chemistry,* **26**, 234-38 (1934).

"Microscopic Study of Ancient Bronze and Copper Objects," by Colin G. Fink and E. P. Polushkin. *Metals Technology* for Feb., 1936, Vol. 3, No. 2, A.I.M.M.E. *Tech. Pub.* #693 (Class E, Inst. of Metals Div. #209). Abstracted in *Technical Studies* IV, 242-44 (1936). See also the following:

"Microscopic Study of Ancient Bronze and Copper," by Colin G. Fink and E. P. Polushkin, *Iron Age,* **137**, 34-37, 106 (1936).

Dr. Fink's process for the restoration of Ancient Bronzes is used in all important museums throughout the world. This past summer (1938), Dr. Fink visited the Vatican Museum at Rome where his process has likewise been adopted.

PLATES

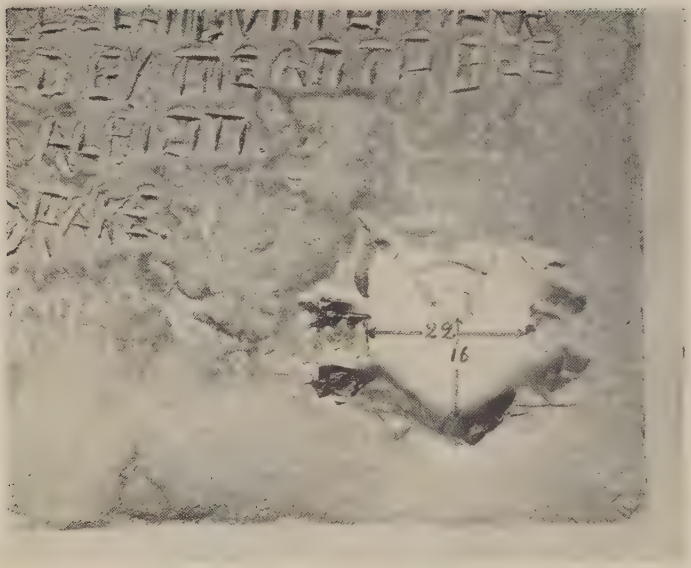

FIG. 1. Hole cut in Plate to hold the sixpence.
Natural size.

FIG. 2. Same as Fig. 1.
Magnification 3.

Fig. 3. Typical appearance of edge of Plate
Magnification 2

Fig. 4. Burr (X) at edge of Plate
Magnification 3 1/2

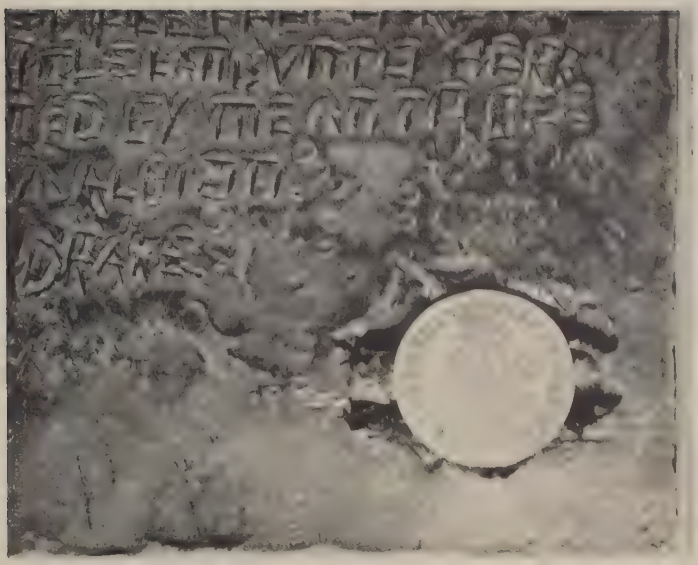

Fig. 5. A Queen Elizabeth sixpence inserted into hole shown in Fig. 1
Natural size

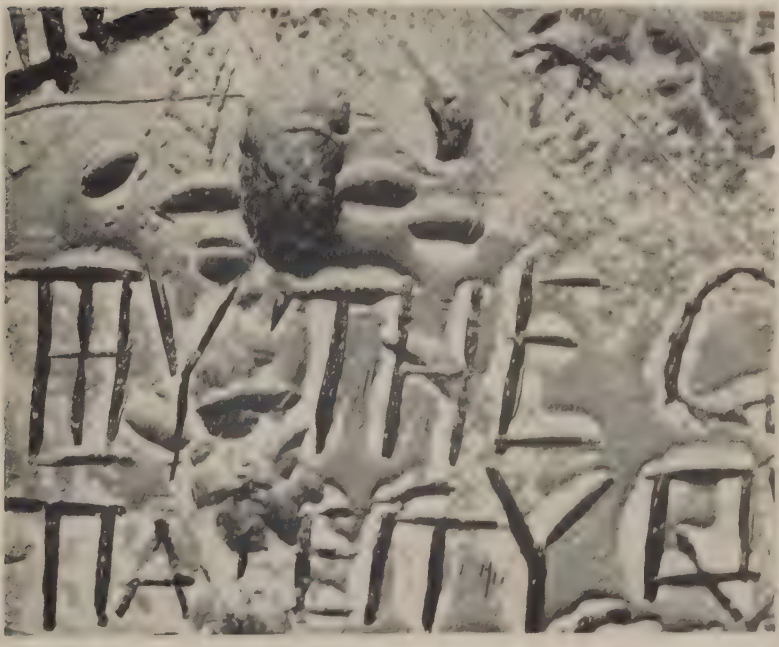

Fig. 6. Parallel lines and a large indentation in the Plate
Magnification 3 ½

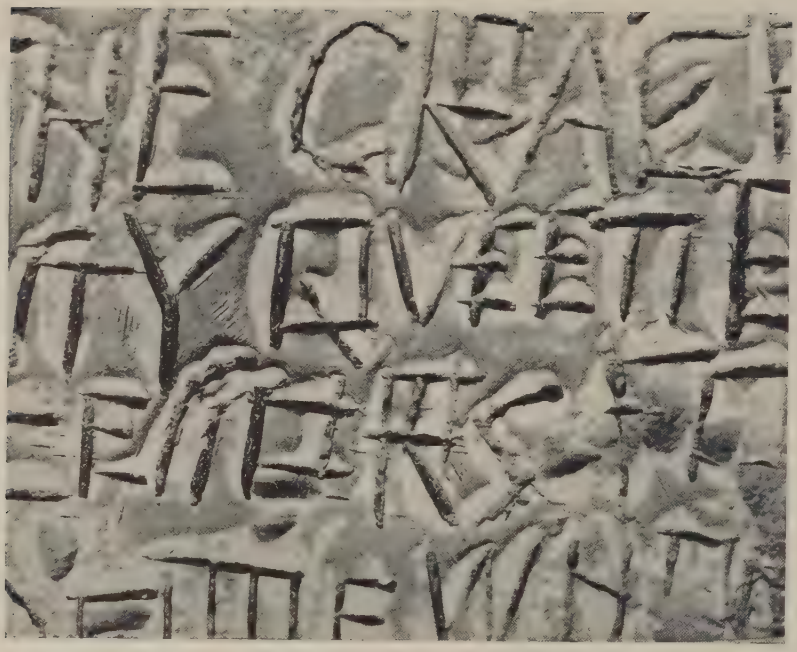

Fig. 7. Parallel lines on the face surface of the Plate.
Magnification 3 ½.

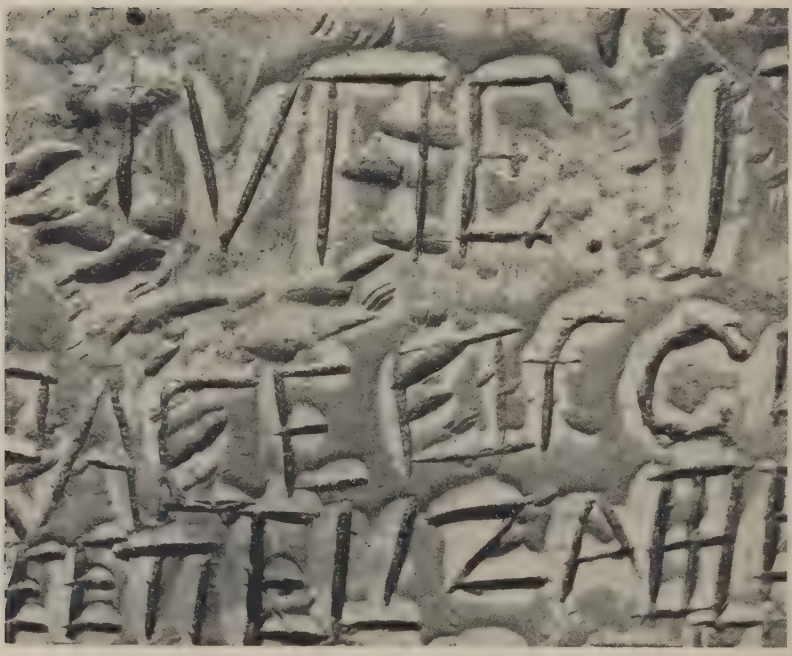

Fig. 8. Parallel lines and small indentations in the surface of the Plate.
Magnification 3 ½.

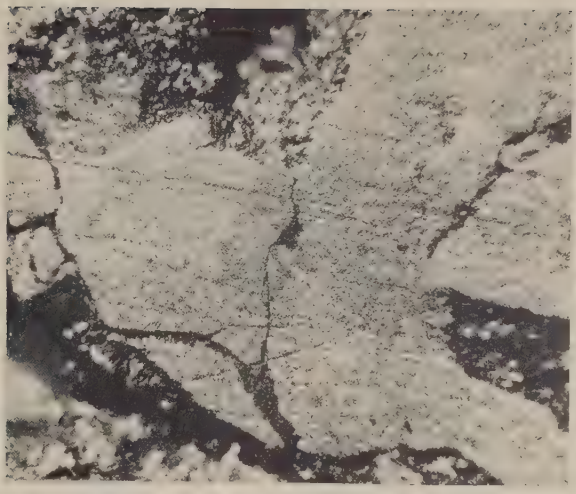

FIG. 9. Cracks in the face surface of the Plate.
Magnification 35.

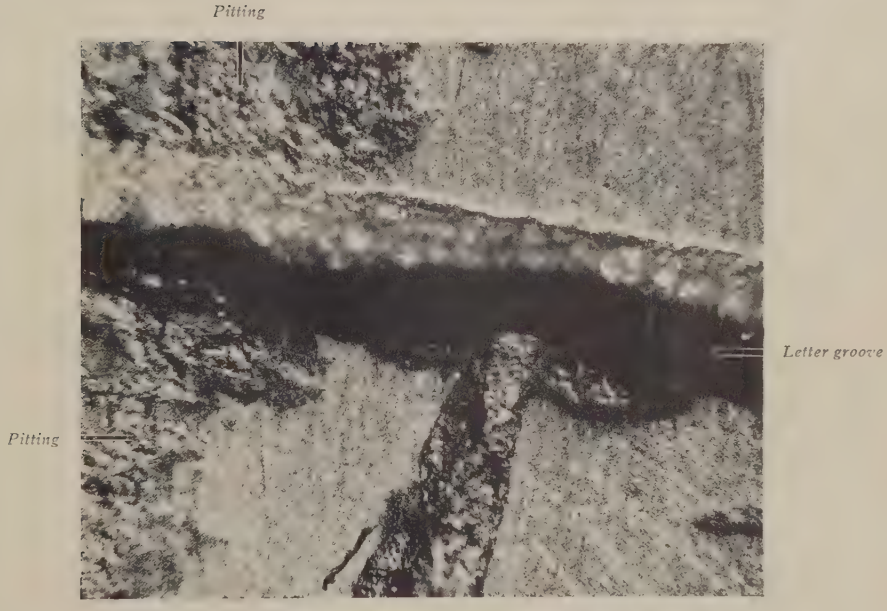

FIG. 10. Pitting in the face surface of the Plate.
Magnification 30.

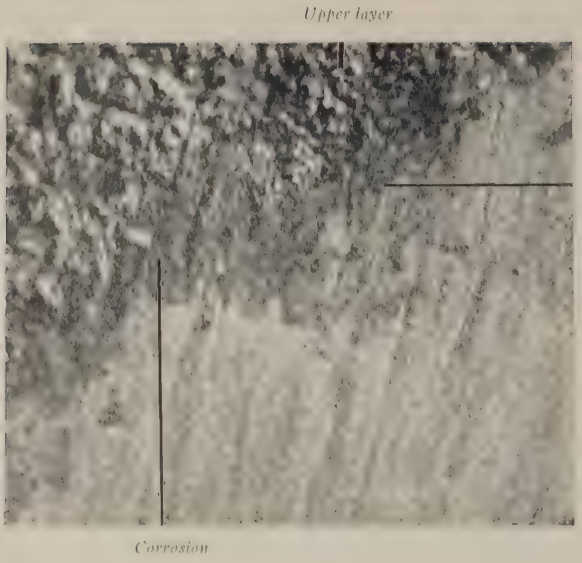

FIG. 11. Badly corroded area in the face surface of the Plate.
Magnification 85.

FIG. 12. Large indentation in face surface of the Plate.
Magnification 3 ½.

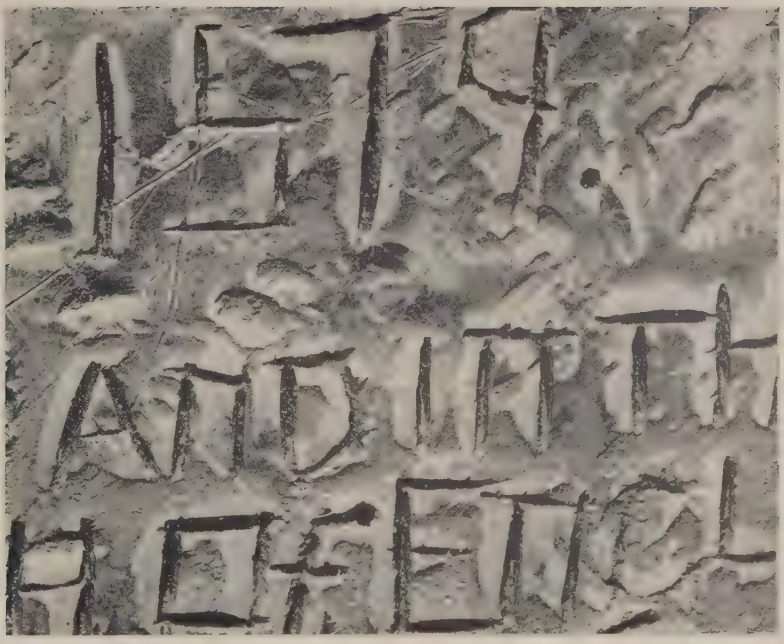

FIG. 13. Small indentations. Distorted figures "7" and "9."
Magnification 3 ½.

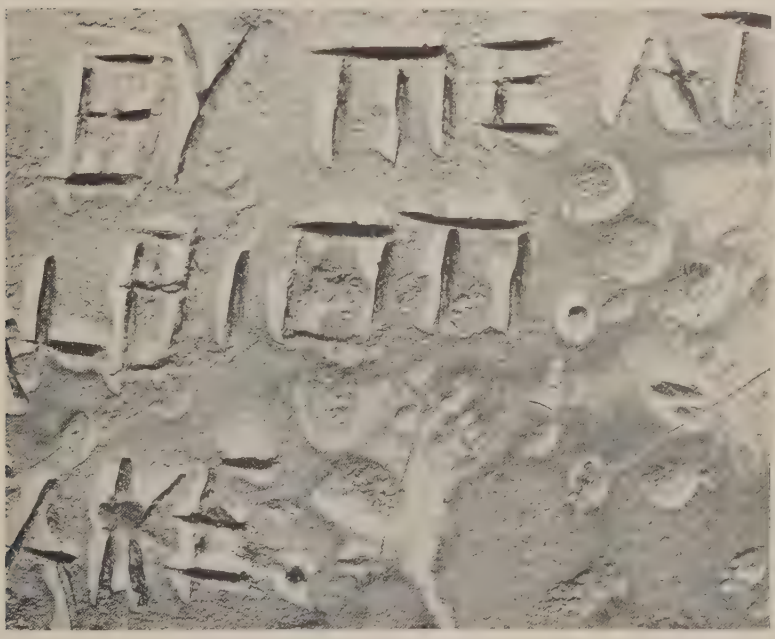

FIG. 14. Small indentations. Distorted letter "K."
Magnification 3 ½.

FIG. 15. Large indentation on face surface.
Magnification 8.

FIG. 16. Indian stone ax used to duplicate the indentations shown in Fig. 17.
Natural size.

Fig. 17. Indentations made by the authors on a piece of modern brass with stone ax, simulating those shown in Figs. 6 and 15.
Magnification 3 ½.

Fig. 18. Part of back surface of the Plate.
Magnification 3.

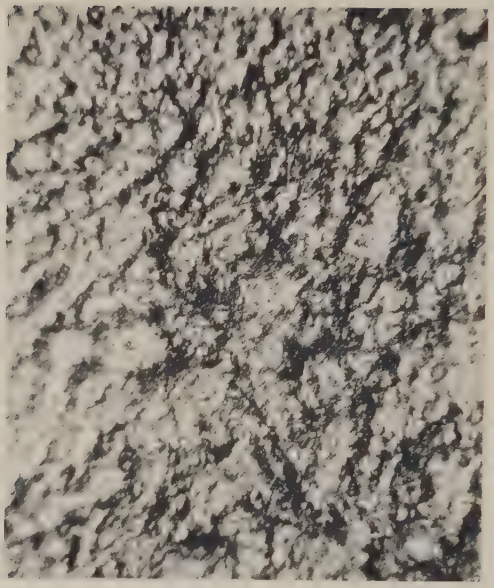

FIG. 19. Same as Fig. 18 but at a magnification of 35.

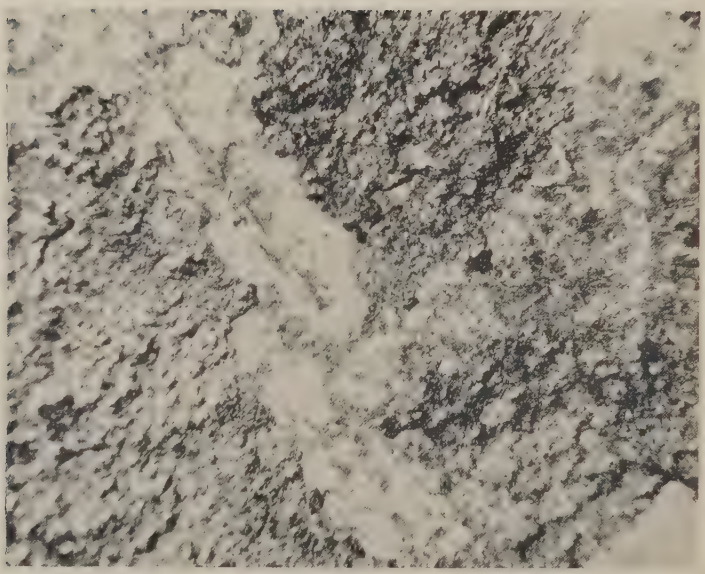

FIG. 20. Different types of surface irregularities on back surface of Plate. Magnification 35.

FIG. 21. Black circular area on back of Plate due to exposed underlying layer of the patina. Magnification 35.

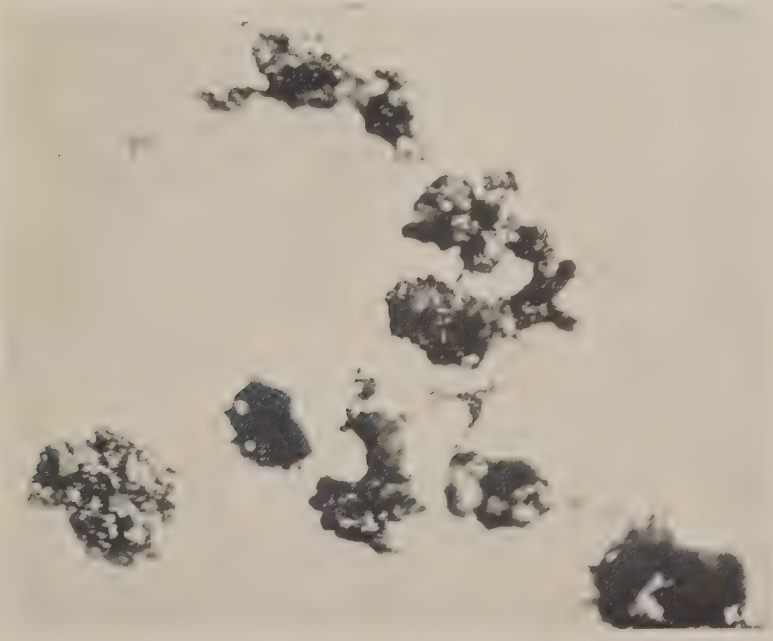

FIG. 22. Particles of patina scraped from the Plate surface and out of the letter grooves. Magnification 100.

FIG. 23. Particles of patina before heating. Predominant color, black. Magnification 75.

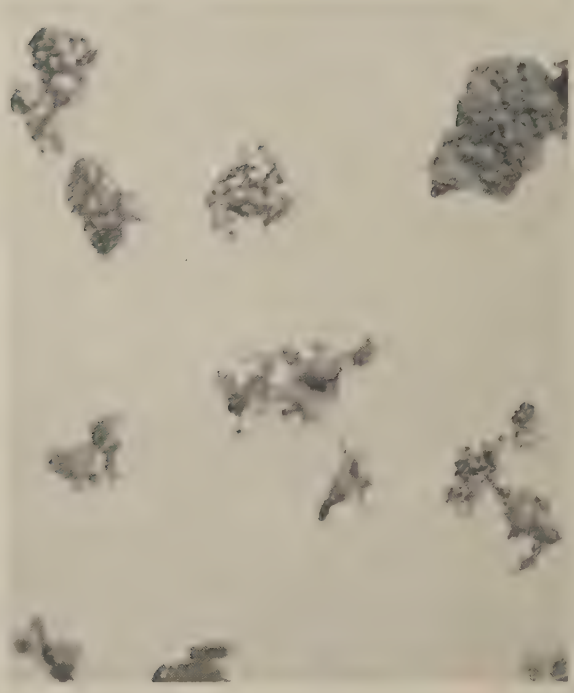

FIG. 24. Particles of patina after heating. Variously colored: orange, black, white and deep blue minerals. Magnification 75.

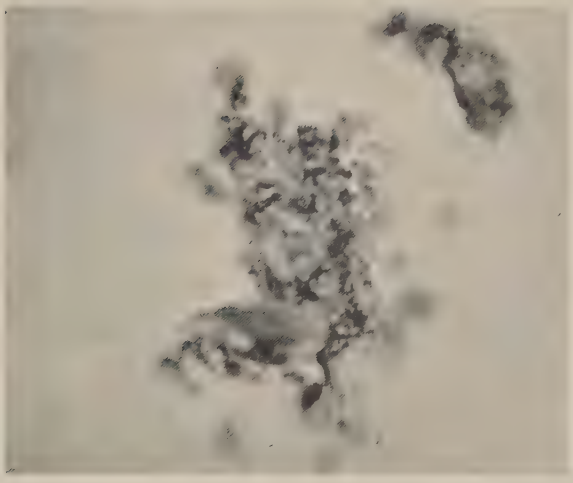

Fig. 25. Particles of patina scraped from an old brass article of the 16th Century, showing the same minerals as in Fig. 24.
Magnification 75.

Fig. 26. Particles of patina from the coin groove of the Plate.
Some particles show a fibrous structure.
Magnification 100.

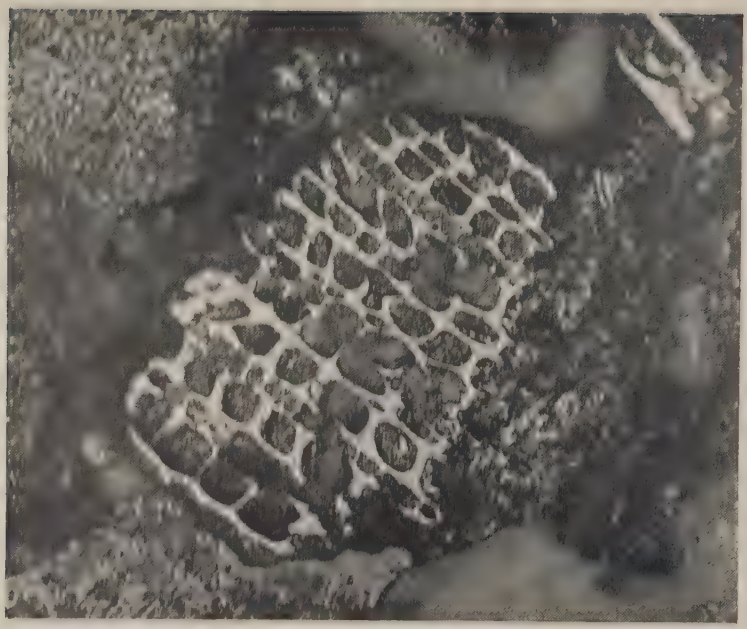

FIG. 27. Mineralized plant cells embedded in the patina of the coin groove. Magnification 200.

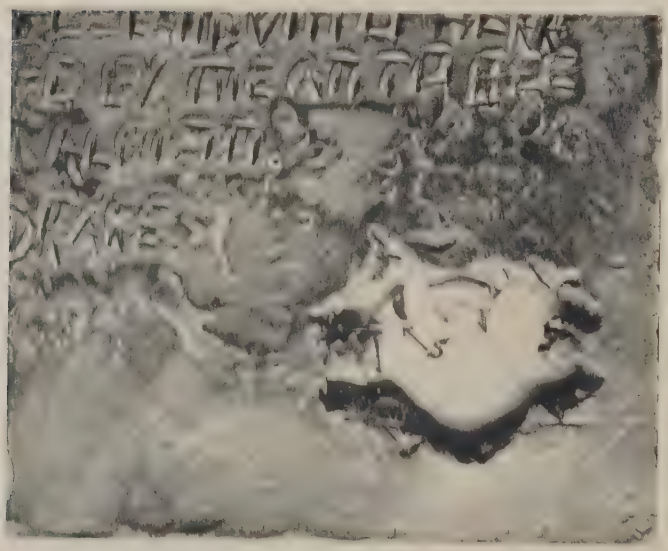

FIG. 28. Small triangular piece of metal (8) cut off the Plate by the authors for metallographic examination and spectrographic analysis. Natural size.

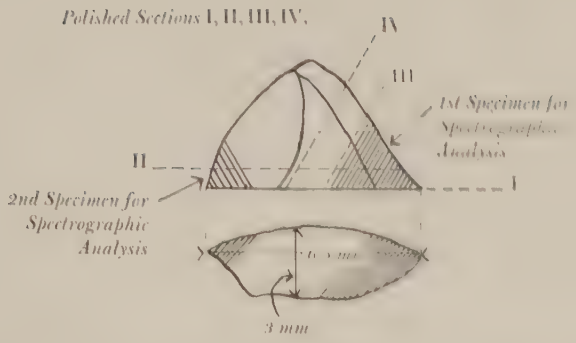

FIG. 29. Sketch of the triangular metal specimen shown in Fig. 28, indicating its dimensions and the location of the four polished sections of the specimen.

FIG. 30. Polished section of the Plate specimen showing inclusions (dark spots) of impurities in the metal. Magnification 100.

FIG. 31. Inclusions (dark spots) in another polished section of the Plate. Magnification 200.

FIG. 32. Appearance of inclusions at high magnification, 1000.

FIG. 33. A large, transparent inclusion (dark area); probably a grain of quartz sand. Magnification 750.

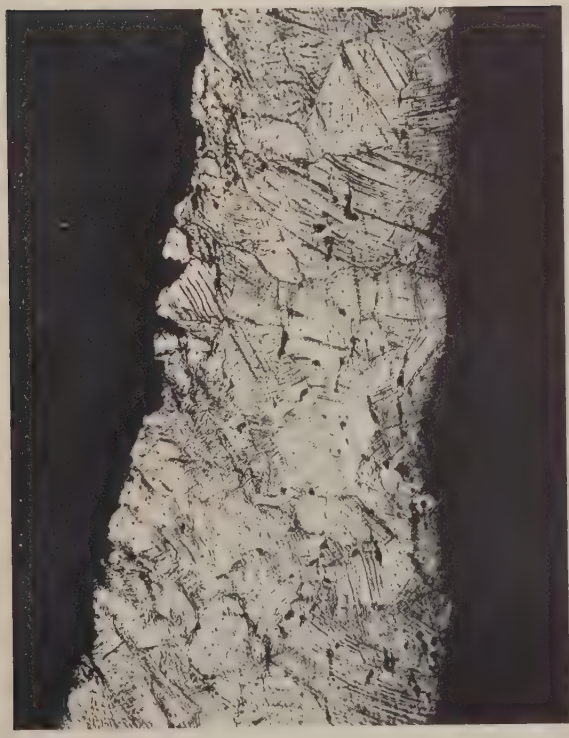

FIG. 34. Piece of old brass of the 17th Century used for comparison. Etched section showing inclusions (dark spots). Magnification 200.

FIG. 35. Globular inclusions in the Plate following a fine, wavy crack. Magnification 200.

FIG. 36. Elongated inclusions in an old brass used for comparison study. Inclusions are not in parallel arrangement. Magnification 200.

FIG. 37. Crack in the body of the metal below the surface of the Plate. Magnification 200.

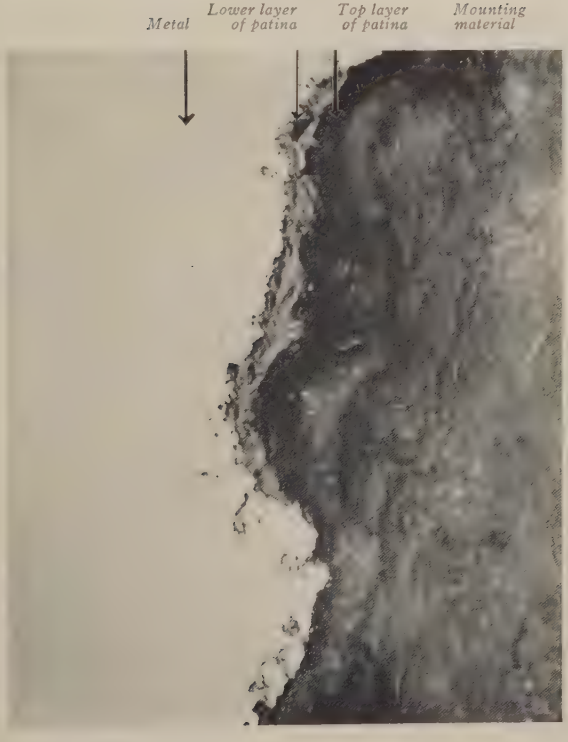

FIG. 38. Cross section of the underlying layer of patina on the face surface of the Plate. Magnification 1000.

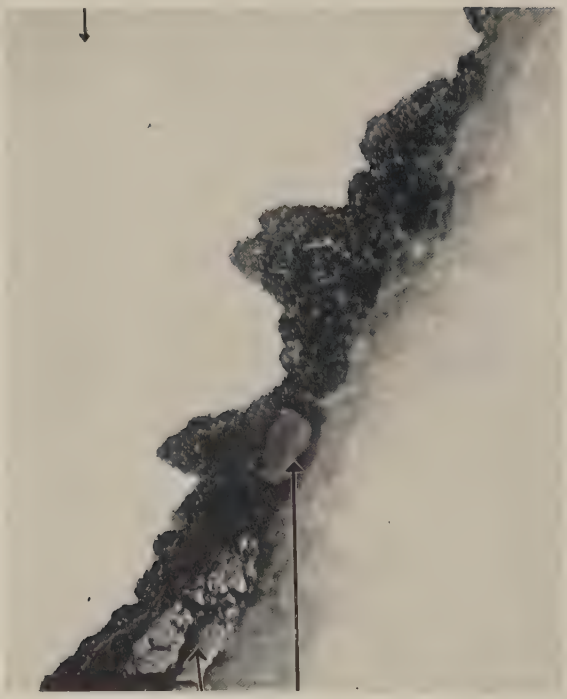

FIG. 39. Cross section of the patina of the Plate showing accidental inclusions. Magnification 750.

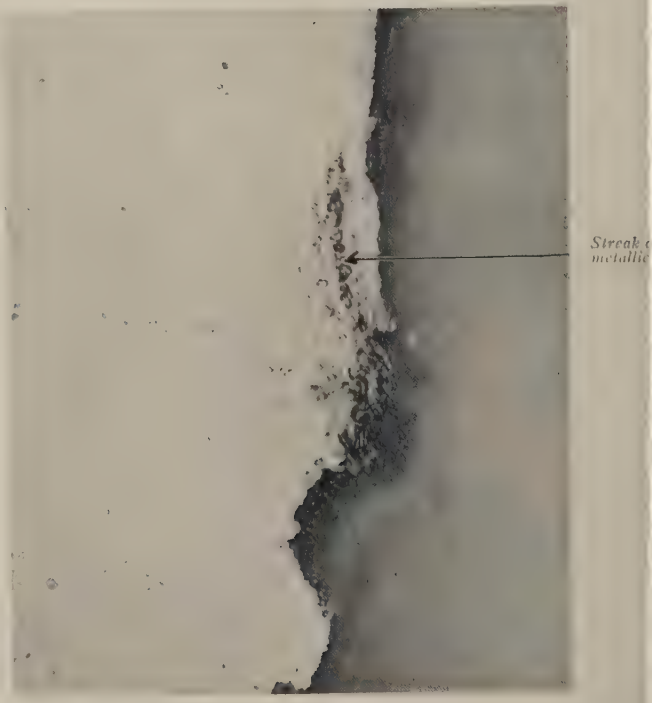

FIG. 40. Edge of the polished section of the Plate showing streaks of metallic copper as a product of corrosion. Magnification 1000.

FIG. 45. Microstructure of another section of the Plate showing large and small grains. Etched with ammonium persulfate. Magnification 200.

FIG. 46. Same as Fig. 45 but another area. Magnification 100.

FIG. 47. Microstructure of an area of a section of the Plate showing small grains only. Etched with ammonium persulfate. Magnification 200.

FIG. 48. Typical microstructure of a piece of cold worked 16th Century brass used for comparison study. Etched with ammonium persulfate. Magnification 200.

Fig. 49. A fine, wavy crack in a section of the Plate. (Same as shown in Fig. 35.)
Etched with ammonium hydroxide.
Magnification 200.

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