

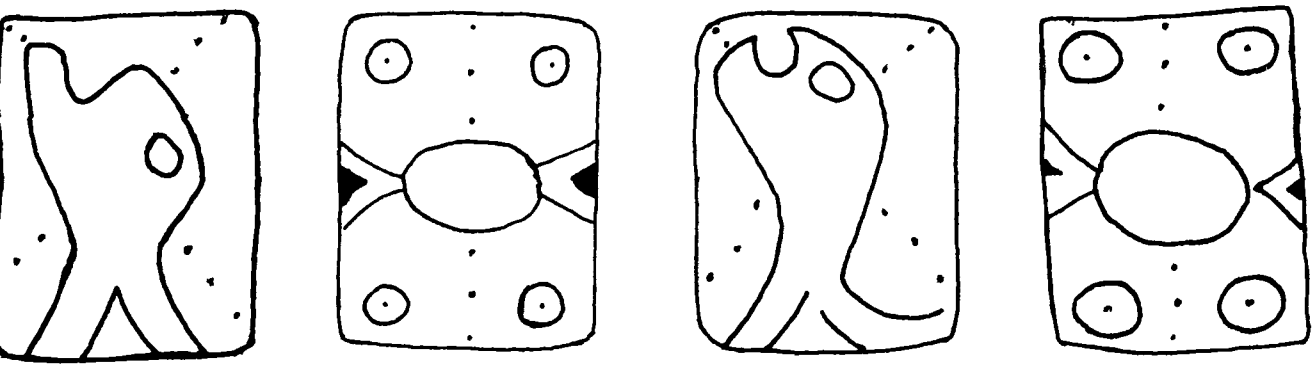
NOTES FROM A CERAMIC LABORATORY

by ANNA O. SHEPARD

with HANS B. GOTTLIEB

E. W. ANDREWS

H. E. D. POLLOCK



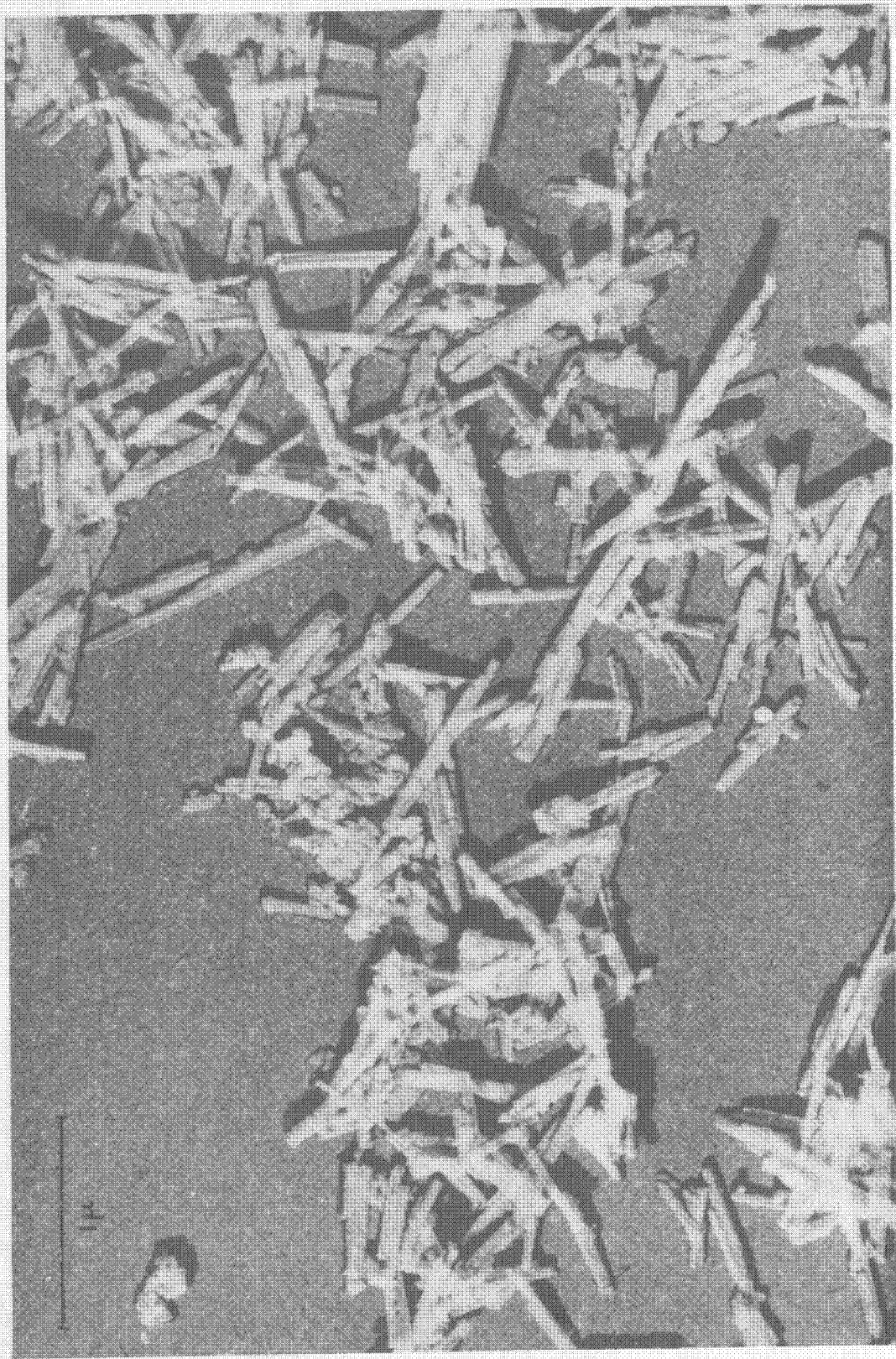
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Electron micrograph of Maya blue showing the rod-shaped crystals of attapulgite. Magnification 33,000 times.

TABLE OF CONTENTS

Beginnings of Ceramic Industrialization: An Example from the Oaxaca Valley	1
Imitation Jade Ornaments from Dzibilchaltun, Yucatan	27
Maya Blue: Alternative Hypotheses	45
Maya Blue: An Updated Record	67



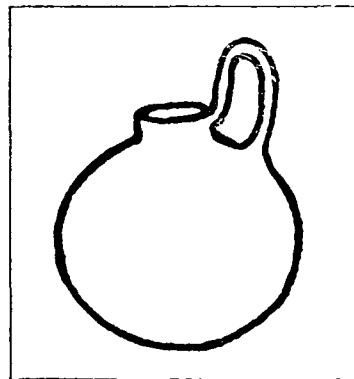
Enedina Aguilar, Atzompa, using revolving plato.



Carmen Martin, Ocotlan, using mushroom mold.

Oaxaca potters.

Beginnings of



Ceramic Industrialization:

An Example from the Oaxaca Valley

ANNA O. SHEPARD

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Carnegie Institution of Washington*

1963

Introduction

Ethnological studies dealing with economic aspects of the potter's craft are a reminder of how threadbare the archaeological record is. Material objects mirror only a fraction of the life of man, and time has been ruthless with these. What can the potsherd tell of the economic importance of pottery, or the social status of the potter? More often than not we cannot even guess the function served by the vessel from which the sherd came. Perhaps meticulous description and elaboration of taxonomic systems serve as tranquilizers, helping us to forget how much of vital interest is forever lost, because these procedures are accepted as indicative of a thorough scientific job. But the ethnological record is not a tranquilizer, and, although it is humbling to us as archaeologists, it is also stimulating; it phrases questions that we have not asked, and suggests where hidden evidence may be sought. This note is an attempt to elaborate the point.

Despite the fact that trade pottery has been recognized practically from the beginnings of American archaeology, little thought has been given to its significance as a record of economic relations. Instead, attention has been concentrated on its value for establishing the contemporaneity of occupations. The relative ceramic dating thus recognized is dependent on pottery types that can be distinguished by the unaided eye. Laboratory analysis has extended its application by including sherds of distinctive paste that are too small or poorly preserved to be identified by style. But the very spottiness of such evidence of trade has discouraged efforts to trace its volume and extent. No less serious is a hidden handicap: distinctive style marks only part, and undoubtedly the smaller part, of trade pottery. Such pottery might be called foreign because its very identification rests on association with indigenous pottery of a different stylistic tradition. Domestic trade, that is trade among culturally homogeneous settlements, cannot be recognized by simple inspection. Under these circumstances a large amount of trade and the intermingling of specialized products of different villages simulate independent, local production. Consequently, it may seem naïve to expect archaeology to reveal how the transition from a home craft to a commercial industry took place, but this is where ethnology points out possibilities.

Stages of ceramic economic development may be evaluated with reference to methods of production and means of distribution, but there are many intermediate steps between the first stage, when the potter collects clay and makes vessels for her own domestic use only, and the stage in which the owner of a shop buys clay, employs potters, and markets the ware through middlemen. And there are many influences that may promote the trend toward commercialization, such as the production of superior pottery that serves particular functions better or is unusually attractive; inventions--a wheel or a kiln--that increase the efficiency of production; competition for other products; and new requirements of a developing culture. Of these influences, specialization is a tangible one from the archaeological point of view, whether it arises from the possession of unusual resources or from the development of special skills or methods. Pottery making in the Oaxaca Valley of Mexico affords a clear illustration of the effects of specialization on trade. A thorough ethnological record of the economics of pottery in this area would be extremely illuminating, but for the present my own observations, which were incidental to a petrographic study of the pottery of Monte Albán, will have to suffice. Had these observations not been a by-product of an inquiry into the persistence of prehistoric techniques among present-day potters, the illustration would have been more effective; but even a sketchy account will indicate archaeological applications.

Contemporary Pottery Techniques in the Oaxaca Valley

The Oaxaca Valley of southern Mexico is a high-altitude, relatively arid region. Although a spacious valley, it is snugly enclosed by high ranges, the Sierra Madre Oriental on the east and the Sierra Madre Occidental on the west. Owing to centrally located hills, the arable part of the valley is U-shaped with its open end to the south. The one permanent stream in the eastern limb flows northwest to make a broad bend south of the city of Oaxaca before it joins the Río Atoyac, which flows south in the western limb of the valley. Archaeological survey has shown that there was a long and extensive occupation of the valley during prehistoric times. Today there are just four pottery-making villages among the Indian settlements (fig. 1). Two of them, San Bartolo Coyotepec and San Andrés Ocotlan, located on a main highway in the western limb of the valley, are easily accessible. Coyotepec, long known for its black jars, is the principal village visited by tourists. Ocotlan is known for its large Friday market. Santa María Atzompa, north of the ruins of Monte Albán, the village nearest Oaxaca, is not as easily reached because of a troublesome crossing of an acequia, but its green glazed pottery is the principal Indian ware displayed in the Oaxaca market and its casseroles are popular with Oaxaqueños and American visitors alike. The fourth village, San Marcos, far up the hill slope above the town of

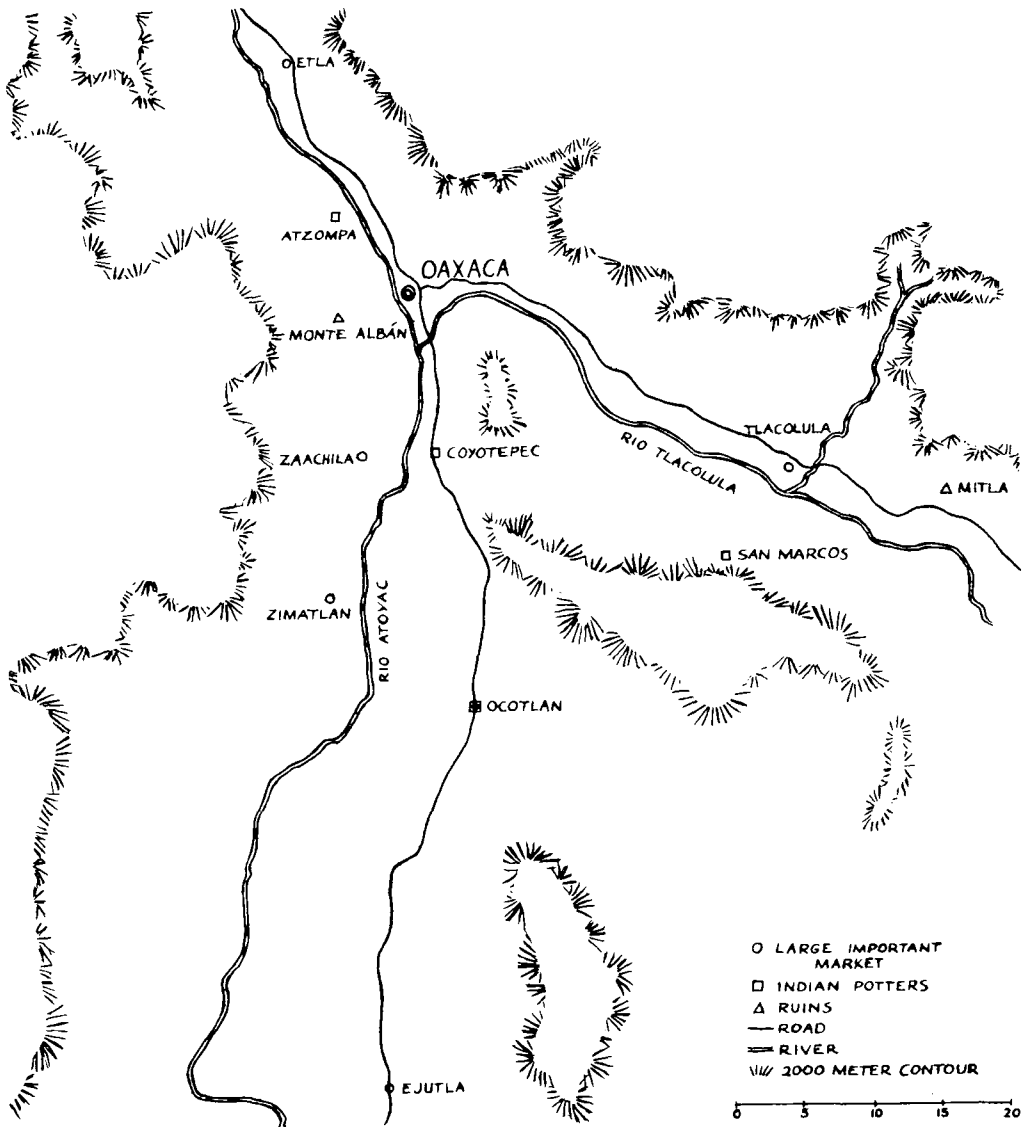


Fig. 1. The Oaxaca Valley.

Tlacolula in the eastern limb of the valley, is much less accessible and seldom visited; one often hears that its people do not welcome visitors.

I became acquainted with potters' families in the first three villages while studying prehistoric pottery. I have watched them work, measured their firing temperatures, and on many occasions talked shop with them as with old cronies. My acquaintance with San Marcos is limited to a single visit. The people were friendly, and I watched a potter forming vessels and talked with others who had just finished firing.

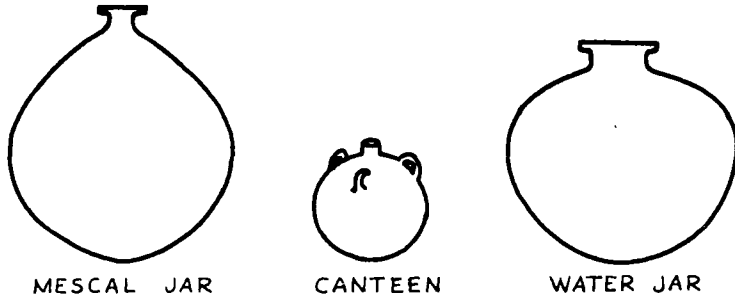
The pottery of each of these four villages is sufficiently distinctive to be recognized whenever seen in markets or homes in other villages. The general features are summarized in table 1. Some shapes are peculiar to certain villages,

Table 1. General Features of Contemporary Oaxaca Valley Pottery

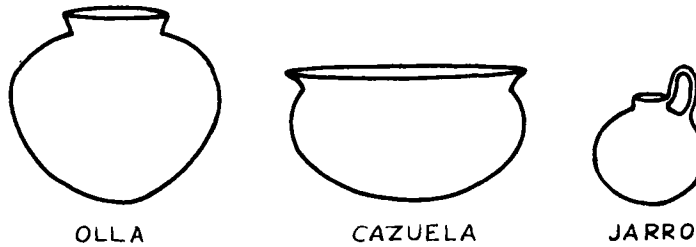
<u>Village</u>	<u>Ware</u>	<u>Decoration</u>	<u>Principal Shapes</u>
Santa María Atzompa	Green glaze	Plain, pre-glaze incising, modeling	Casseroles, <u>cazuelas</u> , ollas, <u>apaxtlis</u> , <u>jarros</u>
San Bartolo Coyotepec	Matte or lustrous black	Plain, minor pattern polish	Water and mescal jars, canteens, <u>pichanchas</u> , <u>cajetes</u>
San Andrés Ocotlan	Thin orange slip	Plain, white paint	<u>Apaxtlis</u>
San Marcos	Red slip	Plain	Ollas, <u>comales</u> , <u>cajetes</u>

but a number of basic shapes are shared (fig. 2). Potters of any one village are unfamiliar with the details of techniques of others; some have intimated that they consider it impertinent to inquire. Two villages, Coyotepec and Atzompa, are known for the production of vessels serving special functions. With a few notable exceptions, methods show little effect of Spanish contact or present-day tourist trade. The green glaze of Atzompa is applied on hand-formed pottery. A few potters in two villages are producing new forms under the guidance of dealers to satisfy or stimulate tourist trade, but the great majority of potters produce traditional shapes for native domestic use. This is the pottery one sees in village markets, and as yet it has met relatively little competition from commercial agate ware.

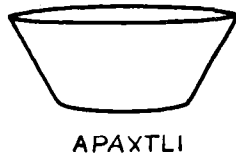
SAN BARTOLO COYOTEPEC



SANTA MARÍA ATZOMPA



OCOTLAN



SAN MARCOS

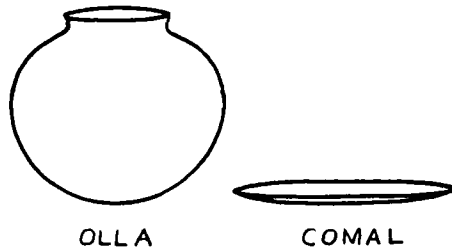


Fig. 2. Principal contemporary Oaxaca vessel forms.

San Bartolo Coyotepec is the best known of the villages. The large black jars of Coyotepec are seen in all the markets, and one potter, Rosa Nieto, has been demonstrating her technique to visitors for many years (Van de Velde and Van de Velde, 1939; Foster, 1959). The exclusive reference to Rosa's technique in the literature might lead one to question whether it is representative of the village or is an individual specialization, but acquaintance with other potters soon convinces one that it is typical; the publicity that Rosa has received rests on her willingness to demonstrate and her flare for advertising.

The forming of a Coyotepec jar starts with hand modeling; a depression is punched in a large cone of clay, which is then patted into a crude body while it rests on the left fist. The incipient vessel is placed on a saucerlike support, usually referred to in the literature as a molde. I have substituted the word

plato (plate) on the advice of Mr. John Paddock of Mexico City College, who informed me that this is the potters' term; they use molde in its literal sense, a mold. A simple but clever device that facilitates rotation of the vessel under construction is formed by setting the plato on an upturned round-based bowl or jar. Since the contact of the plato and its support approaches a point, friction is reduced, and the plato practically spins on its support. During the shaping of jar bodies, the plato is rotated slowly, serving merely to bring successive surfaces to convenient working position; but, when necks are shaped from a few added coils, the speed of rotation is greatly accelerated and shaping simulates throwing, that is, the hand serves merely as a guide and is nearly motionless. The most impressive part of this unusual method of forming is the great skill potters exercise in keeping the plato balanced, for it gyrates at times like a top.

The only decoration of Coyotepec pottery is produced by polishing simple patterns on the smooth matte surface. This is a pre-Hispanic decorative technique. All-over polish is not employed on vessels made for the domestic market, but within recent years it has been encouraged by the tourist trade, and luster is sometimes enhanced by the use of graphite. Although graphite occurs on some pre-Hispanic pottery of the area, this is clearly not a carryover.

The cylindrical kiln of Coyotepec is entirely subterranean, and the firebox is fueled from a deep pit dug adjacent to it. This form of kiln was undoubtedly adopted to facilitate smudging, for it is easily sealed. The kiln mouth, covered with large sherds during the firing, is quickly coated with adobe when the pottery is sufficiently fired and ready for smudging; even the kiln wall facing the fire pit is plastered with mud. A particularly interesting feature of the firing is the method of determining the time to seal the kiln. Some observers have reported that this is done when flames from the firebox shoot up above the mouth of the kiln. In the firing I observed, the kiln was overfueled, and there was insufficient draft for the flames to reach this height. What happened was very clear, because firing, which started in midafternoon, was not finished until after dark. Adobe was puddled ready for immediate use when the time came. While the potter remained in the pit fueling the kiln, his wife took her stand at the top. When the firing was deemed sufficient, she flicked a lighted pine torch over the kiln mouth. The issuing gases ignited, flames shot high into the air, and she hastily started sealing, ringing the lower half of the covering dome of potsherds with mud. By then the flame had died out, and she again tested the gases with a pass of the pine torch. This time they did not light, so her husband forced additional wood in the firebox, and a few minutes later the flames reignited and the sealing was quickly completed. I did not ask the potters to explain this procedure; their explanation would have been different from mine, but the fact remains that they were using a sophisticated test. The gas from the kiln ignited because hydrocarbons were present; that is, the kiln atmosphere was reducing.

The untempered clay of Coyotepec fires to a hard, dense body. It seeps less than the pottery of the other villages because of its low permeability and is therefore the traditional ware of the area for mescal jars. Water jars and canteens are also a specialty, but the ware is unsuitable for use over the fire; consequently, one does not see Coyotepec cazuelas, comales, or cooking ollas.

Santa María Atzompa produces a totally different ware. The green glaze, a foreign trait, is the conspicuous feature, but the difference in paste is more fundamental and rests on a ceramic tradition that goes back to Monte Albán I times. A buff-firing clay is tempered with ground feldspathic rock. It makes a soft, porous body that has one great advantage: it withstands the expansion and contraction to which a cooking vessel used on an open fire is subject.

Atzompa vessels are modeled and shaped by a technique comparable to that of Coyotepec, even to the spinning of the revolving plato during the shaping of jar necks. A minor variation observed in the shaping of jars is the substitution of a flat slab for the saucer-shaped plato (frontispiece, upper part).

Although the use of glaze requires two firings, the procedure is short and simple compared with that of Coyotepec. The cylindrical surface kiln, which is provided with a firebox, is easily loaded and fueled. As in Coyotepec, the open top is covered with large potsherds, but a good draft is maintained because the ware is oxidized. On a windy day, a straw mat may be held in front of the firebox opening to prevent excessive draft and uneven firing. Firing requires only about an hour, and the rate of temperature increase is as rapid as in an open fire. The hot vessels are immediately removed from the kiln, which is proof of their resistance to thermal shock. The temperature recorded for a preliminary or biscuit firing was 700°C. The potters emphasize that a very hot fire is required for the glaze. In one firing, a maximum of 905°C was attained in 50 minutes.

San Andrés Ocotlan uses an untempered paste comparable to that of Coyotepec. But similarities end here. The vessel-building technique of Ocotlan is unique for Oaxaca. Neither the shape of the flat-based, flaring-sided apaxtlis nor their surface finish bears witness to the fact that they are partly formed on the mushroom mold. Moreover, Ocotlan is about 130 airline miles south of the tentative southern limits of this implement (Foster, 1955). In the forming process, a "tortilla" of clay, flattened on a stone slab with the hand and a discoidal, handled tamper, is laid on the exterior of the mold, a large bowl provided on the inside with a vertical handle (frontispiece, lower part). First the hand and then a lump of plastic clay serves as "paddle" in the process of shaping the tortilla to the mold. The clay tamper yields to the curvature of the vessel at the same time that it exerts pressure, hence it leaves no mark of the

shaping process. When the incipient vessel has been stretched until its rim hangs an inch or so below the edge of the mold, it is transferred to an apaxtli, which serves as plato while a few coils are added by a technique of spreading with the index finger quite distinct from the Pueblo pinching technique. The added section wilts to the form of a flaring rim. When the vessel is firm enough to be removed from the plato, but still plastic, it is thumped on the stone slab a few times to flatten and widen the base. The sides are then straightened to a uniform flare with a mango-seed smoother. Exteriors are scraped to remove unevenness when vessels are leather-hard. In the final finishing, a thin orange slip is applied on the interior with cursory polishing. Floral or bird motifs with geometric borders are freely drawn on the interior in white paint. If a visitor drops in on a family the afternoon of a firing, grandmother, mother, and daughter may be intently painting. When the lengthening shadows indicate that it is time to start firing, brushes are dropped and the remaining plain apaxtlis, together with the painted ones, are loaded in the kiln. The apaxtlis are made in graduated sizes so that they can be stacked in groups of three or four in the shallow, cylindrical, semisubterranean kiln. As at Coyotepec, the kiln is fueled very slowly at first; potters recognize that the dense paste of the thick-walled vessels requires a long "water smoking" period. A firing commenced at three or four in the afternoon will be finished at one or two at night, the potters dozing by the kiln because early the following day they will take the pottery to market. I failed to obtain a record of firing temperatures in Ocotlan.

It would be interesting to know the source of Ocotlan mushroom molds and whether there is a relation between shape and building technique. Atzompa potters also make apaxtlis, but I did not observe the process, and inquiries brought no mention of the use of the mold nor does Hendry (1957) make any reference to it.

San Marcos pottery-making techniques are the simplest of the four villages, and the red, sand-tempered paste makes a soft, friable ware. The potter I observed started a jar by punching a depression in a cone of clay in much the same way as Coyotepec and Atzompa potters do, but she blocked out a rough form by stroking the exterior with a wet corncob as the vessel was held in the left hand with its axis horizontal and turned with a slight tossing motion. The rude flowerpot shape that resulted was set on a gourd rind plato and shaped by scraping the interior with a gourd rind tool while the plato was slowly rotated on the dirt floor. The vessel wall was then heightened by the addition of three tiers of heavy coils applied with the smearing technique observed in Ocotlan and characteristic of Yucatán. Final shaping of the jar body was done with the scraper before the vessel was set aside to become firm enough for the addition of a neck.

My information about firing method is largely inferential as I chanced to pass a yard where a firing had just been completed. About twenty small ollas, stacked in inverted position, rested on a bed of ashes. They had also been covered by fuel, as shown by the ash scattered over and between them. A ring of old pots surrounded them, evidently a base on which large sherds had been placed to form a loose covering, a sherd kiln, as it were, that would retain some heat as well as protect the pottery from direct contact with the fuel. When questioned about fuel, the potter pointed to a stack of dry maguey leaves leaning against the fence. These would burn very rapidly.

Table 2. Contemporary Oaxaca Pottery-Making Techniques

<u>Village</u>	<u>Paste</u>	<u>Forming Technique</u>	<u>Firing Method</u>
Santa María Atzompa	Buff-firing clay tempered with rock	Modeling with supplementary coiling, shaped on revolving <u>plato</u>	Cylindrical surface kiln with firebox
San Bartolo Coyotepec	Light red-firing clay, untempered	Modeling with supplementary coiling, shaped on revolving <u>plato</u>	Subsurface cylindrical kiln with firebox
San Andrés Ocotlan	Orange-firing clay, untempered	Mushroom mold with supplementary coiling	Shallow cylindrical subsurface kiln
San Marcos	Red-firing clay, sand-tempered	Hand modeling	Without kiln, pottery surrounded by light fuel

Marketing Pottery in the Oaxaca Valley

The visitor cannot fail to be impressed by the amount of pottery offered for sale in the Oaxaca Valley, by the street of potters in the city market lined by Atzompa families, each with their display of cazuelas, jarros, and ollas arranged along the curb; the oxcarts loaded with canastos of pottery that come into the village markets, and the huge bundles of Coyotepec mescal jars tied in nets and left on the highway for transport by bus to more distant markets. Many villages

hold weekly markets. The Friday market at Ocotlan attracts tourists as well as natives from other parts of the valley. But this is the only large market held in a pottery-making village.

There is a great difference in the popularity of the pottery of the four villages, to judge by distance of transport and number of vendors. Although the big Oaxaca market is the principal outlet for Atzompa pottery, this pottery also has the widest distribution, reaching markets in all parts of the valley, and it is usually represented by the largest number of vendors. Coyotepec pottery is second in popularity, also being represented in the principal markets, but even in the southern part of the valley less of it is offered than of Atzompa, although Atzompa is carried much farther. Ocotlan and San Marcos pottery is much more restricted in distribution. In Ocotlan itself, local pottery occupies less space in the market than the wares of Atzompa, but Ocotlan apaxtlis are well represented in the other southern markets, such as Zimatlan and Ejutla. They are poorly represented in the Tlacolula market across the hills to the east and are rarely seen in the Oaxaca market. San Marcos trade, as might be expected, is also limited. The chief classes of vessels are displayed in the Tlacolula market by a half dozen potters in the section with saddles and livestock, whereas pottery of the other three villages is sold in the section of household merchandise. This is the market nearest San Marcos and much more accessible to it than to the other three villages. Two or three San Marcos men sell jars in the Ocotlan market, and I have observed one, the husband of a potter, in the Zimatlan market. The sale of San Marcos pottery in these villages is explained in part by the fact that it is cheaper and therefore finds buyers among the poorer people. It seems that women who barter with a San Marcos merchant try longer to bring him down a few centavos than the women buying from Atzompa or Coyotepec merchants. Another interesting factor affecting the sale of San Marcos ollas was called to my attention by Mr. Arthur Train of Oaxaca. Oaxaqueños believe that ollas of this village are superior for boiling beans because they impart a good flavor.

The Oaxaca Valley offers a fertile field for a study of the economics of the potter's craft in Indian Mexico. Malinowsky and de la Fuente (1957) and Hendry (1957) cover some aspects of the economics of Atzompa pottery but do not supply data on such matters as number of families dependent on pottery for support, income of potters compared with that of farmers, proportion of pottery sold outside the village, or the amount sold in the Oaxaca market compared with that in village markets. The general pattern of distribution is clear, however, even without quantitative data. Monopoly by Coyotepec and Atzompa in production of vessels serving essential domestic functions--liquid storage and cooking--has greater effect on the trade pattern than distance or expense of transport. These "monopolies" have not arisen as a phenomenon of acculturation. Rather they follow from the use of pastes having quite different properties.

Another factor influencing the trade pattern is the economic status of the purchaser. People of a poor, unfavorably located village like San Marcos will perforce make more of their own pottery than more fortunately situated people who can choose between production and purchase. Also, the poor nonpotter in a pottery-making village will seek the cheapest ware. For example, in the Ocotlan market the ollas of San Marcos can compete with those of Atzompa for this part of the village trade. Defective local pottery also finds outlet among the poor, and one wonders if carelessness in production is influenced by the fact that seconds are marketable.

The status of the potter's craft in the Oaxaca Valley illustrates an early stage of commercialization in which pottery is produced in the home, largely by members of the family and without benefit of mechanical devices for forming, save the simplest kind. Clay is obtained in various ways. Mr. Train informed me that Coyotepec has a municipal clay deposit. Ocotlan potters buy or mine clay according to circumstances. The head of one family owns land with a clay bed. Atzompa potters use clay from a number of different sources, and some of it is purchased. Fuel is generally purchased. Efficiency of firing is increased by use of a kiln in all the villages except San Marcos, and in Atzompa and Coyotepec a large part of the pottery is produced for trade. The specialization in vessels serving essential domestic functions in these two villages stems from the different classes of paste used. Specialization is one of a number of factors that may influence commercialization, and it is one that can be recognized in an archaeological situation.

Post-Conquest Influences on Pottery Production and Trade

Economic conditions among contemporary Indian potters can offer suggestions for the analysis of archaeological material only if we can establish that conditions of production and distribution have not been materially altered by the Indian's contact with Europeans. Could a situation parallel to that sketched have existed in pre-Spanish times? Traits of European origin should be isolated and evaluated. In Oaxaca Valley ceramics, the most conspicuous European trait is the green glaze of Atzompa. This can be discounted as a primary factor affecting function. It contributes to the attractiveness of the ware but not to its suitability for use over the fire. In this connection it is noteworthy that Atzompa also produces some unglazed ware for trade.

A second conspicuous trait, the revolving plato, is of unknown origin. It may have been suggested by acquaintance with the wheel that generations of Indian potters have seen in the Mexican pottery shops of Oaxaca, but, whatever

its source, it has not had a revolutionary effect on efficiency of production, because it is spun only during the forming of vessel necks.

The history of the kilns is also unknown. Although we do not yet have a record of a pre-Spanish kiln, it would be premature to draw conclusions before a systematic survey with the magnetometer has been made (Aitken, 1961, p. 16-24). Regardless of the source of these kilns, firing records indicate that they have had relatively little effect on the quality of ware. Curves for the firing of Atzompa glaze and polychrome pottery of Zia Pueblo in New Mexico are remarkably similar (fig. 3). The Zia pottery was heaped on an improvised grate and

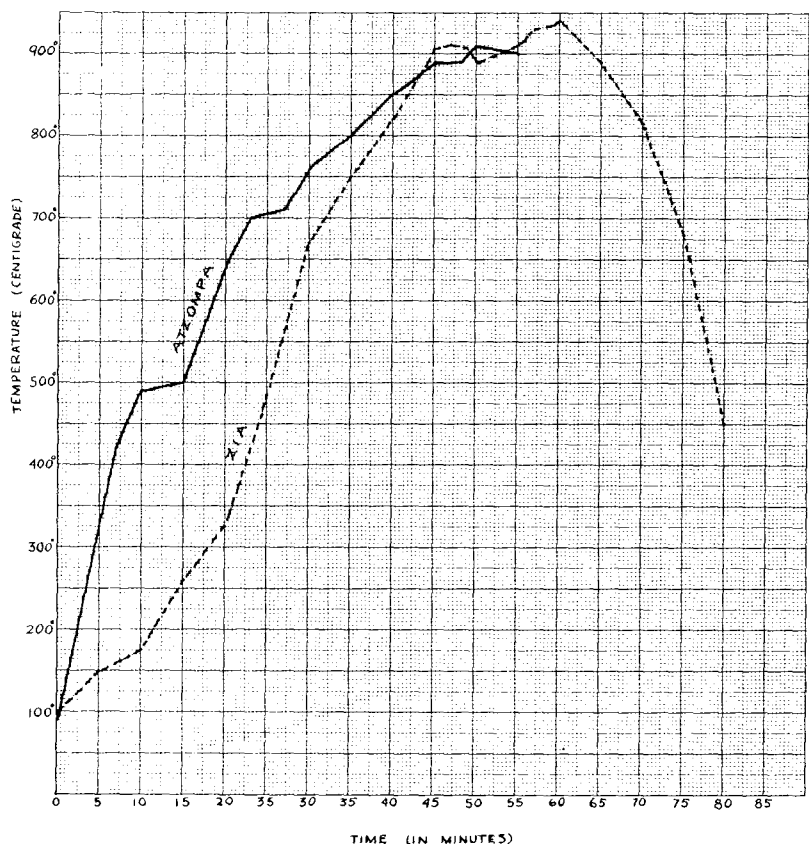


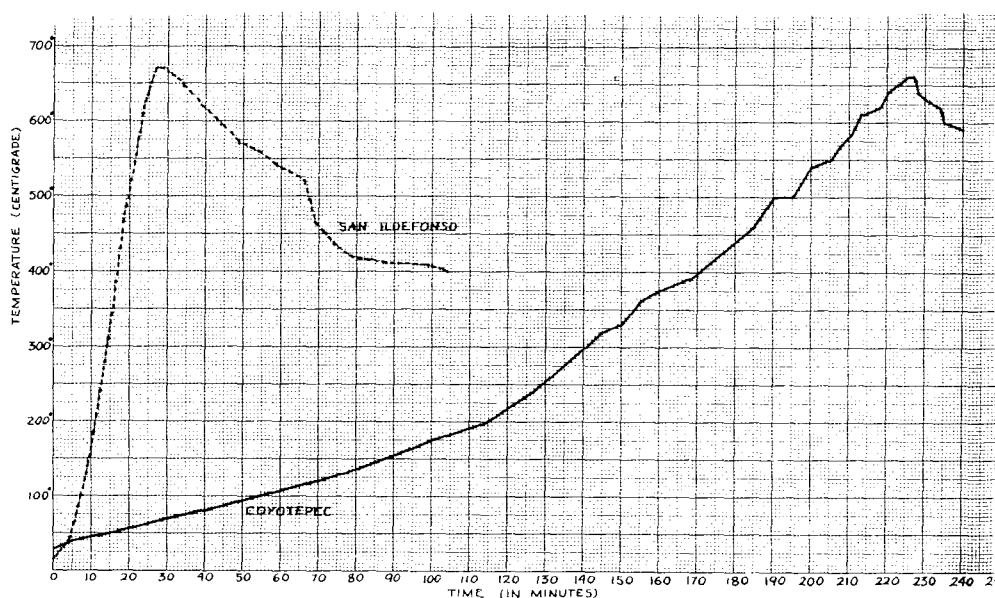
Fig. 3. Firing records, Atzompa and Zia, New Mexico, compared.

surrounded with slabs of dung from the corral. The fire was started with juniper kindling, and there was no addition of fuel until the temperature began to drop. The potter was watching the pyrometer, and it may have been pride that prompted her to poke corncobs between the well-burned dung slabs and thus gain a short temperature spurt. The fact that there was no addition of fuel until after the first maximum was attained is reflected in the smoothness of the curve, which contrasts with the uneven curve of Atzompa. Although heat was more effectively retained by the kiln, Atzompa's method of fueling could not maintain a uniform

heating rate; the two short plateaus in the heating curve indicate where the light, rapidly consumed wood had burned low and more fuel had been added. The cooling period in this firing is not recorded, because the potters opened the kiln as soon as they decided that the firing was sufficient.

Comparison of firing curves of Coyotepec and San Ildefonso black wares tells another story (fig. 4). Although the maximum temperatures attained in both firings were surprisingly close, Coyotepec potters took more than eight times longer than the Pueblos to attain maximum temperature. This very slow rate of heat increase was necessary because of their dense, untempered paste. San Ildefonso potters use a volcanic ash-tempered paste that can be heated rapidly. The kiln is undoubtedly an aid in maintaining the heating schedule required for the Coyotepec class of paste, and density of paste is in turn the factor that reduces porosity of the ware and makes it practicable for liquid containers. Nevertheless, equally dense wares were produced in prehistoric times. Therefore, there is no basis for attributing quality or serviceability of ware to the introduction of a kiln. But the kiln is more convenient than an open fire and may increase volume of production.

With respect to marketing, the principal innovation has come in ease of transport; pottery comes into village markets by oxcart or bus. It would be difficult to evaluate the effect of this factor on volume of trade, but there is the record of extensive human transport of pottery in Guatemala. Consequently, modern transport does not invalidate the hypothesis that a situation parallel to that of Oaxaca could have existed in prehistoric times.



Although the effect of tourist trade on the potter's craft is interesting, it is a development quite independent of that of village marketing. In Coyotepec a few potters, following the example of Rosa Nieto, advertise on the highway and demonstrate for visitors in workrooms where their pottery is attractively displayed. There are also two families that produce entirely for an Oaxaca wholesale crafts dealer. These are the innovators in shape and decoration, but their experimentation with technique is limited, except for polishing. These potters supplying the tourist trade are a minority; most Coyotepec potters produce for village markets. The situation is different in Atzompa, because there are comparatively few visitors to the village; tourist trade is in the Oaxaca market, but it is again independent of the village market. One potter makes large figures inspired by the water cooler stands of Tehuantepec and encouraged by the wholesale craft dealer, a development that has no connection with native demands or consumption. Consequently, there is no factor in the specialization and native trade in the Oaxaca Valley that would preclude the occurrence of a similar development in pre-Conquest times.

An Archaeological View of Contemporary Oaxaca Pottery

When potters select pastes suited to particular functions they have reached a definite level of ceramic advancement. This development may take place within a ceramically self-sufficient community, or it may involve several communities, as in Oaxaca, where differences in properties of the clays available to the two chief pottery-making villages led to intercommunity specialization, which in turn promoted trade. Recognition of the prehistoric beginnings of such specialization and trade offers a challenging problem. I have sketched the picture of Oaxaca Valley pottery in some detail in order to pose the question how the archaeologist and ceramic technologist would interpret the evidence if these villages were projected back some centuries to become the subject of archaeological investigation. Would the situation be recognized by present methods of pottery study, and, if not, is it feasible to seek evidence of economic level of the potter's craft?

Given a large sample of sherds from the excavation of a single ruin, the archaeologist would distinguish four classes of pottery: black, plain and pattern polished; buff or cream, unslipped or red-slipped, plain or incised (Atzompa ware stripped of its glaze); fine orange, plain and white-on-orange; and red, plain red-slipped. There is a startling resemblance between these and the major classes of Monte Albán pottery defined by Dr. Caso and Dr. Bernal, their groups being gray, cream, orange, and brown. Their cream is actually the same class as buff from Atzompa, but their gray and orange wares are largely sand-tempered, although untempered pastes appear in the later periods.

The four groups in our hypothetical case would be subdivided and assigned type and variety names. It is interesting to note that the distinction between plain and decorated vessels would seem more important to the archaeologist than it did to the potter. Thus the sherds of Ocotlan would be separated in plain and bichrome classes, whereas it is a matter of chance whether an apaxtli is painted or left plain, and the same price is asked for both in the market. Painting is a kind of creative play that has no other reward or purpose than the satisfaction of expression.

If the archaeologist happened to be a lumper, he might consider Coyotepec black and Ocotlan orange oxidized and reduced varieties of the same ware. The correlation of shape and ware would raise puzzling questions, but we have few, if any, precedents in contemporary archaeology for the consideration of such questions.

If the archaeologist were interested in building techniques and found traces of coil junctures on jar-neck sherds, he might conclude that coiling was the basic technique, but he would have to look closely for traces because imperfect joining of coils is much less frequent with the smearing than with the pinching technique of coil application. If by chance the archaeologist were to find a sherd from the base of a Coyotepec or Atzompa plato or its support, he would not be prepared to interpret the abraded area correctly; usage alone will wear off the finish of a vessel base. Aside from this consideration, such sherds would occur only in the two ruins where the revolving plato was once used. Sherds of orange pottery would have no identifying traces of the mushroom-mold technique. The only possibility of identifying this forming method would be by discovery of a mold in the ruins of a potter's house or in a burial.

This is a discouraging picture, the more so because of the challenging questions regarding the source of these very different building techniques. But the first step in the investigation of their history in the Oaxaca Valley is a realistic recognition of the limitations of methods of identification. It is clear that more thorough scrutiny of sherds will not give the answer; a major breakthrough in method of identification is required.

The archaeologist would note that three of the classes of pottery were oxidized and the fourth "reduced." If he were particular about details, he would observe that firing clouds are frequent on the orange and red wares and would probably attribute them to "carelessness in firing." Actually, method of stacking vessels in the kiln is responsible for uneven oxidation of Ocotlan orange, whereas contact with fuel causes the fire clouding of San Marcos red. It would in fact be somewhat difficult to distinguish the difference from sherds alone, although a greatly reduced circulation of air by the tight nesting of Ocotlan apaxtlis leaves a readily recognized pattern on vessels.

The description of rim form, which the archaeologist who works largely with sherds is reduced to, would give an incomplete picture of vessel shape; nevertheless, it would reveal significant differences between the wares. It would be only a step from the observation of the high frequency of jar necks in black ware and of wide-mouthed forms in cream ware to raise the question of functional differences, but this is outside the bounds of current archaeological practice. The archaeologist might speculate about the meaning of the association of wares as different as these four and raise questions regarding local production versus trade, but the data obtained from sherds of a single site would not answer them, no matter how meticulous the description.

At this point some "representative sherds" might be submitted to a ceramic technologist, who would make a quick check of paste with the binocular microscope and observe that there are three major paste classes. The orange and black he would lump as untempered and difficult to analyze. The rock-tempered cream would interest him more than the sand-tempered red, and he would obtain a thin section. His classification of diorite would be tentative because of the degree of alteration of the rock, but he would note with satisfaction that the alteration is deuteric and that epidote is conspicuous--facts that would make identification more specific. If a sherd of this pottery were found elsewhere some day, this particular rock temper would help clinch identification. The association of the distinct pastes would puzzle him, especially as they all occur in wares of similar finish, and some shapes are common to all of them. Without a geologic map he would have no idea of the source of the rock. He might guess that it marked trade ware, but he could offer no evidence for this view and would therefore keep his speculations to himself and merely write a paste description for an appendix. Such technological observations taken out of cultural context can have no meaning.

It is clear that broad reconnaissance rather than single-site excavation will be required to obtain the basic data necessary to recognize village specialization. Ceramic survey is often included in the study of settlement patterns, which has proved so fruitful in recent years. In our hypothetical Oaxaca example, analysis of large, random sherd collections from a general survey of the valley would show association of gray and cream classes and restricted distribution of red and orange. The problem would be to interpret this pattern correctly. Restricted distribution would indicate the general locality of production of the orange and red, but the reason for the wide distribution and usual association of the gray and the cream would not be self-evident. Without additional data, any interpretation of the distribution of these two wares would be sheer speculation, and not inconceivably it would be completely erroneous because classification of both as local products wherever they occurred in abundance would seem reasonable. But contemporary Oaxaca pottery plainly demonstrates that relative frequency of occurrence does not offer a reliable means of distinguishing local from trade pottery.

If there is demand, pottery will be traded in large quantities. On the other hand, it may be produced in small quantity if essential materials are limited.

A new approach is required to identify intercommunity trade. The archaeologist and the ceramic analyst, by working together with an adequate sample, can make the essential observations. Once the primary requirements of a reliable paste classification and a plot of areal distribution of pastes have been met, the next step is to test correlation of paste with vessel shape. Correlation indicates one of two things: functional specialization conditioned by paste composition, or development of localized styles in settlements drawing on different ceramic materials. If there is significant correlation, the possible function of major shapes should then be studied, together with the fitness of the paste for the functions postulated.

Reference to the hypothetical Oaxaca example shows that this procedure is not as tedious as it may seem. Since paste is accepted as a major criterion in current taxonomic systems, the requirement of paste classification would not be an added burden. Paste would be treated as a mode, however, not as a criterion of a type; in fact, we would deal with modes, not with types, throughout the study. Paste classification would be based on color, texture, and temper. The gray paste would be recognized as a dense untempered body intentionally smudged. The color difference between red-firing San Marcos and the cream-firing Atzompa clays would be distinguished easily, and, since both colors are obtained when firing conditions are oxidizing, the pastes would be interpreted correctly as products of different classes of clay. Furthermore, the texture of both would indicate tempering, and the sand of San Marcos could be distinguished from the feldspathic rock of Atzompa with a binocular microscope or even a hand lens. When pastes are as distinctive as these, classification can be made with the binocular microscope almost as quickly as the sherds can be handled for ordinary visual inspection.

Shape classification of the Oaxaca sample by rim form would differentiate the narrow necks of large Coyotepec jars from the wide necks of Atzompa ollas and the collars of Atzompa pitchers; the apaxtli and several bowl forms, the comal, pinchancha, and minor forms would be recognized. If shapes are classified within the previously established paste groups, the correlation of narrow necks with gray paste and wide necks with cream would at once be apparent, but only if these shapes were considered in terms of possible basic functions would the significance of the correlation be understood. The liquid containers could be recognized with more confidence than cooking vessels. Shape alone would not distinguish a cazuela from a large food bowl. Evidence of use over fire is necessary to identify a cookpot, and such evidence, either deposition of carbon or extensive spalling, is observed on body sherds more often than on rims.

In the shape classification, size and proportion of vessels would be more significant than details of rim form, although the everted rim of Coyotepec jars, the flare rim of Atzompa ollas and cazuelas, and the straight rim of Atzompa pitchers would offer convenient keys for classification. In order to judge vessel size, diameters of equators of body sherds would have to be measured. Paste composition affords a ready means of relating body to rim sherds; in fact, if shape classification were made within the major paste classes as suggested, the procedure would be simplified and correlations would be apparent at once. A good skeptic would reverse the order of criteria to check reliability of classification and correlation. The Oaxaca Valley sample would show high correlation between jar rim forms and paste classes.

Although the relation of paste to function would be apparent, determination of fitness of paste for given functions is at the present time an exploratory venture. Simple tests that can be performed rapidly must be used, because it is necessary to classify statistical quantities of sherds. Apparent density may be sufficient to judge whether permeability is low enough to meet the requirements of a liquid container. The time required for the absorption of a drop of water also affords a quick test of relative permeability. The chief requirements of a cooking-pot paste are low coefficient of expansion and freedom from inclusions that will cause spalling or flaking. There is no rapid test for coefficient of expansion, but the classes of pastes known to be used for cooking vessels are relatively porous and well tempered. Potters are quick to recognize harmful inclusions.

Having established functional specialization of pottery, the next question to answer is whether this specialization occurred within villages or between villages. Here we return to the evidence of distribution, not the distribution of specialized forms because these were most extensively traded, but rather of the more general forms which are common to the two major paste classes, particularly bowls. If the bowls from sites of the Atzompa region are almost exclusively of rock-tempered cream paste and those of the Coyotepec region are untempered gray paste, general sources of the two pastes are indicated and the case for intercommunity specialization is supported. The paste distribution pattern in the total sample would be less clear because it would be weighted by the widely traded forms.

The record of paste distribution should be complemented by information on sources of materials. Ideally, in the hypothetical Oaxaca example, this would be done for rock and sand temper and the clays. It would be impracticable, however, to attempt to locate the sources of the clays; our tools for this purpose are not yet as sharp as they should be, whether physical properties or mineralogical composition is relied upon. This is a subject that needs to be explored much more fully.

Between the extremes of groundless guess and complete information, there is a practical compromise that is sufficient to postulate and, at best, substantiate specialization and trade, namely, to find key materials that are distinctive, can be identified quickly and with certainty, and are likely to be restricted in distribution. In Oaxaca, the diorite temper is such a material. A geologic map suggests its source in the general locality of Monte Albán because the ridge on which the site is located is a Lower Cretaceous erosion remnant that has been protected by an underlying body of igneous rock, a stock. When I sought the source of diorite that I had identified in Monte Albán pottery, John Paddock of Mexico City College suggested that Atzompa potters might be using the same material as pre-Hispanic potters. This proved to be so; they were working an outcrop of the stock not far from their village. If diorite temper occurs in greatest abundance and also in the greatest variety of vessel shapes in this locality, it is marked as a chief center of production, and the chances that the potters were using rock from other sources are minimized.

Granted that the combination of natural occurrences and paste distribution offers reasonably firm evidence of the source of temper, there is still the question whether pottery or raw material was traded. There would be no proof that people of Coyotepec and Atzompa did not exchange clays and rock. Some classes of temper, however, may afford strong circumstantial evidence of trade--for example, if the material belongs to a widely distributed class and the criterion of differentiation of a local variety is one that would not be recognized by the potters. Sands that can be identified by a suite of heavy minerals, or sherd temper that has a distinctive paste of restricted distribution, are examples. Atzompa diorite does not belong in this category. As a final test of the trade hypothesis, one would have to seek minor but consistent local peculiarities of workmanship or style. The most direct approach is by comparison of the same class of vessel, say food bowls, in different paste groups. When minor stylistic differences such as details of rim form, area of slip application, or direction of polishing strokes consistently correlate with paste, import of vessel rather than of raw material is indicated. In a group of sherds of mixed paste composition these differences would appear to be normal variations in technique. It is only when sherds are first classified by paste that minor local differences in technique are recognized.

The procedure I have outlined involves identification of basic paste classes, correlation of these with vessel shape, recognition of possible functional classes, testing relations of quality of paste to function, plotting distribution of paste classes, locating the sources of key materials, and seeking evidence of correlation of minor variation in workmanship or style and paste. This need not be a laborious task because many of these data are accumulated in the course of thorough, routine pottery analysis. The important difference is that at present we do not consider the correlations that are pertinent to questions of specialization and trade. The procedure I have outlined is not recommended as a routine.

It is the correlation of distinctive pastes with particular stylistic classes that gives the signal for a follow-up. These signals should be recognized in the process of standard analysis and description.

Archaeological Evidence of the Beginnings of Ceramic Specialization

A review of the literature on Mesoamerican pottery will not reveal an example of identified or postulated functional specialization that parallels that in Oaxaca, although pottery from the area has been submitted to the laboratory for analysis at intervals during the past quarter century. Is the situation in Oaxaca peculiar to contemporary pottery, or have our methods been inadequate for such problems? Although I have argued that there is nothing to preclude a development comparable to that in Oaxaca in prehistoric times, the entire life of the Indian has been revolutionized by contact with the white man, and we cannot safely project the present into the past; we can only investigate questions posed by the present. On the other hand, it would be unreasonable to expect to differentiate levels of ceramic economic development during the early stage of archaeological investigation when attention must be concentrated on regional cultural differentiation and chronological ordering. Moreover, primary factors controlling the course of ceramic studies in much of Mesoamerica have been the near limitation of excavation to large ceremonial sites and the difficulty of conducting surface surveys in important parts of the area. Finally, most of the pottery submitted to the laboratory for analysis has consisted of small, unrelated samples for which only identification was desired.

It may seem strange that the question of functional specialization was not considered in my study of prehistoric Oaxaca pottery. The question was not phrased, however, until I had become aware of the present status of the potters' industry in the valley. Dr. Caso and Dr. Bernal introduced me to Oaxaca pottery many years ago, when they sent a small sample of Monte Albán sherds to the laboratory with questions about the pastes of types they had defined. At that time I was puzzled to find sand and diorite in vessels of the same shape and finish. Lacking a geological map, I could not guess the source of the diorite. It was only a few years ago that the Monte Albán data were reviewed and the source of the diorite was located. The different tempering materials in this pottery that appeared to belong to a single ceramic tradition suggested that Monte Albán might have been dependent on surrounding farming settlements for the bulk of its pottery, obtained perhaps as tribute. Archaeology can tell little enough of the relations of ceremonial centers to the villages they served. Pottery differs from most of the objects that may have passed between them, not only in its imperishability, once it is in the form of sherds, but also in the marks it may

bear of its place of origin. The Oaxaca Valley invited investigation. With the guidance of maps and notes Dr. Bernal had made in a survey of the valley, I collected sherds from some of the major sites in various parts of the area to learn whether it would be feasible to investigate village-religious center relations.

The picture of ceramic relations glimpsed in this preliminary test was, of course, much more complex than the contemporary one, partly because a long time span was represented, the divisions of which I was not prepared to separate completely. But, even with due allowance for this circumstance, the variety of pastes encountered pointed to a much greater number of pottery-making settlements than exist at present. The concentration of diorite-tempered pottery in sites of the Atzompa region was conspicuous, but this class of pottery did not have the wide distribution that it has today. Particularly interesting was the limitation of some tempering materials, such as metamorphic rock, to certain marginal sites, suggesting that these settlements bore a position in the valley economy similar to that of San Marcos today. In general the recognized variety of pastes indicated that relations could be traced, given samples from stratigraphic tests in well chosen sites that could be handled statistically.

Southwestern archaeology, in contrast to Mesoamerican, presents no obstacles to surface survey. In consequence there are several postulated examples of specialization that led to extensive trade. Reference to these will serve to balance the picture, because they rest on development of special decorative techniques and unusual manual skill rather than on improvement in the quality of pottery.

Glaze-paint ware from the Upper Rio Grande Valley in New Mexico can be covered briefly, because it is relatively familiar. The lead glaze used for painted design in this area between 1300 and 1700 was very popular, to judge by its distribution and quantity. Its production depended on ore of restricted occurrence, access to which could be controlled by a few communities. Although this represents an exceptional situation, the extent of specialization and the volume of trade resulting from it were not recognized until the pottery was analyzed petrographically, sources of material were located, and the distribution of paste types was traced. The methods of analysis used and the manner in which the story was recovered illustrate an approach that is widely applicable (Shepard, 1948).

The second example is from northwestern New Mexico. An unusual igneous rock temper, sanidine basalt, was found in Classic Pueblo III pottery of this region, and its source was traced to the Chuska Mountains on the Arizona-New Mexico boundary (Judd, 1954). In this region it is almost the exclusive temper of culinary pottery. Surprisingly, it also occurs in considerable abundance

in certain classes of pottery in Chaco Canyon some 50 miles east of its nearest known source. It is so conspicuous in the paste that its dark particles were noticed many years before it was identified petrographically. Contrary to what one might expect were it a mark of trade pottery in Chaco Canyon, it occurs principally in corrugated rather than fine painted pottery. Although indented corrugated pottery was used principally for storage and cooking vessels, it reflects, at its best, remarkable skill. From a technical standpoint, the pinching technique of coiling is not an efficient method of vessel building. The coil juncture is a potential source of weakness and flaws; unless welding is firm and all air pockets are eliminated, the vessel will be a loss. But the potters who made indented corrugated ware met the demands of soundness, and, as though rejoicing in their skill, they used the technique to obtain decorative effects, preserving the form of the coil and impressing it to obtain textured surfaces. When the cook crimps her pie crust, she has no fear that she is thereby risking loss of her pie; these potters were so sure of themselves, they tempted fate.

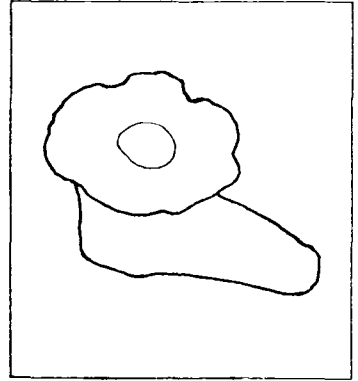
Typical Chaco culinary and corrugated pottery is sand-tempered, but sanidine basalt-tempered pottery gradually increases in abundance after its first appearance until in upper levels it is present in more than half the sherds. Moreover, this rock temper occurs in some black-on-white pottery decorated with organic paint. Chaco black-on-white pottery has an iron oxide paint and sherd temper. The association of sanidine basalt temper with a nonlocal painted pottery, together with the distribution of the paste, is the basis of the hypothesis that this pottery was traded into Chaco Canyon. Had there been only a few rock-tempered sherds the hypothesis would not have been questioned. But the high percentage and its occurrence in vessels classed as culinary cast doubt on this interpretation (Judd, 1954, p. 235). A logical explanation was suggested by Earl H. Morris, who knew the region from years of exploration. In conversation he mentioned that he had noticed that indented corrugated pottery was highly developed in sites of the Chuska region, and that the area was outstanding for both quality and the variety of its techniques. This observation, made many years before the petrographic analysis, offers a clue that can easily be followed by surface survey.

These examples of pottery distribution, which are most easily explained by the hypothesis of specialization and trade, were stumbled on accidentally in the course of routine analysis. If the question of level of ceramic development is recognized as one that can be answered under favorable circumstances, it is reasonable to expect that many more examples will be found, provided archaeologists and ceramic analysts work on the problem jointly. Evidence snowballs only as questions are tossed back and forth between them in the process of checking and counterchecking. But just as the snowball held in the hand melts, so questions left to the narrow specialist fail of solution and are soon forgotten.

Acknowledgments

Dr. Alfonso Caso and Dr. Ignacio Bernal introduced me to the problems of Oaxaca ceramics. It is a pleasure to recall my study of their material, because of their recognition of the importance of interplay between archaeologist and analyst. I am further indebted to Dr. Bernal for advice and loan of maps and site records that greatly facilitated my collection of sherds. Mr. Arthur Train of Oaxaca wakened my interest in the properties of contemporary pottery and introduced me to potters of Coyotepec and Atzompa. A preliminary draft of this manuscript was read by Mr. John Paddock of Mexico City College and Mr. Arthur Train of Oaxaca. I gratefully acknowledge their emendations and suggestions. To the potters of Atzompa, Coyotepec, and Ocotlan I am indebted for many discussions of their craft and for opportunities to observe their firings and measure firing temperatures. Many times their patience and good humor, as well as their skill, have aroused my admiration.

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Imitation Jade Ornaments

from Dzibilchaltun, Yucatan

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IMITATION JADE ORNAMENTS
FROM DZIBILCHALTUN, YUCATÁN

Is it likely that Mesoamerican Indians would attempt to imitate a gem stone as valued and as difficult to work as jade? This question is posed for the first time by three small ornaments found in the cenote at Dzibilchaltun. Before the unusual green coating of these objects is described their archaeological setting will be reviewed.

Archaeological Background

E. W. Andrews

The archaeological zone of Dzibilchaltun, 12 kilometers north of Mérida, Yucatán, and about an equal distance south of the coast, occupies an area approximately 4 by 12 kilometers marked by a dense distribution of ruined structures representing an active occupation beginning in "Formative" times in the first half of the first millennium before Christ and continuing until the present day. Near the middle of this zone there is a compact aggregation of massive ceremonial architecture dating largely to the Early Period and the first phase of the Florescent Period. (Cf. Andrews, 1961, for an explanation of these terms.) In the "Great Plaza" of this central group is a deep natural well known as Cenote Xlakah, some 33 meters in diameter and more than 45 meters deep.

It became apparent in 1956 that the muddy slopes of this well were honeycombed with archaeological artifacts, and for three seasons teams of scuba divers explored these rich and often dangerously deep deposits (Marden, 1959; Andrews, 1959, 1960, 1961). These unusual subaquatic excavations yielded a remarkably rich product. More than 30,000 pieces of pottery and artifacts were found, containing an extraordinarily large number of intact or restorable vessels that have been of great value in interpreting more fragmentary remains encountered in surface excavations. Many of the artifacts were well preserved, particularly those of wood, which almost never survived the alternation of dry and wet conditions on the surface.

It was soon clear that the collection contained much more than accidentally introduced material, and that the pottery had not simply been dropped or broken by the housewife in drawing water from the well. Pottery with partly burned copal incense was found. Many other vessels would have been of little use for drawing or carrying water. Moreover, the artifacts tended to concentrate in large part in two categories: (1) piercing or sewing tools, some elaborately decorated; (2) ear, cheek, nose, or lip plugs in a variety of materials. Objects in neither of these categories would normally fall into the cenote by accident; some form of ceremonial offering seemed indicated. However, the amount of human skeletal material recovered, though considerable, was still insufficient to indicate any consistent practice of human sacrifice.

Dr. Alfredo Barrera Vásquez suggested that the artifacts might well be an archaeological reflection of the modern Maya hetzmek ceremony, described by Thompson (1930, pp. 78, 110-11) in British Honduras and by Redfield and Villa R (1934, pp. 188-90, 374) in Yucatán. At this ceremony, children 3 or 4 months old, when they are ready to be carried on the mother's hip in her daily rounds, are given presents symbolizing their activities in later life, according to their different needs as boys or girls. Thompson actually lists a needle as a typical gift for a female child. And, although facial plugs could not be present in the modern ceremonies described, they would have been ideal distinguishing gifts for the male in earlier times, for Landa (1941, pp. 113-14) states positively that this type of body mutilation was practiced only by males. Redfield and Villa R (1934, p. 374) associate the modern ceremony with pre-Columbian practice in Yucatán (cf. Landa, 1941, p. 88) and with the Aztecs in Mexico. The parallel is an intriguing one, although the possibility must be borne in mind that the piercing implements in category 1 might simply have been or symbolized those used to accomplish the necessary mutilations for the insertion of the associated jewelry. Any conclusions we may reach about the time level of the artifacts involved or their geographic origin and distribution will therefore be of ethno-historical as well as archaeological interest.

An unfortunate feature of cenote archaeology (at least at Xlakah) is the complete lack of stratigraphy in the deposits, owing to the constant movement of the liquid mud on the sides of the underwater cavern. Careful layered removal of deep staked-off areas during the last season failed to show any differentiation in age of material from top to bottom. Thus even direct spatial association with sherds of known age is no criterion of antiquity. The only inference of age--and a weak one at best--is that the overwhelming majority of material recovered (more than 90 per cent) dates to the second phase of the Early Period and the first phase of the Florescent, the time when the massive surrounding architectural complex was built. Occasional intact specimens have been found of both earlier and later date, however.

Therefore, to date this cult and associated ceremonial objects we must fall back on comparison with forms found elsewhere and on information that the technologist can furnish.

Twenty-two facial ornaments were found in the cenote, four of pottery, four of wood, and fourteen of shell. As distinct from the complex assemblages of stone, jade, and shell, sometimes glued and sometimes strung together with other ornaments (cf. Kidder, 1947, pp. 42-45; Kidder, Jennings, and Shook, 1946, pp. 106-11, figs. 43, 45), these were "unit" artifacts, worked from a single piece of material. The form is relatively consistent throughout the Maya lowlands and adjacent parts of Mesoamerica. Five examples were found in surface excavations at Dzibilchaltun. Two, of jade, were associated with burials of the first phase of the Early Period; three, of shell, with burials of the second phase. They are exceedingly common in private collections of Yucatán artifacts, invariably of unknown chronological association. Farther afield, the distribution is broad, as indicated in the table.

Some Occurrences of Flange-type Facial Ornaments

Material	Site	Period	Reference	Illustration
Pottery	Ulúa Valley, Honduras Copán, Honduras	Second part of Early Classic and full Classic	Gordon, 1896	22
			Longyear, 1952, p. 103	82, g-i
	Uaxactún, Guatemala	Tzakol and Tepeu	Ricketson and Ricketson, 1937, p. 221	145, a
	Chiapa de Corzo, Mexico	Istmo	Lowe and Agrinier, 1960, p. 50	29
	Pánuco, Mexico	Period V	Ekholm, 1944, pp. 467-68	47, a-g
Jade Stone	Palenque, Mexico	Early Period	Ruz, 1955, p. 100	42
	Uaxactún, Guatemala	Tzakol and Tepeu	Kidder, 1947, pp. 64-65	56
Shell	Roatán Island, Honduras		Strong, 1935, p. 71	15, k-m
	Guaytan, Guatemala	Magdalena phase	Smith and Kidder, 1943, p. 169	54, b
	Uaxactún, Guatemala	Tzakol and Tepeu	Ricketson and Ricketson, 1937, p. 201	132, c
Copper	Piedras Negras, Guatemala	Late Early Period	Coe, 1959, p. 58	55, q-t
	Guasave, Mexico		Ekholm, 1942, p. 97	19, b

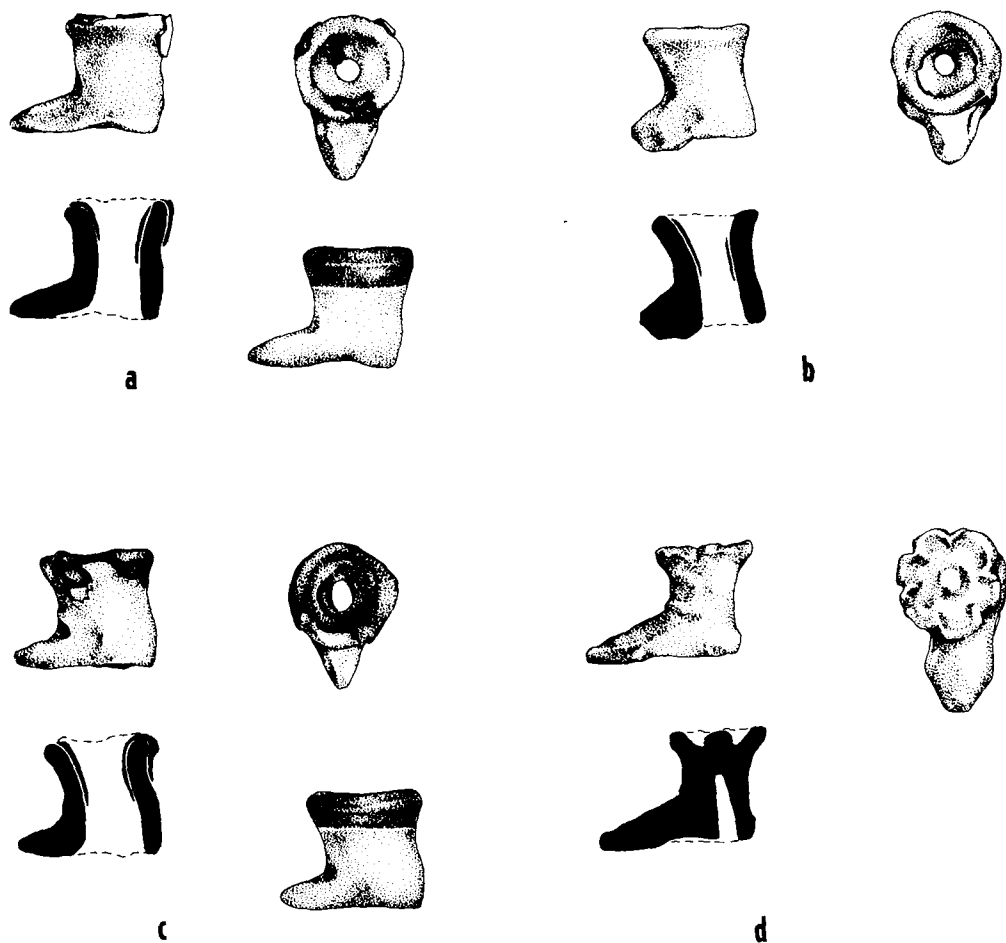


Fig. 1. Pottery face or ear ornaments from Dzibilchaltun (natural size). a-c, specimens partially coated with the substance imitating jade. The illustrator has represented the substance as darker than the clay but it is actually lighter (cf. fig. 2). a and c upper figures, side and interior views of the specimens; lower right, restorations indicating the width of the green substance on the exterior. b, specimen on which green substance remains only on the interior. d, lobed pottery ornament without coating.

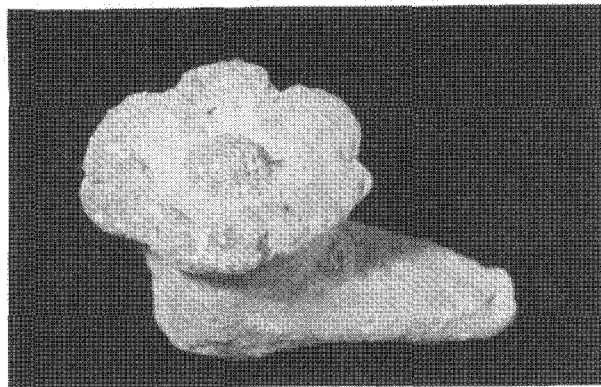
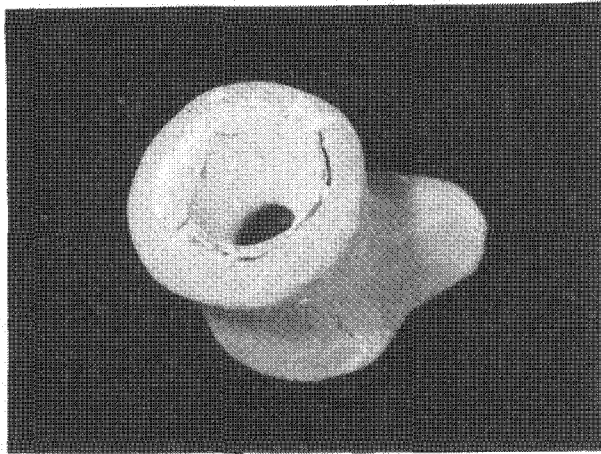
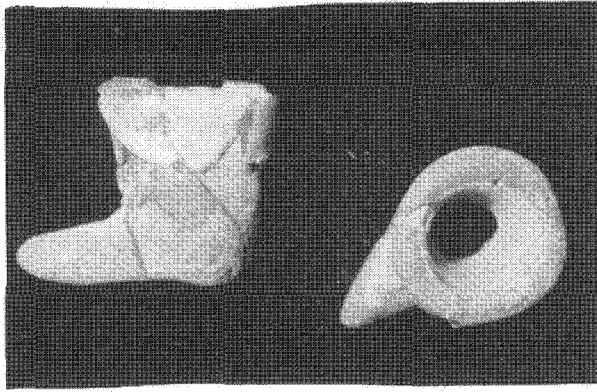


Fig. 2. Four specimens illustrated in figure 1, a-d.

We see from the table that the known distribution of these face or ear ornaments is considerable. Most specimens of known age date from the Early Period, although the Chiapa example is slightly earlier, and the Roatán and Huasteca material may be much later.

Three of the four pottery ornaments from Dzibilchaltun cenote, virtually identical with the others in form, differed sharply in manufacture and ornamentation (Figs. 1, a-c, and 2). These, a matched pair and a single specimen, bore a white coat and seemed to have their upper extremities (the visible part if worn on the face) dipped in a substance strikingly like glass. If it were glass, it would imply either the first known use of such a substance in the time period postulated or a radically later (post-Conquest) date for the artifacts and a hitherto unreported extension of body mutilation into the period of Spanish control of the area--either alternative of considerable interest.

With this background, the specimens were submitted to Shepard for study. Her conclusions are described below.

Composition and Significance of the Green Coating

A. O. Shepard

Preliminary examination. Dr. Francis Benedict, the Director of Carnegie Institution's former Nutrition Laboratory, liked to entertain his colleagues with exhibitions of magic. There was a moral in these exhibitions. They demonstrated how easily we could be deceived, how essential, for reliable conclusions, extreme care in observation and independent checking are. At times one receives startling illustration of one's liability to deception. Such was the case with the preliminary examination of the Dzibilchaltun ornaments. For this reason I will recount the preliminary incidents of my examination.

When Andrews first showed me the ornaments and asked if the green coating could be a glass, I was completely skeptical. The production of glass represents a level of technological skill and advancement that, as far as we know, the American Indian had not reached. It is true that the Pueblo Indian had produced a lead glaze which was used in decorative design, but to fuse a thin coating of glaze on a vessel is far easier than to melt a glass batch in a pot. Nevertheless, when I examined the green substance on the ornament with the binocular microscope, I had to admit that it looked surprisingly like glass. It was a clear, pale green approximating Munsell G10 6/6 in its clearest parts, and it contained a few small air bubbles. I wondered if it could be a Colonial Mexican glass, and

there ensued a discussion of dating. Andrews considered that two circumstances, absence of Colonial objects in the cenote and lack of record of such facial ornaments in Colonial times, were sufficient to establish these specimens as prehistoric. In view of the improbability that the Indians had produced a glass, I was unconvinced and insisted that the surface coat be compared with Colonial glazes. The quickest comparison that could be made was by refractive index. I had by this time examined a flake of the material in refractive liquids with the petrographic microscope. The material was isotropic; that is, like glasses, it lacked crystalline structure. It contained scattered minute, opaque inclusions, each surrounded by a ring of slightly deeper green. One particle appeared fibrous in structure and had high birefringence, from which I guessed that it was malachite introduced as a colorant. The refractive index of the clear material was very near that of Canada balsam, indicating that the material was not a lead glass. A few samples of early Colonial glazes examined had the high refractive index characteristic of lead glazes.

The next step was to determine the chemical composition. Rather than waste material on preliminary qualitative microchemical tests for particular elements I decided to obtain a spectrographic analysis, which would give a complete elemental analysis together with quantitative estimates. Since Dr. E. V. Sayre of Brookhaven National Laboratories is engaged in an extensive study of ancient Old World glasses (Sayre and Smith, 1961), I enlisted his interest. He graciously consented to run an analysis, and he promptly returned a report.

The composition of the green coating. Dr. Sayre's results are summarized in a letter of January 25, 1962:

“We had an interesting surprise when we ignited a specimen of the Dzibilchaltun glaze at the spectrograph. The specimen burned rapidly with a yellow flame leaving only a slight residue. Specimens heated on a platinum cover glass similarly burned readily leaving only a small amount of ash. Our best guess would be that the glaze is some form of organic resin. I have tried the effect of a few organic solvents on it. Although I found none that would dissolve it completely the glaze definitely became swollen and soft and rubbery in some of them.

“The most prominent lines observable in the spectrum of the ash were those of copper, which might be responsible for the green color. I would hesitate to guess in what chemical form copper might be dispersed in this organic medium, however. A purely organic dye might just as likely be responsible for the color. Additional elements present in small amounts were beryllium, magnesium and calcium, aluminum, silicon, titanium, vanadium and zirconium, iron and molybdenum. None of these appear to me to be surprising or significant.”

Dr. Sayre's report was cause for embarrassment. How could I have failed to identify the material when a simple, nontechnical test would have shown that it was not a glass? By: (1) relying on a single analytical method and (2) not considering that the coating might be something quite different from what it appeared to be. It is important to understand why the resin was not identified with the polarizing microscope. Analysis with this instrument rests almost entirely on crystalline structure--not outward crystal form, but properties determined by atomic or molecular arrangement. These properties can be quantitatively determined, and taken together they are exceedingly useful and reliable diagnostics. However, glass is noncrystalline; in fact, structurally and with respect to state of matter, glasses and resins are very similar. Consequently, the petrographic microscope, our most effective instrument for identifying crystalline matter, provided that it is not extremely fine-grained, will not distinguish a glass from a resin; it shows that both are isotropic. The important exception to the statement that the petrographic microscope relies almost entirely on crystalline structure is refractive index, a property that can be easily measured and is definitive for material of well defined composition and structure. But glasses have a wide range of composition and a correspondingly wide range of refractive indices. Consequently, when the refractive index of the green substance proved to be near that of Canada balsam, the traditional mounting medium for mineral and rock sections, it did not cast doubt on the possibility of its being a glass.

Igniting a substance is a simple test that can be performed in the field. Should this be done before samples are sent to the laboratory? It would be unfortunate to destroy material without prior laboratory examination. More often than not the analyst is seriously hampered by the limited amount of available material. Consequently, nondestructive tests should always be made first, and destructive tests should be confined to the laboratory, where they can be conducted on a small scale.

Coloring the resin. Dr. Sayre cautiously qualified his statement about the identity of the green coating. Although we lack proof, all evidence points to a resin; consequently, for the sake of simplicity, I will drop qualifiers in the following discussion and consider the implications of this tentative but highly probable identification.

Dr. Sayre's report showed that the Indian had not exceeded the bounds of his known level of technological advancement, and it relieved us of the chore of comparing the material with Colonial glazes, a difficult comparison to make satisfactorily because of the paucity of samples. At the same time, it presented us with an interesting and puzzling question, how did the Indian artisan color a resin green? We have been trying for years to learn how he colored a clay to make Maya blue. Identification of this green colorant might be no less difficult.

Remembering the small inclusion that I had tentatively identified as malachite, I asked Dr. Sayre if he could estimate the percentage of copper from his spectrographic plate. He replied (February 26, 1962), "We have read our plates with a densitometer and would estimate copper to be present in the coating in slightly under one-tenth of one per cent concentration. This is reported as weight per cent CuO. The standards used for comparison were glasses, and the difference in matrix composition would have some effect on the results, but the order of magnitude of the concentration should be reasonably correct. In a typical soda lime glass this concentration of copper would not usually produce much color. It would seem more likely that the color stems from a purely organic compound although a strongly colored copper complex might not be ruled out."

If the colorant is a dye, identification would be very difficult, for it would necessitate recognition of a small amount of one complex organic substance in another. On the other hand, undissolved remnants of a mineral colorant could be recognized microscopically. Therefore, I re-examined the spots of deeper green in the resin. They contain minute dark specks, some of which are opaque and amorphous but a few are mineral particles. They are tufts of a green fibrous mineral which is pleochroic, has much higher refractive index than the encasing resin, and high birefringence. It was one of these that I originally guessed was malachite because the properties are consistent and malachite is a common copper mineral. But identity is difficult to prove because the tufts are encased in the resin and refractive indices cannot be accurately determined. The significant fact is that the colorant is mineral; the Indian had learned how to react organic and inorganic substances. One is tempted to say facetiously that he had entered the field of plastic production in his empirical way.

Since there was a question of the effectiveness of a copper-organic colorant when copper is as low as Dr. Sayre found, I turned to Dr. Hans Gottlieb for advice. He informed me that abietic acid, which occurs in some resins, might dissolve malachite, a basic copper carbonate readily soluble in acids. He also stated that a small quantity of the products of reaction might have a strong coloring effect. The next step was to test the effect of malachite on resin. Copal, which is extensively used for incense in Mesoamerica, was an obvious resin to test. Andrews, with the assistance of Eduardo Toro, promptly supplied me with copal. It proved to be highly volatile and vaporized before it became soft enough to flow. Neither in the soft state nor in solution in an organic solvent did it have an observable effect on powdered malachite. Canada balsam, likewise, had no solvent properties for malachite. This is as far as tests have been carried. It is disappointing to leave the question of method of coloration unanswered, but, whatever it was, it may not be easily duplicated. The Indian may have had gums not available in our laboratories. Therefore, rather than delay this note for unpredictable results, it seems advisable to bring the unusual green resin to the

attention of archaeologists who may be in a position to extend our knowledge of its distribution.

A few peculiarities of the coating may be mentioned. The exterior surface of many fragments is brown, but the color penetrates only an eighth or less of the coating and ends sharply. The green zone becomes somewhat paler adjacent to it. The brown coloration may have been caused by deposition from the cenote water. It is absent from the inner surfaces of the resin that were in contact with aragonite.

The coating on the interior of one ornament separated and fell out, retaining its conical form. Its exterior surface, that which had been in contact with the pottery and was coated with aragonite, was marked by vertical pairs of minute globules of resin. They were too regular in position to have been fillings of natural vugs in the clay but suggested that the interior of the ornament had been punctured after it was coated with aragonite. Depressions would give the resin a better hold, yet these were too small to have had an appreciable effect.

Is the green resin imitation jade? We have boldly labeled this green resin "imitation jade." Obviously, there is no way to prove the intent of the artisan who made it. But its color, its application to ornaments sometimes made of jade, and the high valuation placed on this stone all point logically to imitation.

It would be interesting to know more about the Maya's use of jade. Was it used for personal adornment by whoever could afford it, or was it worn only by members of the religious hierarchy on ceremonial occasions; and was this imitation something for the laity or the humbler members of the religious group? I cannot say "cheap imitation," because, as I shall show in a moment, these artifacts were imported.

But perhaps we should backtrack. Were these particular Dzibilchaltun ornaments actually worn, or were they used only to symbolize jade for offerings thrown into the cenote? Dr. Vásquez' interesting suggestion about the possible significance of the classes of artifact found in the cenote points to this last question.

As far as we know, this green resin is the only example of its kind so far reported, but the type of ornament on which it occurs has wide distribution in Mesoamerica and includes shell, stone, and copper, as Andrews' tabulation shows. The geographic distribution of the pottery ornaments extends from the Ulúa Valley of Honduras in the south to Pánuco, Mexico, to the northwest. In none of the descriptions of the pottery ornaments is there any reference to a green coating. Most reports do not say whether the pottery object was sufficiently well finished

to serve as an ornament without further embellishment. Ekholm's report is an exception; he found incised, highly polished, fine-paste ornaments in the Pánuco region of Mexico (Ekholm, 1944, p. 467). It seems unlikely that the recipe for coloring resin green was known throughout the entire area in which these pottery ornaments have been found. It would be interesting to locate the centers of the craft and trace the range of trade in the ornaments. Clay ornaments should be carefully examined for traces of coatings. The effect that burial would have on the resin is unknown, but there is no doubt that it would chip off easily. The resin on the Dzibilchaltun specimens was partly broken away from the exteriors but was protected on the interiors of the tubes. It is therefore advisable to examine specimens of this kind before they are cleaned.

Clues to the source of the ornaments. The paste of the Dzibilchaltun ornament and the white coating add a few more pertinent facts. The dark brown paste is medium-textured, and mineral inclusions are easily detected on the granular surface of exposed areas. Individual grains, ranging in size from 0.15 to 0.4 mm in length, that were picked out for identification in refractive liquids included plagioclase, quartz (less common than the plagioclase), a dark green hornblende, and minor biotite. These minerals do not occur in native Yucatecan pottery. Of the many thousands of potsherds from major ruins in different parts of the area that have been examined, only three sherds with abundant plagioclase have been found. One of them had the style of Cempoala polychrome; the other two, being very small, were confused with local Red-on-Slate before the paste was analyzed. The paste of the ornament and sherds could not be fully compared because the ornament was not thin sectioned, but its mineral inclusions clearly show that it was not made from Yucatecan materials nor did it come from the Petén, which is also a limestone country.

The powdery white coating under the resin was evidently applied to enhance the green color, because the resin is sufficiently clear to have been modified by the underlying dark brown clay. The white material was identified by X-ray analysis as aragonite, a mineral having the same chemical composition as calcite but a different crystalline structure. It is much more limited in natural occurrence than calcite and is less stable. It is common in shells, although not to the exclusion of calcite, and the two minerals may be associated in different parts of the same shell. Because of its comparative instability it is not found in ancient sediments. Since X-ray analysis of Mesoamerican plasters and stuccoes has been limited, we cannot yet outline its distribution. I have noted it as the stucco on a sherd from Monte Albán, but this is only one pinhead on the map.

Beginnings of chemical technology in Mesoamerica. There is no doubt that the green resin was an artificial product. It shows not only that the Indian was exploring the resources of his environment but also that he was compounding

new products. This situation recalls several interesting parallels. We have good grounds for believing that the exceptionally stable pigment Maya blue was artificially compounded, but it is so unusual that the colorant has not yet been identified. Especially fascinating is a discovery recently announced by Dr. C. L. Lundell (1962, 1962a). He reports that, in the course of experiments designed to determine whether an organic substance had been added to plasters, a strong odor of a herbicide was recognized in the laboratory. The plaster was from the ruins of Tikal, Guatemala, where many monuments are unsculptured. The plaster of these monuments is white, although it has been exposed for centuries in a climate where fungi discolor plaster in a season. Dr. Lundell reasons that the Maya had discovered a herbicide that would inhibit this growth and that painting replaced sculpture for monuments when this discovery was made.

One is tempted to probe beyond these facts of the beginnings of chemical technology to understand what these bits of evidence mean in general cultural terms. How far can hypothetical interpretation be extended? All three substances seem to have been related in some way to ceremonialism; this is plain in respect to the herbicide. Maya blue was a pigment used on idols, incense burners, and temple frescoes. The green ornaments seem to have been ceremonial offerings. Does this mean that members of the religious hierarchy were tinkering with gums and juices and even clay instead of confining themselves to codices and calendric calculations, or did they have a class of artisan acolytes who were experimentally inclined? Although we can only speculate about the discoverers of these processes, the ceremonial associations are suggestive and tempt one to pursue the trail further. As to the basis of these discoveries, it is clear that the Indians were experimenting with a variety of materials and that they were observing closely and thinking from effects back to causes, or they would not have attained these unusual results.

Acknowledgments

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The contribution that Dr. E. V. Sayre has made to this Note speaks for itself. We are further indebted to him for his prompt handling of the sample and especially for his willingness to analyze it and estimate the percentage of copper at a time when he was burdened by a heavy schedule. Dr. Hans B. Gottlieb,

formerly of du Pont de Nemours and the University of Colorado, has brought his extensive knowledge and experience with dyes to bear on our question, thus adding considerably to its interest and providing leads for further investigation.

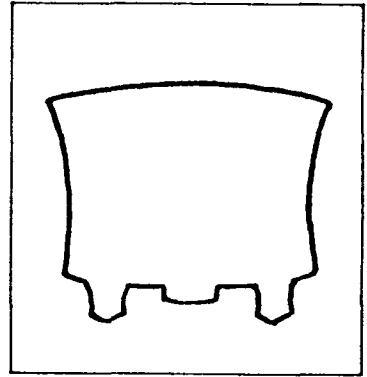
Dr. Ray E. Wilcox, of the U. S. Geological Survey, lent his skills to the effort to identify the minute mineral fragments in the resin. He also read the manuscript, and we gratefully acknowledge his comments.

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Maya Blue:



Alternative Hypotheses

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Foreword

The mineralogist and the chemist have a good deal of fun analyzing pottery: the fun of solving puzzles, using fine instruments to learn something new, finding that facts piece together to reveal unsuspected relations, and that questions answered lead to more and more questions; they even have fun laughing at themselves (or at least they should) when a promising hypothesis falls before hard facts or when their explanation of the prescientific potter's method proves too simple. Unfortunately, this zest of inquiry is usually filtered out of formal, technical reports. One of the purposes of this series of short papers is to share some of the fun, partly through accounts of experiences in the laboratory and partly by direct collaboration with the archaeologist in phrasing questions and translating results into cultural terms.

Within the field of ceramics, these papers will be free ranging in subject matter. Some will report definitive results, others will describe progress on unsolved problems or advance hypotheses that require either additional evidence or samples before they can be adequately tested; some may be reviews or critiques of methods, others will discuss the significance of ethnological reports of the potter's craft. Choice of subject will not be limited by provenance of the pottery or method of analysis but by archaeological significance of questions and answers. These papers will be distinctly informal in style and perhaps a neck will be thrust out now and then, but they will not be hasty or careless. Lest they be suspect of hiding a promotional motive, I will state quite frankly that their primary purpose is to cultivate the area of interest and understanding that archaeologists and physical scientists share: to plow the field more deeply, and to extend its boundaries.

MAYA BLUE: MULTIPLE HYPOTHESES

The pigment Maya blue is beginning to look like a blot on the analyst's escutcheon. Here we are with the latest methods of analysis at our command, unable to identify a pigment used, and perhaps produced, by a prescientific people. Why do we find ourselves in this embarrassing position? Do our ten and twenty-five thousand dollar instruments afford less powerful means of exploring the nature of things than we had believed, or are there other reasons for our failure? We are certain that there are other reasons. We have pointed out from time to time that our samples are inadequate for the kind of analyses we should like to make. We have to admit, however, that we have identified many pigments with as little or even less material. This leaves us with the fact that Maya blue is an exceptional pigment, probably one of the most unusual pigments that ever flowed from an artist's brush. Is it a natural material—an earth or ground mineral, perhaps—or something that the Maya concocted themselves? This basic question we are not yet prepared to answer. From the archaeological viewpoint, however, it is certainly a most pertinent one. Obviously, we shall have to determine what the pigment is before we can answer it. We would be a long step toward the answer if we knew whether it is wholly inorganic or includes some organic colorant.

Maya blue was first recognized as a distinct pigment thirty years ago by Merwin (Morris, Charlot, and Morris, 1931, pp. 355-56). Gettens named it (1942); he has recently described the history of his researches on it (1962), researches which have defined some of its basic properties and its major constituent and have not explained the source of its blue color. Consequently, this paint now seems more remarkable and also more puzzling than it did ten or fifteen years ago.

Maya blue has thus far been found extensively only in Yucatan, a limestone region poor in mineral resources. It appears to be most common in the late pre-Spanish period, a time of cultural decline. Gettens has been working on the hypothesis that Maya blue is completely inorganic. He bases his argument on the remarkable stability of the paint, the fact that the color is not destroyed by hot acids, including concentrated nitric acid and aqua regia. This property proves conclusively that the color is not the result of a superficial coating of dye. It does not, however, constitute proof that it is totally inorganic. To accept it as inorganic, one has to grapple with the fact that spectrographic

analysis, which gives a complete record of chemical composition including trace elements not detected by classic methods of chemical analysis, reveals no metallic ions that would explain the color. Two other interesting properties have led us to consider an alternative hypothesis, that the pigment represents some complex union between inorganic and organic substances.

When Shepard (1958) first examined samples of Maya blue from Carnegie Institution's excavations at Mayapan, Yucatan, some years ago, two properties, one optical and the other thermal, suggested that an organic colorant might play a role in this pigment. Gettens has mentioned that the pigment looks like a dye, especially when it is immersed in a matching refractive liquid and viewed microscopically. This is not deceptive to one accustomed to using refractive liquids. There is a much more significant property that suggests that this is not a typical mineral pigment. The depth of color of particles viewed microscopically is independent of particle size, whereas a colored mineral ground to a powder becomes paler the smaller the particles. In a sample of Maya blue some fine particles can be found that are deeper in color than large ones. Moreover, the uneven coloration of a few particles suggests incomplete penetration of a coloring agent.

The firing behavior of Maya blue is equally distinctive. As Gettens has mentioned, the color first changes from blue to gray before it is destroyed. What remains is the bulk of the original sample, nearly white in color, but otherwise unchanged in optical properties. Now the normal reaction of most organic materials when heated to a sufficiently high temperature is to char, just as biscuits burn. Carbon is liberated before it is oxidized to pass off as a gaseous substance. Can this be the significance of the color changes that Maya blue undergoes on heating?

If it were not for the stability of the pigment, these properties would be accepted as reasonably good indications that some organic matter is present. But this exceptional stability has presented the greatest puzzle. Attempts to explain it have led into two fascinating fields of modern research. The first can be disposed of briefly; it afforded an hypothesis that proved to be one of the many blind alleys on the trail of Maya blue. There is a class of chemical compounds called chelates, from the Greek word for claw, which are composed of complex organic radicals distinguished by appendage-like groups of atoms having great affinity for metallic ions—hence the name. Some compounds of this class are familiar pigments: for example, rose madder, known from ancient times, and a blue used on some motor cars to the improvement of which Gottlieb contributed while engaged in research for du Pont de Nemours.

The suggestion that Maya blue might be a chelate came from Gottlieb, who thought that the coloring agent might have been derived from logwood. Logwood

extract is purplish. Extraction of logwood with hot water and subsequent oxidation yields a product known to give a blue aluminum lake, which is a chelate. Gottlieb prepared this lake, but it turned out to be a red-blue whereas Maya blue is greenish blue. A manganese lake made with the same organic compound was also red-blue. Manganese, aside from iron, is the only heavy metal that could be detected in spark spectra of Maya blue, albeit in very small traces. The idea that a mere organic chelate by itself represented the pigment Maya blue was dismissed when Gettens informed us that Elisabeth West had identified the main constituent of Maya blue as the rare clay mineral attapulgite by X-ray diffraction using the powder camera method. This discovery was an important milestone in the investigation of Maya blue, and it did not contradict a second possible relation between organic and inorganic substances that we had been considering.

Attapulgite is an eccentric among the clay minerals. Instead of crystallizing in plates as do the common clay minerals, it forms long, submicroscopic rods, as shown in an electron micrograph of Maya blue taken by John Hathaway, U. S. Geological Survey (frontispiece). It also has unusual properties that were only beginning to be understood at that time. This brings us to the second kind of union between organic and inorganic substances, the so-called clay-organic complexes. Here, instead of starting with an organic molecule and hooking metal ions or atoms on it, one commences with clay and lets it take organic molecules into its structure. The result is a union between the two that is quite different from a mechanical coating. Not all clays form these "complexes." Kaolinite is among those that do not, and montmorillonites are the chief ones that do. Shepard was toying with the idea that Maya blue might be a clay-organic complex when the announcement of Elisabeth West's discovery seemed to undermine it, since attapulgite is not a "swelling clay." But we soon found that attapulgite also has unusual reactions with organic substances. It is sold as fuller's earth, which is used as a decolorizing agent for oils and sugars. It would have been premature, therefore, to dismiss the clay-organic hypothesis.

The structure of attapulgite is intricate, and the various ways in which it forms colored compounds were only beginning to be understood. We thought we might by-pass this involved aspect of the subject; if we could identify organic matter, we could let the question of the mechanism by which it is held rest until the attapulgite-organic complexes were better understood. A test for organic matter should be very simple; we need only determine whether or not carbon, over and above that in any calcite or other carbonate impurity, is present. A standard chemical analysis was out of the question, however, because of the small amount of material at our disposal; resort had to be made to microchemical analysis. With a few hours of patient and careful scraping, we might obtain barely enough material for such an analysis, although appearances are often deceiving; a large area of paint may be so thin that it offers little material.

But tedious and discouraging as collection of a sample is, there is an even greater obstacle, contamination. What proof have we that humic acids have not been deposited in the sample from soil water, or that it is free of fungi or other low forms of plant or animal life that would leave their mark as carbon? At first, we thought that this difficulty might be overcome by analyzing a mineral pigment that would serve as a control, for example, a hematite that was adjacent to the blue and had therefore been subject to the same contaminating conditions. If it turned out that the blue contained a higher percentage of carbon than the red, we might reason that an organic substance had been added to the blue. We found a Mayapan sherd that afforded skimpy samples of Maya blue and a red pigment, but by this time we realized the fallacy of the reasoning. Even though subject to the same conditions after discard, the red paint would not necessarily take up the same percentage of organic impurities as the blue because its texture and adsorptive properties would differ from those of attapulgite; furthermore, in their original natural state as earths these pigments might have acquired some carbonaceous matter, and at that stage in their history they were not subject to the same conditions; and, finally, the artist might have used an organic medium to give the paints better spreading quality. We therefore abandoned the idea of obtaining a microchemical determination of carbon.

When we reached this impasse, Gottlieb suggested that we make an analysis by infrared spectroscopy, which is a means of identifying organic radicals that requires very little material. We secured curves for two samples of Maya blue from Mayapan and hematite adjacent to one of them through the cooperation of Dr. B. Weberg, at that time in the Chemistry Department of the University of Colorado. The results were disappointing, because the curves for Maya blue showed peaks for attapulgite and a few small unidentified peaks but none that could be recognized as organic. Unfortunately, these results were inconclusive because an organic colorant, if present in the attapulgite, would constitute too small a proportion of the sample to be detected by this method. In other words, infrared spectroscopy requires only a small sample, a great advantage to us, but it is not sufficiently sensitive for our purposes.

The next step was to try to extract a blue coloring agent from the pigment. Gottlieb attempted this, using a microextractor and an organic solvent (boiling tetramethylenesulfone). In view of the stability of the pigment, one could not expect an easy extraction; after the experiment had been run for three weeks, no color could be detected in the solvent. The experiment seemed foredoomed by insufficient quantity of the pigment, and Gottlieb decided to postpone extraction experiments until an adequate sample could be obtained.

Gottlieb had still another idea, identification by color. A color is scientifically defined by its reflectance spectrum, a measurement of the percentage of light it reflects at each given wavelength throughout the spectrum. The

reflectance spectrum of every pigment is unique, like a fingerprint. An unknown can be identified by comparing its spectral curve with standard curves of identified pigments. Obtaining a reflectance spectrum of Maya blue presented difficulties. Aside from the necessity of having a clean, flat pigment surface, standard instruments require a much larger area of paint than we could obtain. Instruments for microdeterminations that would handle our specimen are not in common use. At the time of our inquiry there were only a few in this country. General Electric Company had one of them, and, through the interest and kind cooperation of Dr. R. O. Fehrs, spectral data were obtained. As we might have anticipated, no recorded spectrum of a blue paint or dye was comparable. The data for Maya blue are included (p. 14) for the record.

At this point we seemed to have reached a blank wall. It might be supposed that, among the outstanding new analytical methods that physics offers, one could be found that would crack the Maya blue mystery. Nuclear magnetic resonance was suggested, but this would be subject to the same limitations that we encountered with infrared spectroscopy. Consequently, our evidence is negative; we have been unable either to prove or to disprove the presence of an organic constituent.

Gettens considers the remarkable stability of Maya blue proof that the pigment is totally inorganic. This property has not seemed to us to constitute proof. We might think for a moment about permanence. The fading of colors in sunlight, especially blues, is all too familiar. Even some mineral colors are impermanent, a fact with which the archaeologist is familiar, although often the color change of objects exposed to the air after being taken from damp earth is the result of drying. Dehydration, oxidation, and reduction may all play a role in color changes. Some changes take place almost before our eyes; others are imperceptibly slow but no less certain. Maya blue is hundreds of years old. We are not prepared to say what changes have taken place since it left the artist's brush, although the color does not look faded; it is light but not weak. The important point is that we have no proof that our samples have the same properties as the pigment the Maya artist used some 700 years ago. Furthermore, it is possible that, instead of weakening the color, time has allowed it to become more permanent. In other words, even though we knew the constituents we might not be able to duplicate Maya blue without the assistance of time. A hint of this possibility comes from soil science. Both cobalt and zinc ions enter the structure of some clays. The process is slow, and extractability varies with the length of time during which the clay has been in contact with the metallic ions.

The behavior of attapulgite toward organic substances was incompletely explored because we thought we could side-step it by merely determining whether or not the pigment contains carbon. Since this proved impracticable, we returned to the subject of clay-organic complexes. A symposium on the

subject at the National Clay Conference in 1960 afforded an opportunity for discussion of our problem with a number of specialists. The stability of the Maya pigment surprised them, but they were not prepared to rule out the possibility that it is a clay-organic complex; they referred us to the National Cash Register Company. The NCR paper manufactured by this company consists of a sheet sized with attapulgite over which is a second sheet containing a colorless organic substance. Writing on the top sheet brings out a blue copy on the attapulgite-sized one. Did some old Maya painter anticipate National Cash Register's development? At present we can only speculate, but Mr. Robert W. Sandberg, Section Head, Chemical Development Department of National Cash Register Company, kindly examined a sample of Maya blue and also our infrared curves and spectrophotometric data. He explained that the National Cash Register Company used two kinds of adsorbates (an organic compound held on the surface or in the structure of a clay mineral by electronic bonds): one has an acid-base reaction with attapulgite and gives an intense dark blue-purple color; the other has a reaction thought to be an hydrolysis followed by oxidation to form a stable blue-green color. When a pellet of attapulgite that has reacted with the second compound is dropped into hot or cold nitric acid, it changes to an intense blue.

The spectrophotometric data for attapulgite colored with the NCR adsorbates do not agree with those Dr. Fehrs obtained for Maya blue. Furthermore, Mr. Sandberg found no peak for an organic radical in our infrared curves of Maya blue. He generously went further and tested the possibility of recognizing the presence of an adsorbate by this method. He secured an infrared curve of attapulgite that had been reacted with 5 per cent of an NCR adsorbate, enough to give an intense blue color. The adsorbate could not be detected in the curve. This test confirmed our suspicion that infrared spectroscopy is not sufficiently sensitive to test for the presence of an organic colorant in Maya blue. We had thought that an organic blue might be taken into channels of the attapulgite crystal structure and that this might explain its stability. Mr. Sandberg states that the molecules of the adsorbates they use are about 20 Å in diameter. Caillère and Hénin (in Brown, 1961, p. 350) state that the attapulgite channels are rigid and well defined in size (4 Å by 6.8 Å) and that nonpolar molecules such as hydrocarbons can lodge in them. They cite a study in which attapulgite was used to separate long-chain from aromatic hydrocarbons, the latter being too large to enter the channels. Since most dyes are aromatic or ring compounds, it is questionable that any could enter the structure.

The Maya blue problem was shelved at this point until Gettens reopened it with the review of his research (1962). We then recalled the samples that we had tediously scraped from a Mayapan sherd for microcarbon determination, not with our original idea of determining carbon as an indicator of an organic colorant but on the slim chance of finding no carbon. Obviously, the absence of

carbon would prove that the hypothesis of an organic colorant is untenable. The chance was poor because of the various likely sources of carbonaceous matter: as an original constituent of the attapulgitic clay, as a medium used by the artist, and as a contaminant from soil water or microorganism introduced after discard. There was no way of checking any of these conditions. Chemical analyses of attapulgitic do not generally include carbon or carbon dioxide, although one analysis does report 0.10 per cent carbon dioxide (Kerr, 1937). In any case, the amount would not be constant in different deposits. We knew nothing about the possible use of organic vehicles by the Maya artist or the conditions to which the sherds were subjected after discard. Nevertheless, on the very slight chance that there might be only an insignificant amount of carbon, we obtained a microchemical determination. To our surprise, a higher percentage of carbon was reported for the red than for the blue pigment, the figures being 5.5 and 2.3, respectively. On first thought, this might seem to be an indirect disproof of the hypothesis of an organic colorant in the pigment, although there is a possibility that the red had adsorbed or absorbed more carbonaceous matter than the blue. The red paint was soft and porous, whereas the blue was so firm and coherent that it had been possible to pry it off in large, filmlike flakes. Microscopic examination of the residue from combustion of the samples in the carbon determination threw further light on possible sources of the carbon. The flaky form of the blue paint was perfectly preserved even though the attapulgitic apparently had become semivitrified, whereas the earthy red paint had separated into two components, a fine granular red material and a buff-colored, earthy substance that was evidently clay and may have been in part an original constituent of the red (the pigment could have been a ferruginous earth instead of a hematite). The common red earth of Yucatan, the Kancab of the Maya, leaches out from the limestone and collects in depressions; it is therefore frequently soaked with surface runoff. The red sample also contained some clay from the sherd, because the extremely rough, grainy surface made it impossible to remove the thin coating of paint without including some body clay. At the time this was considered too small to introduce serious error, but there may have been more than was apparent. In any case, there was three or four times as much buff as red in the residue, and the buff was in all probability the source of some of the carbon.

Still another recourse was suggested by this unsuccessful attempt to obtain a significant carbon determination. In the preparation of clays for X-ray analysis, various means of removing carbonaceous matter are employed. Presumably, any contaminating carbonaceous material in the blue pigment would be less tenaciously held than the hypothetical organic colorant. If a sample of Maya blue could be treated by some of these methods, a subsequent carbon determination should be more significant. As a preliminary test, a drop of 30 per cent hydrogen peroxide was applied on the blue of a painted sherd. The reaction was violent, the paint was loosened from the surface and settled into

pits and cracks of the sherd, but its color was not destroyed. The strong effervescence was caused by the reaction of the peroxide with the clay and especially with inclusions of gray limestone. The effect was nearly as destructive as that of acid treatment. It seems worth while to pursue this lead further, but at present we do not have suitable samples for it.

This is as far as we have followed the trail to date. We can imagine how astounded, and perhaps amused, an old Maya painter would be by our efforts to discover the secret of his blue. The Maya's discovery may well have been accidental, especially if the pigment is a clay-organic complex, because the adsorbates that are known to form a blue with attapulgite are colorless. We have approached the problem with direct questions: What is this pigment? How can we analyze it? It is worth while to consider the problem for a moment from another point of view: How would the Indian be likely to discover Maya blue? What materials did his environment afford that would enable him to produce it?

Our knowledge of the distribution of Maya blue is still sketchy, but we are reasonably certain that one center of its production was in the Yucatan Peninsula, because it was lavishly used there on incense burners as well as in wall paintings in the late pre-Spanish period. Dr. H. E. D. Pollock, in a letter dated January 24, 1962, lists some specific occurrences: "In regard to the distribution of Maya blue, it was indeed fairly common at Mayapan, or at least blue paint was. And we of course know it from Chichen. There is a lot of blue paint in the Tulum wall paintings (Lothrop, 1924, pls. 4-8) and on the Mayapan-like figure censers from the East Coast (Sanders, 1960, pp. 245-46). The wall paintings that E. H. Thompson (1904, pls. 2 and 8) illustrates from Chacmultun and Tzula in the Puuc region have blue in them, and I have noted blue in several other Puuc ruins. There is blue in the Santa Rita frescoes (Gann, 1901, pls. 29-31) and on effigy pottery (*ibid.*, pls. 35-36) from northern British Honduras. Some years ago Spinden had the paint on some Jaina figurines, suspected of being fakes, tested, and he reported it to be Maya blue ("The personality figurines of Campeche," paper read before the XXIX Int. Cong. Amer., New York, 1949). There is of course the Maya blue at Bonampak. There is, or was, blue paint on the walls of the Palace at Palenque. This does not pretend to be a thorough coverage of the occurrences of blue paint but just the locations that immediately come to mind." Blue pigments are less frequently reported from other parts of Mexico and the remainder of the Maya area. Among some twenty samples of greenish blue and green pigments from stucco-painted vessels of the Guatemala Highlands, Shepard has found no example of Maya blue. Blue pigments from the Central Lowland Maya sites have not been analyzed, but in this region blue is found only rarely in postfiring pottery decoration. When evidence of distribution is evaluated, the possibility that the pigment was widely traded must be considered. It would not be surprising if it were obtained from distant sources for temple frescoes, particularly if the color had ceremonial signifi-

cance. When it occurs frequently on pottery intended for household ritual, as at Mayapan, a local source of supply is more probable.

For the present, therefore, it is reasonably safe to consider the Yucatan Peninsula as a source of Maya blue. Yucatan is a low-lying limestone plane with very slightly dipping beds. It is not known to be mineralized, but clays occur in pockets of the limestone, often exposed in natural wells or cenotes. These clays are residual from the solution of limestone. Three chief clay minerals, occurring either singly or in natural mixtures, have been identified by X-ray diffraction analysis in eight potter's clays from six contemporary villages. Although attapulgite was not among them, the possibility of its occurrence is not ruled out, especially as it has been found in a clay from a well near Merida, Yucatan. This clay, which occurs at a depth of 300 feet, is of mixed composition.

Natural resources do not give any leads when we turn to Gettens' hypothesis that Maya blue is completely inorganic. Since X-ray diffraction shows only attapulgite and thus seems to rule out admixture with an unidentified blue mineral, there remain just two alternatives to consider: (1) we have a rare variety of a rare clay mineral carrying some impurity that gives it a greenish blue color; (2) Maya blue is not attapulgite but some colored mineral having a deceptively similar structure, a suggestion that comes from Dr. W. F. Bradley, the chemist and clay mineralogist who first worked out the structure of attapulgite (Bradley, 1940). He reminded us that jade, like attapulgite, has a chain structure and suggested that we obtain X-ray patterns of "soft relatives of jade." The geology of Yucatan, however, gives no promise of finding jade or genetically related minerals.

When we turn to the possibility of finding a plant source of an extract that would react with attapulgite to form a blue, we are bewildered by the richness of tropical vegetation. The knowledge of a botanist familiar with the vegetation is needed. Fortunately, Dr. C. L. Lundell, the Director of Texas Research Foundation, Renner, Texas, has expressed interest in the problem.

As to the kind of accident that might lead to the combination of attapulgite and an organic substance, plant extracts used as media for pigments immediately come to mind. Possibly, the Maya artist thought that attapulgite would make a good white paint and then discovered to his surprise that it turned blue when he added the extract that he customarily used with other earth colors to improve their spreading quality. The possibility that the Maya used organic media with their pigments is yet to be explored. It would also be interesting to know more about the sizing of Maya paper and the inks of the codices. Von Hagen's references to analyses of sizing (von Hagen, 1943, pp. 62, 63) indicate the need for further work. The Maya blue problem might well be studied in the larger context of Mayan arts and industries. In the course of the study, we should increase

our knowledge of these other industries as well.

The study of Maya blue has afforded an excursion with many surprising byways, but it is not alone the pleasure of recalling interesting experiences that has prompted us to describe our efforts in detail. The history of this bit of research illustrates some of the principles that govern the analysis of archaeological materials. In the first place, it demonstrates clearly the importance—the necessity, often—of drawing on a number of different methods of analysis if a material is new and at all complex. It also indicates our dependence on “reference standards.” As Gettens has said, “The big breakthrough” in the study of the pigment was Elisabeth West’s identification of attapulgitite. But the method that she used, X-ray diffraction by powder camera, was also used in the first study of Maya blue (Merwin, in Morris, Charlot, and Morris, 1931). The analysis was probably made a year or two before publication. At that time clay mineralogy was in its infancy; the structures and X-ray patterns of clay minerals were incompletely known. The first published description of attapulgitite appeared four years later (Lapparent, 1935). Consequently, even though the method that eventually proved the most effective was selected, it could not give the answer until sufficient reference data had accumulated.

So many new and highly specialized methods of analysis are being made available to the archaeologist that he may well feel bewildered when he must decide where to submit his material. The problem is simplified if we think in terms of the kind of information a method yields: Does it report mineralogical or chemical composition, or does it define properties—morphology or thermal behavior, for example—from which identity may be inferred? On first thought, chemical analysis might seem to be the most useful because it is fundamental, but it does not tell directly and often not indirectly what particular materials the craftsman used, whereas mineralogical analysis does, provided that the original atomic structure of the material has not been destroyed in the process of manufacture. This is a limitation on mineralogical analysis that applies to important classes of material; metals that have been obtained by smelting ores, and glasses that have been made by fusing minerals, retain no remnant of their parent minerals. There are other classes of material in which the original mineralogical constitution is fully or partly preserved, and many classes of ceramic materials fall in this category. The most important fact that we have learned about Maya blue is that its base is the clay mineral attapulgitite. Gettens chose spectroscopy when he secured a chemical analysis of the pigment because, unlike some of the newer specialized instrumental methods of chemical analysis, this method gives a complete analysis and also requires relatively little material. But the results of chemical analysis did not enable him to calculate or even guess what mineral or minerals were present in the sample. I hasten to add that chemical data were essential to our reasoning about the cause of the color of the pigment; one method alone was not sufficient, and both mineralogy

and chemistry have made essential contributions.

Our trials with infrared spectroscopy illustrate the importance of knowing the limitations of a method with respect to sensitivity and selectivity. To a large extent this has to be left to the judgment of the analyst, especially in the case of new and incompletely tested methods that are in the process of improvement. There are, however, certain general, well established facts with which the archaeologist should be familiar, as, for example, that X-ray diffraction analysis can be used for mineralogical identification of material too fine grained to be identified petrographically.

We have hints in the Maya blue study of the usefulness of knowledge of a people's natural resources. The role of experimental duplication and the close relation such experiments should maintain with analysis and resource survey are also indicated.

The analysis of material becomes more efficient if questions are phrased specifically. In the study of Maya blue, the question what is it was broken down into such question as: Is it wholly inorganic or inorganic-organic? Does it contain metallic ions that explain its color? Could a clay-organic complex become as stable as this with time? These questions are formulated as a result of speculation, and they afford a means of bringing the target closer and increasing the chances of hitting the bull's-eye.

Both archaeologist and analyst should join in evaluating the significance of an analysis, but the archaeologist is often in a better position to formulate the original questions specifically. In the case of Maya blue, the challenge to identify this unusual and complex material is probably behind much of our effort. This is not illegitimate. As Dr. Fred. E. Wright once remarked in reference to his study of the composition of the surface material of the moon by means of the per cent polarization of light reflected from it, we would be less than human if we were not curious about such things. A great deal of time has gone into the study of Maya blue. We are not working on a commercial basis and do not count our time. If we were to do so, we might all be a little dismayed. Certainly much can and should be done to increase our efficiency, and this applies especially to the collection and care of samples. It is discouraging to undertake an analysis when one knows that his sample is skimpy because the sherd on which it occurs had been allowed to rumble around with other sherds for some time before it was sent to the laboratory.

The suggestion that we may have been specializing too narrowly in our determination to identify Maya blue does not imply that the effort is unjustified but rather that the investigation will be more rewarding if it is undertaken with a knowledge of cultural context. Gettens has suggested three reasons for

considering the identification of Maya blue sufficiently important to warrant more extensive sampling: to increase our knowledge of trade relations; to contribute to technological history; and to learn whether it is useful in the identification of forgeries. Requirements for the first two purposes differ. To consider the significance of the pigment in the history of Maya crafts, we need to have a complete identification and to know whether it is a natural or an artificial product, and, if artificial, its method of production. For this purpose we need as large a sample as can be secured. A gram would be excellent, but it may be unrealistic to expect that, even in the bottom of a paint pot or in a painter's cache. With a half gram we could undertake extraction experiments and make additional chemical analyses. Furthermore, we could do a good deal with even a tenth of a gram, but much depends on the purity of the sample. If pigment found in the soil is hastily scooped up along with some earth, it will become further mixed before it reaches the laboratory and will then be completely useless for quantitative analysis.

Our requirements for tracing the distribution of Maya blue are less stringent. All that is necessary is comparison with Yucatecan Maya blue; two criteria are sufficient to identify this pigment: (1) composition—attapulgite is the chief constituent; (2) stability—it is resistant to hot acids. These tests can be made from a thumbnail-sized area of pigment provided it is not too thin and worn and is not diluted, as with calcite (it is clear that the Maya made tints by such admixture). As far as is known at present, the distribution of Maya blue is not as extensive as one might anticipate, judging from its attractiveness and the comparative rarity of blue paints. Could this apparent restriction be explained by a Yucatecan Maya monopoly maintained because of its religious significance, or have we been misled regarding its distribution because of the spottiness of our sampling? We are dependent on the archaeologist for this answer.

* * * * *

Since the above was written, Mr. Gettens has shared with us a sample of an unusual blue pigment that makes the challenge of Maya blue still more intriguing. It is from Leopoldo Batres' excavations in Escalerillas Street behind the Cathedral of Mexico. After lying in storage for more than half a century, it was brought to light through Mr. Gettens' inquiries and the cooperation of Dr. Gordon Eckholm of the American Museum of Natural History. It resembles Maya blue in color, stability, and thermal behavior, but is mixed with specular hematite. For the Mesoamerican artist, the shiny plates of this mineral served as a means of gilding the lily. After separating the hematite, we found by X-ray diffraction that two clay minerals are present, attapulgite and a second that we had not before recognized in Maya blue. It is a variety of sepiolite, a mineral familiar from its use for meerscham pipes. Attapulgite and sepiolite are closely related structurally, both forming slender, rodlike crystals, a fact

of interest in connection with the relation of fibers and dyes (see p. 14). Whether the two minerals occurred in natural association or were mixed by an Indian artist we are not yet prepared to say, but this find may have a bearing on the basic question whether Maya blue is totally inorganic or a clay-organic complex. It is tempting to speculate: Did the Indian discover how to stain a clay blue and then find that different white clays would take the stain, or did he find two clays, both of which carried inorganic impurities that gave them nearly the same color? We can speculate regarding relative probabilities, but speculation should go hand in hand with testing, and we still regard the idea that the Maya may have discovered a blue clay-organic complex as an hypothesis to be tested and as a means of stimulating interest and suggesting experiments.

Technical Addenda

Optical properties. Bradley (1940, p. 410) has called attention to the fact that, on several occasions, dependence on optical examination has led to the identification of attapulgitite as montmorillonite. He notes that within the oriented flakes ordinarily used for identification there is a similar disposition of optical directions for the two minerals. Consequently they cannot be distinguished by this method of examination.

An interesting optical property of Maya blue is its pleochromism. There is sufficient uniformity in orientation of fibers to cause the flake-like aggregates to act as optical units. These flakes exhibit pleochromism, the color change with optical direction being one of intensity rather than hue. Absorption is stronger in the direction of the slow than the fast ray. This property indicates that the colorant, whatever its composition, is oriented in relation to the structure of the attapulgitite. This could occur with either an inorganic or an organic colorant.

Thermal behavior of Maya blue. On being heated in air in an electric resistance furnace, Maya blue first turns gray and then becomes whitish. The temperature and time required to bring about these changes vary somewhat with the texture of the pigment and possibly with the amount of carbonaceous impurity it contains. Notes from one test are recorded to give an idea of the ranges in which these changes occur. For this test the pigment was not removed from the sherd. It was a firm, compact film.

Color	Minutes of heating	Temperature, °C
Slightly duller blue	15	250
Still duller	8	250-300
Medium gray	8	300-350
Gray, no change	10	350
Slightly lighter gray	10	350
Lighter gray	5	400
Very pale gray	10	450

The compact texture of this sample doubtless affected its thermal behavior.

Spectrophotometric data. Although no pigment having tristimulus values similar to those of Maya blue is known, the spectrophotometric data obtained by the General Electric laboratory are recorded for future reference. For these recordings a magnesium oxide standard was used, and the beam size was $\frac{1}{8}$ inch by $\frac{3}{8}$ inch. Two recordings were made.

Tristimulus values					Dominant wavelength, $m\mu$	Brightness, %	Purity, %
X	Y	Z	x	y			
2940	3070	5040	2661	2778	479.5	27.8	20.2
3066	3213	5055	2705	2835	480.1	28.4	18.0

An observation on colorants and fibers. Gottlieb has suggested that the combination of a colorless organic compound with attapulgite might be analogous to the dyeing of cellulose fibers, such as cotton, with colorless dye materials. In this class of textile dyeing, the colorless water-soluble dye material penetrates into the fibers, combines with them by hydrogen bonding, and is subsequently oxidized to an insoluble combination of the colorant with the fibers.

X-ray analyses of argillic blue paints from Mesoamerica. In view of the unusual interest of recent finds it seems worth while to summarize present data. Miss West has kindly listed her identifications for the following table and has also notified us of her discovery of sepiolite alone in another Mexican sample. The table is limited to X-ray identifications because this is our only definitive method.

Provenance	Object	No. Samples	Method and Analyst*	Source of Material
CLAY MINERAL: ATTAPULGITE, TYPICAL MAYA BLUE				
YUCATAN				
Chichen Itza, Sacred cenote	Sherd	2	EHW	Peabody Museum, Harvard University
	General excavations	1	EHW	Carnegie Institution Collection
Mayapan	Sherd	1	AOS	Carnegie Institution Collection
		3	AOS‡	
		1	EHW	
Cozumel Island Balankanche	Wall painting fragment	1	EHW	Field Museum
	On lump of earth and charcoal from hearth	1	AOS	E. W. Andrews, National Geo- graphic Society
Unknown	Pigment, azul de Tekax	1	EHW, AOS	Edward Forbes, Fogg Museum, Harvard University
OTHER MAYA				
Bonampak, Chiapas, Mexico	Wall painting fragment	1	EHW	Fogg Museum, Harvard University
Piedras Negras, Guatemala	Cache vessel cover	1	EHW	University of Penn- sylvania Museum
	Cache vessel fragment	1	AOS‡	University of Penn- sylvania Museum
Tikal, Peten, Guatemala	On ball of copal	1	EHW, AOS	University of Penn- sylvania Museum
Probably Palenque region	Effigy figure	1	EHW	American Museum of Natural History, New York
CENTRAL MEXICO				
Uncertain	Whistle	1	EHW	American Museum of Natural History, New York
CLAY MINERAL: SEPIOLITE				
No provenance (Aztec)	Spindle whorl	1	EHW	American Museum of Natural History, New York
CLAY MINERALS: SEPIOLITE AND ATTAPULGITE				
Behind Cathedral of Mexico	Pigment	1	EHW, AOS‡	American Museum of Natural History, New York

*The method of analysis is identified by the analyst. Miss Elisabeth West (EHW) has used the powder camera methods, Shepard (AOS) has used the diffractometer method.

‡Diffractometer method combined with special techniques for clay mineral identification employing glycolation with subsequent heating.

It is noteworthy that sepiolite has not yet been found in any Yucatecan or Mayan sample. Clay mineral techniques, which are required for the complete mineralogic analysis of these argillic blue pigments, have indicated small amounts of other clay minerals in some Yucatecan specimens, but somewhat larger samples will be required for satisfactory identification of minor constituents. The chief value of such analyses would be in differentiating sources of attapulгите.

The presence of a variety of sepiolite in the two Mexican samples has given the Maya blue problem a new dimension. It supports the hypothesis that these paints were artificially compounded. And their distribution is now of interest not merely as a reflection of trade in artifacts and materials; it bears directly on the spread of a specialized technique.

Acknowledgments

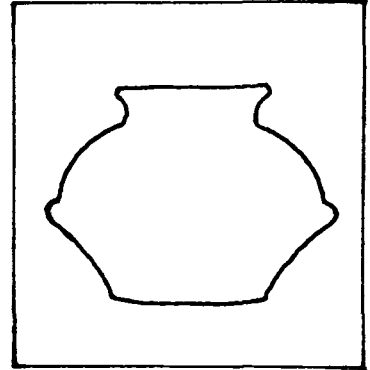
By good fortune, things that the archaeologist digs up stir the imagination and arouse curiosity, not only of professional diggers, but also of scientists in many fields. This circumstance accounts for the archaeologist's opportunities to secure a great variety of identifications, and it often enables him to take advantage of the newest analytical methods.

In our study of Maya blue, research workers in industrial laboratories have made notable contributions. Dr. R. O. Fehr, General Electric Company, now professor of Engineering, Cornell University, who numbers archaeology among his hobbies, secured spectrophotometric data from a small sample that presented special problems. Although the data did not identify the pigment, they afforded a basis for comparison with other pigments by means of tristimulus values. Mr. Robert W. Sandberg, Section Head, Chemical Development Department, National Cash Register Company, has contributed greatly to the interest of our problem by his comparison of the adsorbates of NCR paper and Maya blue. His determination of the sensitivity of infrared spectra for the adsorbates was especially pertinent to our studies. It was important to test the applicability of infrared analysis, and we are indebted to Mr. Bert Wieberg for first probing this possibility. Mr. James Gude, Geologist, U. S. Geological Survey, made X-ray diffraction analyses, by the powder camera method, of several samples of Maya blue to reassure us that it is basically attapulгите. Mr. John Hathaway, Geologist, U. S. Geological Survey, has brought the form of Maya blue within the range of our vision with his excellent electron micrographs secured by the shadowing technique. The many clay mineralogists with whom we have discussed the puzzle that Maya blue presents have had interesting comments. We are especially

grateful to Dr. William F. Bradley, Department of Chemical Engineering, University of Texas, for his suggestions. For a number of years our interest in Maya blue has been maintained by exchange of samples and ideas with Mr. R. J. Gettens, Freer Gallery of Art. We have appreciated his prompt reporting of Miss West's findings, and our divergent hypotheses have been a source of stimulation. Dr. H. E. D. Pollock, Carnegie Institution of Washington, has kindly supplied information about distribution of the pigment. The manuscript has been read by Mr. Gettens, Mr. Hathaway, Dr. Pollock, Mr. Sandberg, and Miss West. Without implicating them in our hypothesis, we acknowledge our indebtedness for their criticisms.

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Maya Blue:



An Updated Record

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Acknowledgments

Many investigators have contributed to the study of Maya blue. The originality of Maya blue potters has been a spur to interest. Rare samples suspected of being Maya blue were submitted by Vivian Broman Morales. Fred Hildebran of the U. S. Geological Survey analyzed them by X-ray diffraction. Weak concentrations of the pigment in some samples increased the difficulty of identification. Despite this difficulty the pigment was found in all but one of them for which there was insufficient sample. The electron micrographs were made by Paul Blackmon of the U. S. Geological Survey. Analyses of clay using recent clay mineralogical methods were made by Len Schultz. I have a special obligation to David Huston, who reawakened my enthusiasm and interest in Maya blue and its makers. Numerous people offered advice through correspondence. Dave Stewart gave much technical advice for a first paper from which I have drawn for this note. Dr. H. E. D. Pollock, who graciously consented to be coauthor of the paper, contributed original ideas throughout the study, beginning with the first interest in the pigment. Although he devoted much time to a study of the literature, he emphasized, in referring to his contribution, that he did not attempt to make an exhaustive review. Correspondence has been maintained regarding technical questions with Dr. H. van Olphen. Arguments with Dr. W. F. Bradley regarding the explanation of Maya blue have always been stimulating. Each person who contributed has enriched the experience of the study.

ANNA O. SHEPARD

INTRODUCTION

Interest in the pigment Maya blue has passed through a number of phases: it has risen with the discovery of new samples, the availability of new analytical methods, and the impact of original ideas. Interest has declined with the exhaustion of these stimulants. Since two papers defining the Maya blue problem were published in 1962 (Gettens, and Shepard and Gottlieb) there has been a gradual accumulation of additional information from important new samples, synthetic experiments, and ethnographic and geologic data.

The period of random expansion of Maya blue studies was climaxed by van Olphen's synthesis of an indigo-attapulgitic complex that has both the color and the stability of Maya blue (van Olphen, 1966). This synthesis was a major discovery, ranking with Elizabeth West Fitzhugh's identification of attapulgitic in the pigment. It does not mark *finis* to Maya blue studies, however; rather, it leaves a basic mineralogic question that bears on ancient techniques, and it suggests a number of distinct lines of archaeological investigation. Consequently now is a logical time to summarize unpublished data and to outline problems that invite further research.

For our knowledge of Maya blue we are indebted to specialists in various fields whose findings have been most meaningful when they have been cross-checked and integrated with one another. Archaeologists have been patient in their recovery of samples, and ethnologists have supplied abundant pertinent data. Indeed, it is clear that the archaeological significance of Maya blue can be fully appreciated only as it is studied within the context of Yucatecan ceramic history. (Part of the present paper had already been written under the title "Techniques of Contemporary Yucatecan Potters" when van Olphen's synthesis was accomplished.) But, impressive as the contributions of ethnology are, they give hard facts for only the historic phase of culture history. The leap in culture when we turn to pre-Conquest Yucatán is long. We should be unhampered in speculation, which has been so greatly stimulated by ethnology, but cautious in accepting inferences.

In this Note I shall review Maya blue in the setting of contemporary Yucatecan ceramics, referring to archaeological data principally as they establish period and geographic distribution of samples. The archaeological aspect of Yucatecan pottery, the roots of which spread more widely into Maya history, is held for a second Note.

Review. Rutherford J. Gettens will always be associated with Maya blue. He named the pigment and defined its basic properties. His search for samples was indefatigable, and he carefully tested all the samples he secured. He was fascinated by the stability of the color in hot mineral acids and searched persistently for natural blue minerals with this property. His interests included both archaeological and more general scientific aspects of the problem, and he drew many specialists into the research for solutions. When his paper of 1962 was published, his assistant, Fitzhugh, had identified the basic constituent of Maya blue.

The idea that Maya blue is a mineral pigment seemed to be supported by the failure of experienced chemists, including Gettens himself, to synthesize a pigment having the properties of Maya blue by combining an organic dye with attapulgite. The color was always a red blue instead of the green blue of the Maya pigment and was immediately destroyed in mineral acids. Another blank in our knowledge at the time the Gettens and Shepard and Gottlieb papers were published was the source of attapulgite in Yucatán, where Maya blue is so frequently found as a post-firing pigment on pottery and in frescoes. Much pertinent information, more or less familiar to the few specialists, accumulated after publication of the 1962 papers, but nothing was printed until van Olphen's note on his synthesis appeared in *Science* in late 1966.

The stability of Maya blue in hot, concentrated mineral acids, a property the Indians could not test and did not need, not only has been accepted as an essential criterion for identification but also has become the center of interest for investigations. Two different hypotheses of the composition of the pigment have been advanced. Whereas Gettens thought that the pigment was entirely of mineral origin, my familiarity with clay-organic complexes of the carbon black paint of Pueblo pottery led me to consider the possibility that an organic liquid was combined with a clay of high adsorptive properties. Samples of Maya blue were occasionally submitted to me by Carnegie Institution archaeologists over a period of years. The firing behavior of these samples impressed me first. The pigment turns gray at low temperatures and then white or light red at higher temperatures, suggesting charring of an organic material followed by oxidation. But these heat effects do not prove the presence of an organic constituent. More convincing is the relation of particle size of the pigment to intensity of color, which is easily recognized microscopically. Geologists are familiar with the increasing paleness of a colored mineral as it is ground. In Maya blue the relationship between particle size and depth of color is often the reverse: the very fine particles are much deeper in color than the large particles. This simple observation seemed quite convincing.

The question of the colorant of Maya blue becomes more interesting when it is phrased in archaeological terms: were the Indians using a natural mineral or had they invented a process of making a blue pigment? There is a special fascination in early inventions. But the argument that Maya blue is an invention did not win support quickly. W. F. Bradley, the clay mineralogist who had defined the structure of attapulgite (Bradley, 1940), reminded us that jade, like attapulgite, has a chain structure. He suggested that we look for "soft relatives of jade." Our knowledge of the geology of Yucatán did not encourage the search for such a mineral, however.

Blue attapulgites were also a distraction at one time. H. E. D. Pollock called attention to a blue clay, erroneously classed as attapulgite, found in a deep well near Mérida, Yucatán. The Maya blue color it had when freshly mined and moist disappeared on drying and was not restored on rewetting. Later many samples of natural blue attapulgite were found, especially in the attapulgite area of the southeastern United States, i.e., Georgia and Florida. All of them had the same limitation of color stability.

A specimen found by Gettens at the American Museum of Natural History lent support to the hypothesis of the invention of Maya blue. The sample had been collected in 1901 and probably came from Batres' excavations behind the Cathedral in Mexico City. The pigment was mixed with specular hematite, the shiny, steel-gray plates of which were frequently used by Mesoamerican Indians to give sparkle to their paints. Gettens shared the sample with me. After I had separated the specularite with heavy liquids, the X-ray diffraction pattern showed two related clay minerals, attapulgite and sepiolite (meerschaum). These minerals have the same structure, but sepiolite contains a higher percentage of magnesium. Later Fitzhugh found sepiolite alone in a small American Museum specimen labeled "Aztec." Hence there were three mineralogically distinct clay bases in Maya blue. When we could not find a stable natural blue in the most common of these minerals, it seemed improbable that the Indians would have had natural sources of all three. Blue pigment found in a tomb in Zaachila, Oaxaca, Mexico (Gallegos, 1963) afforded another line of evidence. The clay mineral, although an attapulgite, was classified by Bradley as a distinct variety (personal communication). It had been recognized in one locality in the United States only a few years before its discovery in the Mexican pigment. When Bradley examined the X-ray diffraction pattern of the Gallegos sample, he was satisfied that Maya blue was a synthetic product.

The study of Maya blue, viewed in retrospect, suggests that understanding of the colorant was repeatedly near our grasp, yet samples essential for experiments were lacking. In the introductory part of "Maya Blue, Alternative Hypotheses," Shepard and Gottlieb discussed reasons for considering Maya blue a clay-organic complex. Gottlieb supplied many of the ideas advanced in that paper; he proposed methods of analysis and knew specialists to whom to appeal for assistance. He first suggested that Maya blue might be a chelate. Since the dye from logwood, the Central American tree that is common in Campeche, forms a blue aluminum lake (a chelate), he experimented with this idea initially. Then, when Fitzhugh identified attapulgite as the basic constituent of Maya blue, we scrapped the chelate hypothesis and turned to clay-organic complexes, already suggested by thermal experiments. Our tests are summarized as an illustration of the course of analysis.

Since attapulgite-organic complexes were not well known at that time, we first sidestepped the problem by trying tests for carbon. We realized that contamination of samples with organic matter was certain, and we knew that carbon was present in the calcite contained in all samples. Gottlieb therefore suggested resort to infrared spectroscopy, a means of identifying organic radicals. It is not surprising that the infrared curve showed only attapulgite and a few weak unidentifiable reflections, because van Olphen has estimated that there is less than one-half per cent of indigo in his synthetic Maya blue. The infrared analysis we obtained was not sufficiently sensitive to detect that amount. A sherd with a line of hematite paint adjacent to a line of Maya blue was used for microchemical tests of the two pigments. We considered the hematite a partial control for contaminants, but the analyses showed that it contained more carbon than the Maya blue. Gottlieb suggested identification of the colorant by its reflectance spectrum. In-

adequacy of sample required micromethods, and the values obtained did not correspond to those of any known pigment. After our results were published, Dorothy Nickerson, color specialist of the U. S. Department of Agriculture, who had been following our work, called our attention to deviations in the tristimulus values from those of typical Maya blue color. The cause of the error has not been ascertained.

The results of Gottlieb's attempts to synthesize Maya blue with attapulgite and indigo were similar to those of other investigators. Gottlieb also attempted a microextraction of the colorant. The solvent was still colorless after the experiment was run for three weeks. Gottlieb also suggested analysis by nuclear magnetic resonance, but at that time we did not obtain significant results, although we had the cooperation of a physicist at the University of Colorado and later one from the Bureau of Standards at Boulder.

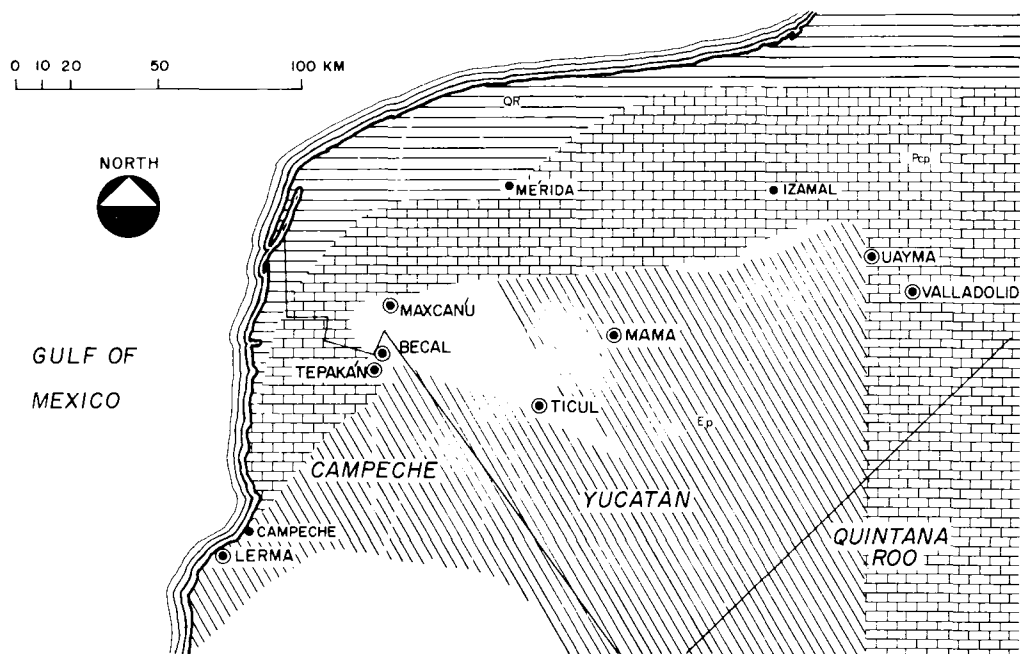
The National Clay Conference held in attapulgite territory (Atlanta, Georgia, 1960) afforded the opportunity to consult attapulgite specialists. We were referred to the National Cash Register Company because their NCR paper was based on attapulgite-organic complexes. Although the complexes they were using at that time were not stable in acids, Robert Sandberg of the company's chemical development department made a number of helpful suggestions. His data on the size of organic molecules as compared with the diameter of attapulgite channels corrected an idea I had on a possible cause of the permanence of an organic blue on attapulgite; the channels of the mineral might have a shielding effect if the organic molecules were held within them. But most dyes are aromatic hydrocarbons, the rings of which are too large to enter the channels. Gottlieb believed that the colorant was on the surface, an hypothesis now supported by van Olphen's conclusion from his synthesis. Sandberg's data on the percentages of organics in NCR papers emphasized the small amounts required to obtain strong colors. Sandberg also obtained infrared analyses. The negative results showed that the method he used was not sufficiently sensitive to detect these amounts.

One of the most intriguing suggestions made at the Clay Conference revived the idea of a mineral blue, although a synthetic product was assumed. In the synthesis of pigments corresponding in composition to ultramarine, known since ancient times, kaolinite is used. Neither the mineral nor the synthetic is stable in hot mineral acids. The substitution of attapulgite for kaolinite in the synthetic was suggested. But involved synthetic experiments were fruitless. We therefore held to the clay-organic hypothesis.

After these various experiments we still did not know, at the time of publication of the 1962 papers, either the composition of the colorant of Maya blue or the cause of its stability. We did not even know the source of attapulgite in Yucatán. However, I had clay samples from eight Yucatecan pottery-making villages that had been collected by R. H. Thompson for his dissertation (Thompson, 1958). A suggestion made at the Atlanta Clay Conference led me back to these samples and to discovery of the distribution of attapulgite in Yucatán.

CERAMIC MATERIALS OF CONTEMPORARY YUCATECAN POTTERS

Ceramic materials that were collected by R. H. Thompson in preparation for his dissertation served for my initial studies of composition of materials. When Thompson collected, in 1951, hand-made pottery was being produced at eight villages (Fig. 1). Thompson also collected a clay from near Mérida, clays of Campeche potters who were following Guadalajara style and making wheel thrown and molded pieces, and a commercial fuller's earth from Campeche. After I had made preliminary analyses of Thompson's samples, I went to Yucatán to gain first-hand experience; in 1958 I visited Lerma and Tepakán; in 1963-64, Lerma, Tepakán, Maxcanú, Becal, Ticul, and Valladolid. I also collected from localities where I had reason to believe attapulgite might occur. I had previously visited the village of Mama with E. Shook in 1952 and had recorded the speed of the *Kabal* in Maxcanú the same year. My trip of 1963 was late. Pottery was no longer being made at Becal; the potters had found hat weaving more remunerative. In Maxcanú, Macedonio Canul, who had been Thompson's chief informant, was the only potter still making vessels. He was an old man beginning to fail. The passing of old experienced potters is doubtless general. On a short stop in the village of Mama in November 1967 I learned that the two principal potters that Shook and I had observed in 1952 were no longer living. Mama had afforded special advantages for pottery studies because it was less subject to outside influences than other villages.



POTTERY MAKING CENTERS

Fig. 1. Pottery-making centers.

Thompson's eight pottery-making villages are well distributed both geographically and geologically. They extend across the peninsula from Valladolid on the east to Campeche in the southwest (circled dots on Fig. 1). The limestone formation of the southern part of the peninsula has been classed as Eocene (*Ep*), that of the northern part as Pliocene (*Pcp*), except for the Quaternary coastal strip (*QR*) (Butterlin and Bonet, 1963). Two villages are in the Pliocene, two in the Eocene, and the remaining four are near the contact of the two formations (blank area on Fig. 1, which is Paleocene to Mid-Eocene).

Conspicuous features of the country are the thinness of soil, the absence of surface streams, and the presence of natural sinkholes or wells, the *cenotes*—formed where the surface limestone has collapsed into underground caverns. The walls of the *cenotes* often expose seams or pockets of clay. Also characteristic are the large artificial pits (*sascaberas*) where secondary limestone (*sascab*) has been dug. It is used with lime for mortar and for one class of pottery temper. The *sascab* is breccia-like in texture with a chalky matrix. The genesis of *sascab* is debatable. In small shallow basins are accumulations of *kancab*, red earth derived from weathering of the clay.

This environment would seem to limit stringently the potter's choice of materials. There is no quartz sand in the area. If the potter does not use potsherds for temper, he seems to be restricted to limestone, either hard crystalline limestone or the soft chalky *sascab*.

The clays occur in relatively thin, irregular beds within the limestone. Superficially the clays look much alike. They are very fine grained, dense, and buff, red, or light brown. Their working properties are similar; they are sticky when wet and have high plasticity, indicated by the large proportion of temper potters use. Thompson reports temper : clay ratios of 1:1 or 2:1 (1958, p. 72). These are potters' estimates based on dry bulk. Laboratory determinations of temper in samples of prepared paste indicate 60–65% temper by weight. On firing, the clays seem even more similar than they do in the hand specimen. They have high drying and firing shrinkage because of the large water loss, and without temper crack on drying. With two exceptions they fire to brown or red brown in oxidizing atmosphere. Exceptions are light buff from Mama and Uayma. Although these properties suggest that the clays are essentially identical, clay mineralogy, determined by X-ray diffraction, shows that there are three distinct classes, as different in basic structure as mica and asbestos are. The clay that seems most consistent with high plasticity is a montmorillonite, a platy clay with a structure that adsorbs large amounts of water, a so-called "swelling clay." The expansion of a particle of sodium montmorillonite on wetting is spectacular, and the clay becomes jelly-like in consistency. The swelling of a calcium montmorillonite is not so extreme. Since Yucatecan clays occur in limestone formations, the montmorillonites are calcareous.

Montmorillonites have many present-day uses, such as decolorizers, drilling muds, and slips for cast ware and they are of concern to the engineer who deals with foundations. Our most familiar example of a montmorillonite in Indian pottery is the slip of Santo Domingo Pueblo, in the Rio Grande Valley. The

important property of the clay for Indian potters is its power to hold on firing a carbon paint derived from a plant extract (Shepard, 1954, p. 34).

Montmorillonite also occurs in the so-called mixed-layer clays. The clay mineral with which the montmorillonite is combined (kaolinite) doubtless reduces its swelling capacity and consequently shrinkage.

The second class of Yucatecan clay is attapulgite. This has a tubular structure (see electron micrograph, Fig. 1, Shepard and Gottlieb, 1962). It was considered rare only a few years ago. Now it is extensively mined and has a wide variety of uses ranging from decolorant, paint stabilizer, and "size" in NCR paper, to cat litter.

The third class of clay is more difficult to define. The X-ray diffraction pattern alone is not definitive. The clay could be classed as either a low-grade kaolinite or a halloysite, two kaolinitic clays that require special methods for differentiation (Addendum 3). The results of differentiation tests were negative; the clay did not behave like either kaolinite or halloysite. An electron micrograph, however, showed that a specimen from Lerma is composed of minute hexagonal plates (Fig. 2). This structure is characteristic of kaolinite. The clay, like the others, is largely colloidal; therefore its fine texture may account for the failure of

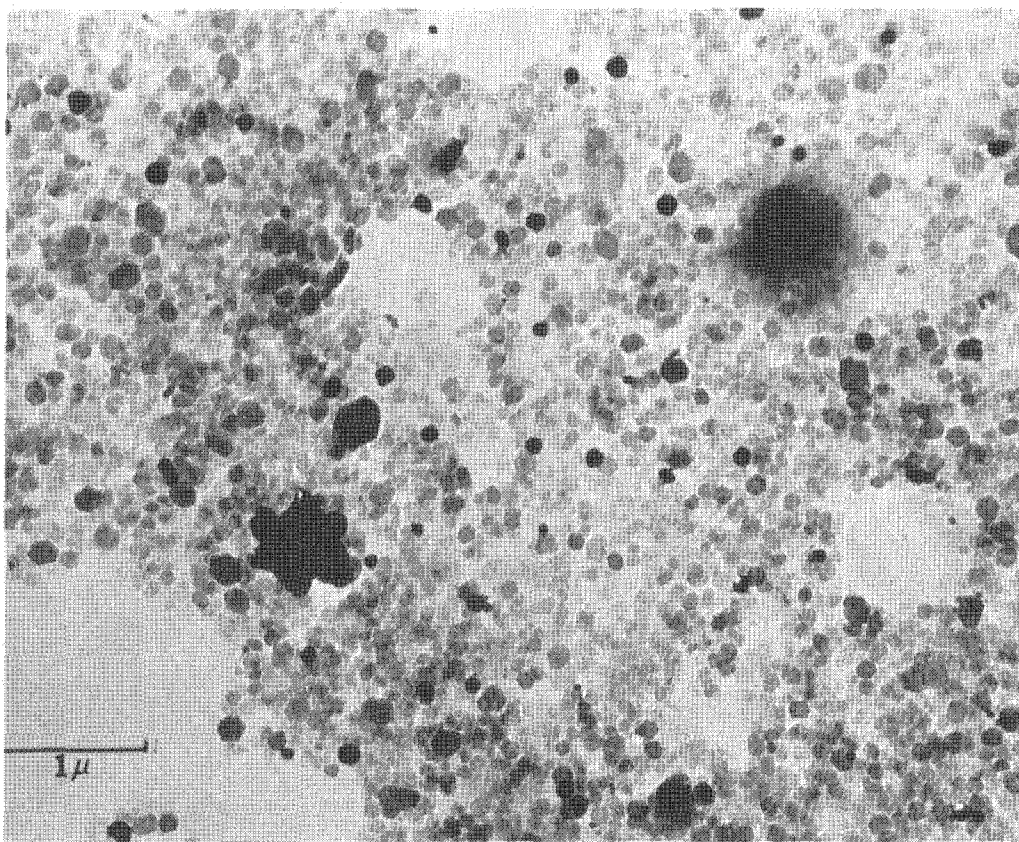


Fig. 2. Hexagonal plates in Lerma clay.

tests. I will refer to it as the kaolinitic clay. The best crystallized specimen occurs at Lerma. Related clays, though of poorer structure, were used by Campeche potters. Thompson collected three samples, a red, a buff, and a black. Kaoline is also a component of the mixed-layer clays of Ticul, Tepakan, and Becal, the other component being montmorillonite.

The clays of the Thompson collection are summarized in Table 1. As mapped by Butterlin and Bonet, the kaolinitic and montmorillonitic clays occur

Table 1. Composition of Clays

Village	Sample	Constituents	
		Major	Minor
Uayma	280	kaolinite	montmorillonite-illite ¹
	281	montmorillonite	montmorillonite-illite
	282	montmorillonite and illite	
Valladolid	283	montmorillonite	kaolinite
Mama	278	attapulgit	illite (?)
Ticul ¹	279	kaolinite- montmorillonite	
Maxcanú ²			
Tepakan	277	kaolinite- montmorillonite	
Becal	276	kaolinite- montmorillonite	
Lerma	270	kaolinite	montmorillonite

¹Hyphen between two mineral names indicates mixed layer clay.

²Maxcanú obtains clay in trade, mainly from Tepakan.

in the Pliocene, and the attapulgit occurs only in the Eocene or near the Eocene-Pliocene contact.

The tempering materials collected by Thompson from the eight villages are all calcareous and they contain variable amounts of clay. They differ widely, however, in ratio of components and in physical properties. The potters' methods of preparation and their choices for vessels with particular functions also differ.

The potters' classification of temper is based on texture. The coarser variety of temper, *hi'*, is crystalline. Much of it is collected in caves where it has crystallized on the walls or formed stalactites and stalagmites. In some villages *hi'* is selected to temper cook pots. The finer variety of temper, *sascab*, is chalky in texture and cryptocrystalline. In some villages *sascab* temper is chosen for water jars.

Among the eight villages, five use *sascab*, five *hi'*, and two do not use these classificatory terms. The only villages in which Thompson reports only one class of temper in use are Lerma, *hi'*, and Valladolid, *sascab* (Table 2). The samples of *sascab* are similar in gross appearance, being fine and chalky. The samples of *hi'*,

Table 2. Tempering Material

Village	Sample	Native Name	Form	Clay Constituent	Insoluble Residue, %
Uayma	65	<i>xne us</i>	crystalline		
	66	<i>sascab?</i>	cryptocrystalline		
	67	<i>pikich</i>	crystalline	kaolinite and hematite	23.8
Valladolid	68	<i>sascab</i>	cryptocrystalline	montmorillonite	10.82
Mama	57	<i>xluum hi'</i>	crystalline	attapulgitic	47.5
	58	<i>sascab</i>	cryptocrystalline		2.42
	59	<i>chi' ich' hi'</i>	crystalline	attapulgitic	15.92
Ticul	60	<i>sascab</i>	cryptocrystalline	attapulgitic	20.40
	62	<i>hi'</i>	crystalline		2.68
Maxcanú	53	<i>hi'</i>	crystalline		1.65
Tepakan	56	<i>sascab</i>	cryptocrystalline	montmorillonite	10.42
Becal	55	<i>cu'ut</i>	crystalline	attapulgitic	48.6
		(dolomite)			
Lerma	51	<i>hi'</i>	crystalline		2.34

on the contrary, are variable and not all are visibly crystalline. The *hi'* of Lerma, composed of irregular aggregates of clear plates of calcite, resembles coquina. One wonders if Gaumer's coquina of Izamal (Gaumer, 1895) was this class of material. The crude *hi'* of Ticul is a coarse crystalline calcite stained with *kancab* on exposed surfaces. The *xne us* of Uayma is similar except that it is free of *kancab*. *Pikich* of Uayma is a hard rock of crystalline limestone firmly cemented with *kancab*. The *hi'* of Maxcanú is composed of fine crystals of calcite (less than a millimeter in diameter) which occur on the walls of the huge cavern near the village. Most variable is the *hi'* of Mama, a village in which several tempering materials are combined. They are obtained at different levels in the same sinkhole in which the clay is mined. *Xluum* (earthy) *hi'* is composed of rounded particles, buff, yellow, and red in a chalky white matrix. *Ch' ich'* (granular) *hi'* is composed of fine angular crystals, loosely cemented. The *cu'ut* of Becal is a highly argillaceous rock composed of fine rhombs of dolomite in a matrix of attapulgitic. The only other tempers in Thompson's collection containing dolomite are the *ch' ich' hi'* of Mama and the *sascab* of Ticul in which it is a minor constituent with calcite. Thompson doubts that *cu'ut* was ground in the preparation of temper. He refers to Gaumer's description of temper preparation in Izamal where "*cu'ut*" was placed in enough water to form an "emulsion"; the powdered clay was then added to it. This would be a practical procedure when a high percentage of clay is an integral component of the temper, as at Becal. The clay would soften, causing the temper to disintegrate readily. We do not know whether Izamal "*cu'ut*" contains attapulgitic. All the attapulgitics so far recognized in the Yucatán peninsula are in or near the Eocene, but Butterlin and Bonet place Izamal in the Pliocene. It would be extremely interesting to know whether Becal and Izamal tempers have the same composition, but no firm inference can be drawn from

available facts, a poignant reminder that ethnological records of pottery making should be made while the craft is still in flower.

Identification of temper by X-ray diffraction suggests that classification based on identity of clay mineral component has useful implications. In Thompson's samples there is a correlation between proportion of clay component and identity of the clay mineral. When the clay mineral is attapulgite, the proportion of clay is high—15 to nearly 50 per cent. When the clay mineral is montmorillonitic or montmorillonitic-kaolinitic, the proportion is low—10 per cent or less. Arnold has proposed that potters recognized an advantage in attapulgite temper (Arnold, 1966). One line of argument on this question might be based on potters' efforts to obtain this particular kind of temper. At Mama it occurs in the same pit with the clay. At Ticul, where Arnold studied, the mines were some distance from the village. Neither Thompson nor I located the *cu'ut* deposit of Becal, but the Eocene formation in which it should occur outcrops near the village. If it had been especially valued for temper, Tepakan might have obtained it in trade, but the clay component in Thompson's sample of Tepakan *sascab* is montmorillonite. Lerma likewise could have obtained attapulgite in trade had a special value been recognized.

The hypothesis that potters recognized the properties of attapulgite temper cannot be established from ceramic practice at one village. That potters recognize fine differences in plasticity and texture through long experience is well known, but we do not know whether any other tempering materials had properties approaching those of attapulgite. The proportion of tempering material used by all the potters is high because of the high colloidal content of the clays. There is considerable difference in the properties of the tempering materials depending on particle size and proportion of clay. Potters learned by experience what proportions to use for their particular clay and temper. Their practices raise some interesting questions which will be discussed in another Note.

ATTAPULGITE IN YUCATAN

Occurrences of attapulgite in Yucatán are listed in Tables 1 and 2. The X-ray diffraction patterns of these Yucatecan attapulgites correspond to that of type attapulgite from Attapulgus, Georgia. All of them contain a calcareous component, the percentage of which varies widely and the composition of which also differs, as shown in Table 2.

The calcareous matter is a diluent, and the depth of color of Yucatecan Maya blue is related to its percentage. The importance of this factor was not recognized until Yucatecan attapulgites were analyzed. We had known that the lime plaster on which murals are applied and from which the pigment was separated with difficulty contributed calcium carbonate to samples. We also suspected that Maya artists varied the intensity of Maya blue by mixing it with lime or with calcium carbonate. Green was made by mixing a yellow pigment, such as limonite, with Maya blue. The Maya artists' intentional selection of different intensities of Maya blue for different parts of a mural can be seen in the murals of Bonampak,

for example, light blue background washes contrasted with much deeper blue in elements of design (Ruppert, Thompson, and Proskouriakoff, 1955).

The Maya's dependence on attapulgitic clays that are calcareous in their natural state raises new questions. The Maya who made Maya blue undoubtedly knew the depth of color that could be obtained from each source of clay. When they made pigment for painting effigies, did they select the deeper blue for special effigies, those for high-ranking families, for example? This question, though not prompted by idle curiosity, may be difficult to answer; at least it is probably too late to obtain an answer from effigies from past excavations. We might have asked, for instance, whether effigies from Mayapan houses of which size and location suggested ownership by the priestly hierarchy were deeper blue than those of the small peripheral houses.

The variation in quality of attapulgitic clay from different localities is also to be investigated. The temper and clay at Mama illustrate the variation in composition as well as in quantity in one deposit. There is no doubt that the Maya who collected clay for Maya blue recognized these differences. The Maya have given us a difficult time with the problem of determining composition of colorant in their pigment. To recover knowledge of their practices and beliefs about the pigment forces us to turn to evidence less tangible than composition. These broader questions are a challenge both to precise and imaginative formulation of problems and to analytical procedures.

IMPORTANT SAMPLES OF MAYA BLUE

Many samples of blue pigment that have been submitted for analysis were so small or impure that they neared the limits of analytical possibilities. *Azul de Tekax* from Yucatán and Zaachila blue from a tomb in Zaachila, Oaxaca, Mexico, are outstanding exceptions.

Azul de Tekax, collected in Yucatán in the 1920's by A. Everett Austin for the Fogg Art Museum, lay in storage until Fitzhugh's identification of attapulgitic clay in Maya blue in 1957 reminded Gettens of the sample. Some mystery surrounds its history, which raised questions of the exact source, but it has made important analyses possible and has aroused stimulating inferences.

The properties of *Azul de Tekax* recorded by Gettens (1962) correspond to those of Maya blue. An attapulgitic base, typical color, and permanence in strong mineral acids are sufficient criteria for the classification. Although it is uncertain where Austin collected the sample, one statement in his report on the pigments is intriguing. In listing colors of wall paintings, he reported "two blues of which one is almost surely a native blue prepared from herbs. It is of cerulian quality and is called *Azul de Tekax*." This is a reminder that Fitzhugh identified in *Azul de Tekax* "a blue organic dyestuff which has the properties of indigo" (Gettens, 1962, p. 560).

H. E. D. Pollock, ever alert to factors bearing on the Maya blue problem, informed Gettens that Tekax is the name of a town on the railroad line between Mérida and Peto. Even a remote chance of obtaining information was a challenge

to visit the village. My trip to Tekax (1958) illustrates the futility of launching into an ethnological inquiry without proper preparation. In retrospect, it is somewhat humorous.

A friend in Mérida who was familiar with the Maya blue problem and who employed a number of Indians, among them people from Tekax, was told that there was a mine of Maya blue in Tekax, and a trip was promised. After several weeks of delay, inquiries were answered by excuses: "There were snakes; the trip would be dangerous." I then arranged for the trip through another friend. The native guide who accompanied us was a voluble fellow who claimed to know all about Yucatecan crafts, including Maya blue. On the way he pointed out a "Tekax bush, which yields a *tinta* [ink] used for Maya blue." He also told us that the *alcalde* of the town of Oxkutzcab, which is near Tekax, had a jar painted with Maya blue. The *alcalde* was cordial; his jar was a good colonial Spanish piece with green glaze. We continued to Tekax without expectation of finding Maya blue, but we had to complete the story. A local friend of our guide said that the people of the town knew nothing of a blue paint. When we insisted on talking to other people, the guide returned after a long delay with the same man, who showed us the *sascabera* in his back yard.

My curiosity about the *tinta* from the Tekax bush lingered. A friend attempted to collect a sample when the fruit was ripe. A number of seasons passed, but informants always said the time was not right. On another trip to the pottery-making village of Tepakan I raised the question of a bush that yields a *tinta*. The potters were friendly and took pleasure in demonstrating their techniques. When the *alcalde*, son of one of the potters, pointed out a Tekax bush I had more faith in the report but relied on a botanist who was going into the area for collection. His trip was canceled, and the plant was never identified.

Now that the distribution in Yucatán of the formations in which attapulgitite occurs is known, the town of Tekax assumes new interest. It is in the Eocene formation where the attapulgitites of Mama and Tecul occur, the only formation in Yucatán in which attapulgitite has thus far been found (Fig. 1). Although it is improbable that the exact source of Austin's *Azul de Tekax* will ever be ascertained, the geologic location of the village of Tekax is significant.

Zaachila blue, an example of Maya blue found by Gallegos (1962) in the tomb at Zaachila, was spectacular, especially a small Mixtec polychrome cup with a blue hummingbird perched on the rim (see Bernal, 1966, pls. 18-20 for illustrations). For the study of Maya blue, plaques of the pigment, evidently intended as offerings, far exceeded in importance any previous finds. The samples of the plaques that Gallegos offered me for analysis I shared with Gettens and with Max Saltzman of Allied Chemical Corporation, National Aniline Division, who was experimenting with extraction of the pigment and spectrophotometric identification.

The plaques were roughly 2 by 5 centimeters with maximum thickness of 0.5 centimeter. They had been carelessly modeled by hand. Two are deep clear blue, one gray blue. The hue of the pigment is close to that of typical Maya blue, but the value is much lower (in the Munsell scale, approximately $\frac{1}{2}$ as compared

with /6 for the deepest Yucatecan Maya blue). When the sample is examined superficially the color appears uniform, but microscopic examination reveals a sprinkling of light brown particles. The pigment has the stability and firing behavior characteristic of Maya blue, but its X-ray diffraction pattern indicates that it is better crystallized than the common attapulgites; the peaks are more numerous and sharper, and there are differences in relative intensities of peaks (see Addendum 5 for data on X-ray patterns of attapulgites). The relation between depth of color and this structure is being investigated.

There is no direct evidence of the source of the attapulgite in the Zaachila blue. The plaques in the tomb suggest that it was not a local product, and the geologic formations in which attapulgite is known to occur are not present in the Oaxaca Valley. Nevertheless, a guess can be made from occurrences of attapulgite in the southeastern United States. The deposits of Georgia and Florida are in a Miocene formation. If it is the same formation that crops out in southern Vera Cruz, it would be within easy trading distance of Zaachila. The few clays that I obtained indirectly from the area were montmorillonites. A systematic survey of these exposures for occurrences of attapulgite is still to be made.

One clay in the United States from Sapillo, New Mexico, corresponds in structure to that of the Zaachila attapulgite (Fig. 3). This similarity has afforded opportunity for synthetic experiments with indigo. The clay was collected by

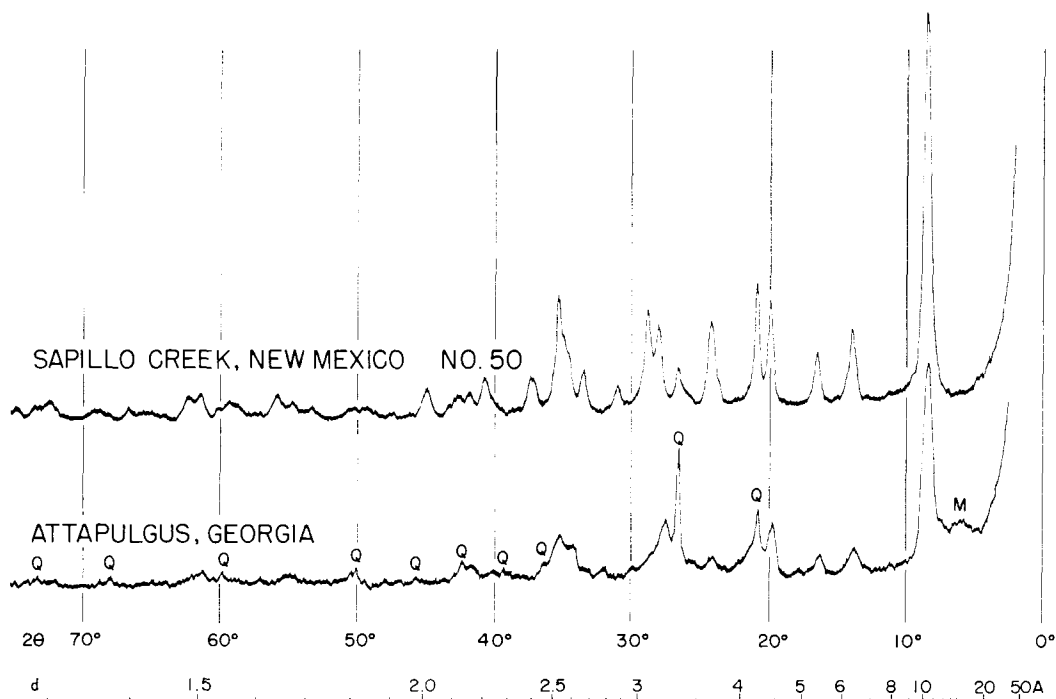


Fig. 3. X-ray diffractograms for attapulgite: Sapillo, New Mexico, and Attapulgis, Georgia. The patterns of Sapillo and Zaachila attapulgites are identical. Impurities in Attapulgis attapulgite: *M*, montmorillonite; *Q*, quartz.

P. B. Hostetter, of the U. S. Geological Survey, and has been studied by him and by John Hathaway, of the Survey. A sample from the source in Sapillo, New Mexico, served for an experiment with van Olphen's "alternative method 1" (van Olphen, 1966). The color of the synthetic corresponded to that of the Zaachila blue. It was stable in boiling nitric acid. Excess indigo was removed with acetone before the acid test. The excess indigo present suggests a caution for the analyst attempting to extract the colorant from Maya blue. A synthetic pigment made by the Indian would not be washed with acetone. The excess indigo removed by the analyst might mislead him to the conclusion that he had extracted basic colorant.

These two samples of Maya blue have been singled out for several reasons in addition to their size: *Azul de Tekax* because of the particle of organic dye it contained, Zaachila blue because of its distinctive variation in clay structure. The known distribution of formations in which attapulgite occurs in Yucatán lends support to the hint of source of *Azul de Tekax* contained in a place name. The source of Zaachila blue is still a challenging question.

SERI BLUE; MONTMORILLONITE BLUE

The investigation of Seri blue, a pigment produced by Indians of Lower California, suggested challenging questions about the sources of colorant in Maya blue. Moser, a linguist and ethnologist, has given an interesting account of the uses of the pigment and its preparation by one of the last members of the Seri tribe who knew the art of production (Moser, 1964). Pierce (1964) identified the constituents of the pigment as a mixed-layer clay, predominantly montmorillonite and the resin of *Guaiacum coulteri*. A root extract from *Franseria dumosa* was also used in preparation of the paint, but was disregarded by Pierce in his experiments because he did not know its "absolute function."

Following the Seri method, except for the omission of root extract, Pierce produced blues with a series of other clays—Wyoming bentonite; Sanders, Arizona, bentonite; Attapulgis attapulgite; kaolinite; and halloysite. There was a wide difference in intensity of colors and some differences in hue. The Wyoming bentonite was lighter than the type material prepared by the Seri, but the Sanders bentonite produced an equally deep color. The kaolinite blue was very pale, and the attapulgite blue was lighter than the type Seri sample. The effects that the size of the clay particles and the duration of grinding may have on these intensities are unknown, but differences in chroma are presumably independent of these factors. None of the samples was stable in hot mineral acids.

Seri blue was a reminder that organic compounds other than indigo may have been used to produce Maya blue. Pierce raised the further question of whether clay composition or type of organic constituent was the critical factor in the production of Maya blue. He pointed out that the resin-producing *Guaiacum coulteri* is reported as far south as Oaxaca, and a related variety, *G. sanctum* is known from Yucatán. Shortly before Pierce's report appeared Pollock had found, in a review of early Mexican records, references to the use of *Guaiacum coulteri* for dyes. (See section 6.)

After van Olphen's production of a stable Maya blue, I attempted to make a blue with *Guaiaacum coulteri* resin (supplied by Pierce) and attapulgitite. Although I had no difficulty obtaining a stable blue with sappio attapulgitite and indigo by van Olphen's simplest method, I was unsuccessful with *Guaiaacum coulteri* and attapulgitite. I obtained a light blue in the course of grinding ingredients together, but heating according to the van Olphen method turned it a greenish blue, which after some weeks changed to a brownish color, presumably from oxidation. These results simply show that clay organic-complexes are complex, and their investigation requires the knowledge of an expert. The importance of the type of clay mineral is demonstrated by van Olphen's tests. He did not succeed in producing a stable blue with indigo and montmorillonite.

HISTORIC MEXICAN RECORDS OF BLUE DYES: CORRESPONDENCE OF H. E. D. POLLOCK

A reference to Hernandez in de Candolle's discussion of indigo (de Candolle, 1904) led me to ask Pollock what could be learned from early Mexican records. Pollock reviewed major sources, Sahagun and Hernandez, and others suggested by them, in his scholarly manner. There followed intermittent correspondence on the nuggets of information he found. He did not attempt an exhaustive review because he realized that it would be a major project involving dozens of sources and requiring both knowledge of botany and familiarity with Nahuatl. In agreeing to quotation from his final letter written in January 1965, he emphasized that he wrote informally and did not attempt an exhaustive study; he offers the quotations because they may "illustrate the kind of material that can be extracted from early documents" (letter of September 29, 1967). The quotation follows:

Both Sahagun and Hernandez describe the process of making indigo. Sahagun does this under the heading *Tlaceuilli*, and says it is a dark blue color (part 12, p. 242). Hernandez identifies the plant as *xiuhquilitlpitzahoac* and calls the dye that is extracted *mohuitli* or *tlacehuilli* (i.e., *pedra de añil*) (part 2, p. 112). He also lists another plant of the same name, which he says is another variety that produces an inferior quality of dye, and he lists *Apitzalpatli huaxacense*, which he says "dyes woolens blue, for which it may be classified among the species of *añil*" (part 2, p. 156). Not to let the matter rest there, he lists *mohuitli* or *purple herb*, which he says "dyes woolens purple" (part 1, p. 78). Lastly, Standley gives *mohuitli* (and *hierba del añil*, *hierba azul*, etc.) as one of the local names of *Jacobinia spicigera*, and says, "The leaves are placed in hot water, which at first assumes a dingy blackish color but later becomes dark blue. This solution is employed by laundresses for whitening clothes, in the same manner as indigo. The plant was employed formerly in Mexico also as a dye" (pp. 1345-1346).

The term *pedra de añil* (indigo stone) should be explained. Indigo used to be sold in this form in the markets of Mesoamerica, but, when interest in Maya blue was first aroused, the use of indigo had virtually disappeared and examples of *pedra de añil* could no longer be found. The meaning of the expression was later questioned, and various suggestions were offered. Perhaps by then a literal translation of *pedra* was suggested by knowledge of the clay base of Maya blue. One archaeologist thought that the dye was absorbed in infusorial earth and transported in this form. I thought that *pedra de añil* might still be offered in the markets of El Salvador and sought the assistance of Stanley Boggs. After many fruitless inquiries,

Boggs obtained through an Agency for International Development worker a sample from a remote village. It apparently was the dye in dried form with no added mineral matter. [Microscopic examination showed this supposition to be correct.]

In Sahagun, Book 11, "Eleventh Chapter, which telleth of all the different colors, First Paragraph, which telleth how all the colors are made" (p. 239), we find the heading *Matlali*, which is translated "blue," and the translated text runs, "Its name comes from nowhere. It is the blossom of an herb, a blossom. This *matlalin* is blue and a little herb-green . . . It is fresh green . . . It colors solidly . . ." (p. 240).

Then, "Second Paragraph," we find the heading *Texotli*, which is translated "light blue," and the translated text runs, "The name, *texotli*, comes from nowhere. *Texotli* is blue. It is blue, very blue, green—a little brown; a little brown; thick" (p. 242). A footnote says that, according to the Spanish text, *texotli* is a dye made of *matlalin* leaves. The Bustamente edition, 1929–30, says that *texotli* or *xoxovic* is much used to dye cloth. I think *xoxovic* is just another word for blue. It is often difficult to tell whether a word means a color, a pigment, or a plant.

Turning to Hernandez, in the section of his great work called *Historia de los Minerales* (i.e., the section is called that), we find:

"*Texotli* or *filático*—It is a kind of earth extracted from the mountains (or forests) in some regions of New Spain, that is triturated, put in bags, and water poured over, the finer part produces color, which dried is formed into blue cakes with which the painters render this color; the thicker part which remains in the bags is crushed, water is put on anew so that the finest runs out again and this is used in the same manner although it gives a paler color of inferior quality" (part 2, p. 407).

Now there seems no doubt that Hernandez thought of *texotli* as an earth. This is shown by his putting it under *History of Minerals*. On the other hand, there is something about this account that is awfully suggestive of indigo. Is it possible that Hernandez saw *pedra de anil* and thought it to be a mineral? His careful account of the making of indigo argues against that supposition.

When we go to Hernandez' section on *Historia de las Plantas*, we find:

"*Matlalin*—It is an herb two cubits long (or high), roots fibrous, stems cylindrical and slender, leaves delicate, numerous, and flowers like purple and blue violets. Soaked in water for an hour, later crushed, with this liquid woolens are dyed, so they say, the color sea-green or blue. Some call this herb *matlalxochitl*" (part 2, pp. 34–35).

Hernandez lists no less than six kinds of *matlalxochitl* (part 2, pp. 35, 53, 247, 248), four herbs, one "species of *satyrium*," one tree, which he says may be a species of *lignum vitae*. There is no particular reason to believe any of the herbs are related. Of one *matlalxochitl* he says "blue spiked flowers . . . from which comes the name, for *xochitl* means flower and *matlal* blue" (part 2, p. 35). If plants are named by the color of the flower, one can imagine how many might get the same name. Continuing with *matlalxochitl*, there is "*Tlalmizquitl* or *small mizquitl* . . . which some call *matlalxochitl* or *blue flower*, and others *coltotl* . . ." (part 2, p. 33). There is "*Blue Itzacpatli* . . . Some call it *matlalxochitl*" (part 2, p. 430). And there is "*Second Hucumucheti* or *tuza tail* . . . It seems to pertain to species of *cynosorchis* or of *matlalxochitl*" (part 2, p. 272).

Under plant names incorporating the word *matlal*, meaning blue, I found "*Second Matlalitztic*—This *matlalitztic*, that others call *matlalin*, puts out numerous roots like those of the asphodel, but white, cylindrical and more slender, and therefore similar to *satirium*, of which it seems to be a foreign species; stems one cubit in length, knotted at intervals, green, grow from them (i.e., the roots), blue thick (or pyramidal) blossoms at the end of the stems, from which comes the name, and veined, oblong and hairy leaves . . . Some call it *tlaltecihuatl*, or *hail of the*

earth, because of the whiteness, coldness, and form of the roots. . .” (part 1, p. 422).

“Purgative *Matlalitztic* . . . It dyes blue the water where it is soaked for some time, from which comes the name . . .” (part 1, p. 423).

Five other *matlalitztic* are described, none seemingly pertaining to colorants.

In the *Badianus Manuscript*, translated and annotated by E. W. Emmart, *matlalxochitl* is illustrated, and is footnoted as follows (pp. 14–15; 218–220):

“*Matlalxochitl*—blue flower. (*Matlal*, *matlalin* or *matlalli*—blue green or blue; *xochitl*—flower.) In the text the adjective *xoxouhqui*—green or sky blue, is placed before the name of the herb. The plate shows without a doubt that the plant depicted is the day flower, *Commelina*, of which a number of species are found on the Mexican plateau. A native variant Nahuatl name for it is *matlalitztic*. Hernandez refers to several varieties of *matlalxochitl*, but none of the illustrations resembles *Commelina*; thus the name must have been applied to several flowers of blue color.”

Going back to Hernandez, we find *Matlalquahuatl* or blue tree (part 2, p. 36) and *Hoayacan* or *palo santo* . . . “that others call *matlalquahuatl* or blue, for its heart or pith is blue . . . blue flowers . . .” (part 1, pp. 394–395). These are almost certainly species of *Guaiacum*, related to *lignum vitae*.

Next we come to an interesting item:

“*Capangapaaqua*—It is an herb with fibrous root from which grow stems with leaves like the willow, and at the ends of the little branches spiked blue flowers with which they dye woolens and draw in blue color all kinds of figures. . .” (part 1, p. 221). Unfortunately, I cannot run down the botanical name of this plant.

Lastly, there is:

“*Coatli* or *water serpent*—The *coatli*, which others call *tlapalezpatli* or scarlet blood medicine . . . Water in which are soaked for a time some chips of its stems takes on a blue color . . .” (part 1, p. 172). Standley identifies this shrub or tree as *Eysenhardtia polystachya* and writes about how it colors water, but unfortunately concludes, “it also gives a yellowish brown dye” (pp. 443–444).

In the introduction to the *Badianus Manuscript*, Emmart, writing about color pigments, says, “Blue pigments were obtained from several plant sources. One form of blue pigments called *mohuitli* was obtained from two species of *Jacobinia*, *J. mohuitli*, and *J. umbrosa*. Another blue dye is believed to have been obtained also from the fruit of the *Cissus sicyoides* L., but the finest blue pigment was the *Xiuquilitl*, known to the Spaniards as *añil*, the *Indigofera suffruticosa*, Mill., which produced an indigo similar to that of the Old World species, *I. añil*.”

Finally, Humboldt says, “At Santa Fe they still write with a juice extracted from the fruits of the *Uvilla* (*Cestrum tinctorium*), and there exists an order of the court, prohibiting the viceroys from using in their official papers any other materials than this blue of the *Uvilla*, because it has been found that it was more indestructible than the best European ink” (part 3, p. 46). And later he says, “The *Uvilla* of Santa Fe, or the *cestrum*, of which the fruit yields a beautiful black color, is not the *Cestrum tinctorium* of Jacquin, but a new species, called by M. Bonpland the *Cestrum mutissi*” (p. 337).

Incidentally, as one reads Sahagun, Hernandez, and some of the other books I have dipped into, one acquires a growing respect for the capabilities of the aboriginal painters. Not only did they pretty surely mix pigments to acquire different shades and colors, but they used gums, oils, and glutens, and probably had turpentine.

A list of sources of dyes and inks is appended: *Jacobinia spicigera*, *J. mohuitli*, *J. umbrosa*, *Commelina tuberosa* L., *Cissus sicyoides*, *Cestrum lanatum*.

The following are from the *Catalogo Alfabético de Nombres Vulgares y Científicos de Plantas que Existen en Mexico*:

Añil	<i>Indigofera suffruticosa</i> Mill.
Añil blanco (Tab.)	<i>Indigofera tinctoria</i> L.
Añil cimarron	<i>Aphelandra deppeana</i> S. & C.
Añil colorado (Tab.)	<i>Indigofera suffruticosa</i> Mill.
Añil jiquelite (Oax.)	<i>Indigofera suffruticosa</i> Mill.
Añil montes (Oax.)	<i>Indigofera suffruticosa</i> Mill.
Añil montes	<i>Indigofera cuernavacana</i> Rose
Añil silvestre	<i>Indigofera thibaudiana</i>
Añilillo	<i>Aphelandra deppeana</i> S. & C.
Añilillo (Tab.)	<i>Indigofera mucronata</i> Spreng.

A CHEMIST'S DESCRIPTION OF THE PREPARATION OF INDIGO DYE

Hernandez' and Sahagun's references to the process of producing indigo dye are sketchy. I therefore add quotations from the article on indigo in Thorp's *A Dictionary of Applied Chemistry*, 1899. The descriptions refer to preparation of dye from *Indigofera tinctoria* of India. Certain details may be suggestive of possible Maya methods of pigment preparation. "In early bloom the plant is cut down, and the colouring matter, which resides chiefly in the leaves, is at once extracted. The plants are closely packed in large stone vats and well pressed down by means of heavy wooden bars. Water is run in till the plants are submerged, and they are then left to steep 9-15 hours according to the temperature of the air. Fermentation quickly ensues, and when, after the time indicated, it subsides the yellow liquid which results is run off into vats situated at a lower level; into these men enter and agitate the liquid for 1½-3 hours by means of sticks or paddles. During this operation the colour of the liquid gradually changes; it becomes first dark green and finally blue, the indigo being precipitated. After allowing the liquid to remain at rest for 2-3 hours, the clear supernatant water is drained off and the dark-blue pulpy sediment is run into a separate vessel. Here it is mixed with water and boiled 4-5 hours in order to stop further fermentation, and also to remove certain useless colouring matters. A second boiling for 3-4 hours with fresh water usually follows, to ensure a good product. Finally the semi-fluid mass is run on to a canvas filter and there drained to the consistency of a stiff paste; this is pressed for about 12 hours in shallow wooden frames, and then cut by means of a wire into the form of cubes, which are finally dried in open-air sheds, protected from direct sunlight.

"So-called Madras indigo is prepared from the dried leaves instead of those of the freshly gathered plant. After being dried in the sun the plant is thrashed to separate the leaves, and these are stored for a period of 3-4 weeks. When the leaf-powder has acquired a bluish-grey colour it is macerated with water, and the indigo is prepared according to the method described above. This difference in treatment is necessitated by reason of the large amount of certain extractive matters present in the plants grown on the Coromandel coast, which prevent the

indigo from settling readily in the beating vats if the ordinary method is adopted. To facilitate the settling of the indigo precipitate it is not unusual to add lime to the vat. According to E. Alvarez the fermenting liquid obtained with the *Indigofera* plants contains both micrococci and bacilli. The indigo fermentation, however, is really effected by a particular bacillus bearing a strong resemblance to the microbes of rhinoscleroma and pneumonia. It is noteworthy, also, that of all pathogenous microbes examined these alone are capable of producing the indigo fermentation, and further that the indigo bacillus possesses pathogenous properties."

Under sources of commercial indigo, Thorp gives the following: "There are numerous varieties of commercial indigo ranging in price from one to ten shillings per pound. From Asia come the indigos of Bengal, Oudh, Madras, Java, Manilla, from Africa those of Egypt and Senegal; and from America those of Guatemala, Caraccas, Mexico, Brazil, South Carolina, and the Antilles.

"The best varieties are the Bengal, Java, and Guatemala indigos. Of these the reddish-coloured variety of Bengal indigo is preferred by dyers, while the Java indigos are esteemed for the manufacture of indigo-extract, chiefly because of their general purity, comparative freedom from extractive matter, and the absence of calcium carbonate."

ETHNOLOGICAL RECORDS RELATING TO MAYA BLUE

The most suggestive and tantalizing ethnological data mentioned by R. H. Thompson refers to *cu'ut* of Becal for white paint. His discussion reads: "*Name: cu'ut*, white earth paint. The Motul dictionary describes *cu'ut* as a white earth used like white lead for painting. Perhaps *zac luum* (Motul), which is also a white earth paint, and *cu'ut* refer to the same material. There may also be some equivalence between *sascab* and *cu'ut* because my Maxcanú informant says the white paint is made of *sascab*. Rendón (1947: 112; 1948a) reports that the white paint preparation is known as *sascab cut*" (Thompson, 1958: 100).

Thompson describes the preparation of the paint: "The *sascab* is ground to a powder and mixed with water in a container. The mixture is stirred and allowed to settle. The water is then poured off and the process is repeated several times. The resulting white paste is allowed to dry and the cake is stored for future use. If a very fine paint is required the paste is squeezed through a cloth, then dried and stored. The paint is prepared for use by mixing it in water. Starch is usually added at Maxcanú, and glue sizing at Becal" (*ibid*). The paint is used as a coating for figurine whistles, candlesticks, and incense burners, which are decorated with water color or oil paints. Thompson's description of the process of preparation is identical in detail to that given me by the wife of Macedonio Canul in 1963. Thompson mentions that the women, usually a wife or daughter of the potter, paint the pottery.

Can this practice be a vestige of the preparation of Maya blue from which the tradition of the use of indigo has been lost? Data on the persistence of indigo in Yucatán will be pertinent.

It is noteworthy that Thompson, who was unaware that Maya blue has an attapulgitic base, refers only to attapulgitic-bearing materials in his references, i.e., *cu'ut*, *zac luum*, *sascab*. Also the early references describe *cu'ut* as "earth paint."

The early descriptions of *cu'ut* temper at Izamal suggest that attapulgitic may occur there. Under the description of paste, R. H. Thompson mentions that Gaumer and E. H. Thompson report dry mixing of clay and temper at Izamal. This method of preparation, which may be related to use of attapulgitic clay "temper," was also used at Mama (Shook and Shepard, 1952, and R. H. Thompson, 1958). Thompson suspects that dry mixing may have been the method at Becal and mentions Gaumer's reference to preparation with *cu'ut* at Izamal. Thompson does not describe the method of paste preparation at Ticul, another village in which attapulgitic is an important constituent of paste. I have previously discussed why the method of paste preparation described by Gaumer would be practical with an attapulgitic "temper"; softening of the attapulgitic in water would relieve the potter from grinding temper. It may be significant that as far as we know at present all villages using attapulgitic temper follow this method in contrast to others where the ground dry temper is added to the moist clay. The hints that Izamal *cu'ut* may be attapulgitic afford a tempting hypothesis, but Thompson's references suggest what a search may involve. "In 1895 Gaumer collected a yellow clay, *kan kan kat*, which was found in mines 40 to 60 feet below the surface of the earth . . . E. H. Thompson claims that the clay was searched for by specialists. He says that about 1900 a valuable white clay called *zahkat* was obtained from nearby Kuychil and from a large deposit near Kantunil" (Thompson, 1958: 66).

A quote from Mercer (1896: 162) under R. H. Thompson's heading Mérida indicates the extent of the search for clay. In 1895 a white clay was obtained from "izamal, the best mine . . . at Yokat, not so good, at Maxkanu, at Bekl, at Muna and other places along the mountains" (*ibid*). It would be interesting to know how many of these were attapulgitic.

It is significant that materials were imported in Mérida for making glazed pottery in 1869—"a paste made of clay from Orizaba and white sand from Europe was prepared" (*ibid*: 73).

This is a reminder of the importance of knowing the extent to which practices of contemporary villages have been subject to outside influences. Main centers of pottery production would attract potters from other areas; for example, there was a period when Campeche potters worked in Ticul. A study of contemporary pottery making might be prefaced by a review of the records of foreign contacts of each village.

The information that can be obtained today from contemporary potters is meager compared with what it would have been fifty or more years ago, but our ability to understand pottery making today rests on recent research, especially on clay mineralogy. As anthropologists we regret that prescientific culture is disappearing so rapidly, but science is required to understand it fully, and we cannot regret the inevitable effects that scientific research will have on all people.

THE ARCHAEOLOGICAL SIGNIFICANCE OF MAYA BLUE

The significance of Maya blue extends beyond its unique properties and yet is related to them. The generalization that pottery has been valued by the American archaeologist primarily as a tool for relative dating is not an exaggeration. But chronology has not been a primary concern of students of Maya blue; its unusual properties, its source, and whether it was artificial or found in nature are the questions that have centered attention. Possibly, when we gain the perspective that comes with time, broadening of the archaeologists' interest in pottery will be judged one of the major contributions of Maya blue.

Van Olphen's results should stimulate systematic investigation of the mode of discovery and method of production of Maya blue. Discoveries made in the prescientific age are often surprising. Pollock in the concluding paragraphs of his section illustrates the reaction of a scholar.

Maya blue, a complex product, affords opportunities to study the factors that influence invention. The needs and desires of a people may be stated more specifically as cultural and physical environment, social and economic conditions of the society, and the character and capacity of individual members of the society. How can specific conditions be established as factors, and when must we resort to speculation? Availability of attapulgitite or a clay mineral with similar properties was essential for production of Maya blue, but it alone did not spark discovery. There had to be individuals working with the physical resources of the environment, people who were observant enough to recognize the conditions that led to a fortunate accident and could learn to reproduce them. But what guiding interest did individuals have to lead them to an accident with these particular materials? Was the religious significance of blue a factor to the Maya? Further, what were the influences of outside contacts?

Maya blue offers an exceptional opportunity for following the course of trade in a complex artifact, as will be indicated in the next section, on future research. Indeed, the possibilities of following trade in Maya blue are so inviting they may well awaken the interest of archaeologists in the means and potentialities of the study of trade.

Maya blue in temple murals and on household effigies points to study of the relation of religion and art: what, for example, can be learned about the religious significance of blue to the Maya from the use of Maya blue in murals? These studies call upon the archaeologist's background on the full range of Maya culture.

Chronology supplies the essential skeleton for the archaeologists' endeavors. To give it meaning it must be instilled with knowledge of all aspects of the culture taken both singly and in their interrelations. The stimulation of an integrated cultural approach to ceramic problems can be the major contribution of Maya blue.

PROBLEMS FOR FUTURE RESEARCH

When van Olphen reported on his synthesis of a stable attapulgite-indigo complex, his title "Maya blue: a clay-organic complex?" reflected his scientific caution. It is difficult for those of us who have worked on Maya blue for some years, and have thought that a clay-organic complex was a likely explanation, to be equally cautious. But the fact remains that the only identification of a colorant from a Maya blue sample was Elizabeth Fitzhugh's spectrographic analysis of an inclusion in Azul de Tekax. She also was cautious, describing the particle as "indigo like." Consequently, identification of the colorant of Maya blue is still a problem. The possibility that craftsmen who produced Maya blue experimented with more than one organic colorant lends interest to the investigation. We know that they had extracts and resins from a variety of plants, some of which are little known to us. It seems unlikely that they did not experiment with these; and they may well have been more successful than I was with my few trials with attapulgite and *Guaiacum coulteri*. From the technical side, the cause of the stability of van Olphen's blue is still to be explained. Although his hypothesis of blocking of the dye molecules adsorbed on the exterior surfaces of the attapulgite particles by silicate layers as a result of a distortion of the lattice due to heating seems plausible, he cautions: "Yet the precise mechanism of the stabilization by heating is not clear." This is a problem for the specialist in clay mineral structure. The archaeological problems can be summed up under the heads chronology, distribution, trade, and invention.

Chronology. There is evidence that Maya blue was used in post-Spanish times (sample from Christian chapel at Dzibilchaltún), but the period of its introduction and its early history are still to be determined. It is best known from the Mexican Stages, Early, Middle and Late, well known examples being the murals of Chichén Itzá and the figurines of Mayapan; see review of chronology (Pollock, 1962).

Regarding its introduction, Pollock has recalled a number of references in the literature. The wall paintings reported by E. H. Thompson (1904) together with Pollock's own observations carry it into the Pucc (Florescent Stage) if these untested blue paints are Maya blue.

Fewer examples of Maya blue are known from the central Maya area. It has been identified in samples from a British Honduras site, from Tikal, Piedras Negras, and Seibal, Guatemala. The Seibal sample was identified by optic properties only. The murals of Bonampak, Chiapas, Mexico, in which Maya blue is extensively used, are well known. All these occurrences would fall within the Maya Classic period and consequently would antedate the period of major use of Maya blue in Yucatán. This seeming incongruity emphasizes the need for fuller data on the history of Maya blue in these two areas.

Distribution. When the two Maya blue papers were published in 1962, the distribution of Maya blue had been traced largely through the indefatigable efforts of Gettens (Gettens, 1962), who scoured museums for specimens and made his interests known to Maya archaeologists. The specimens tabulated (Shepard

and Gottlieb, 1962) were mainly from Yucatán, but included were four from central Maya sites: Tical and Piedras Negras, Guatemala; and Bonampak and Palenque, Chiapas. The southern Maya area, the highlands of Guatemala, was unrepresented. Shepard and Gottlieb mentioned analysis of some twenty samples of greenish-blue and green pigments from stucco painted vessels of Kaminaljuyu, Guatemala. The pigments were malachite. Gettens also reported malachite on a fragment of wall painting from Teotihuacán.

Since 1962 a number of new samples have been submitted. The most important of them is Zaachila blue from Oaxaca; the others are mainly from regions where Maya blue had previously been reported. The southern Maya area has not yet been extensively sampled. Two samples have been submitted by Vivian Broman Morales, one from Iximché, Guatemala, the other from Finca Ballí, Department of Huchuetenango, Guatemala. With them was a sample from a painted fresco from Seibal, Guatemala, a site that can be classed as Central Maya area.

The three samples, together with one of "van Olphen blue" which has a Georgia attapulgus base, were identified by the powder camera method. The van Olphen sample and the data in Christ *et al.*, 1968, were used as reference. The patterns differed, but the minerals in all samples could be identified as palygorskite. In comparison with samples taken from stucco, the van Olphen sample gave a strong pattern because it was free of calcite. The Seibal sample had a comparable pattern but was weakened by a mixture of calcite.

The sample from Iximché was powdery but contained specks of blue adhering to calcite. Treatment with very weak acid left a blue film, apparently the pigment in the preservative with which the sample had been sprayed. It was difficult to prepare a spindle from this material. The pattern obtained, although weak, was strong enough for identification as polygorskite. Foreign matter included quartz crystals and volcanic ash.

The samples from Ballí were the most interesting. They were obtained by the Finca administration, in either December 1967 or January 1968. They were broken fragments on stucco found in the structural fill of a mound. As far as I can ascertain, no trained archaeologist has visited the site since the fragments were found. Consequently, there is no basis for dating. The pattern from the Ballí sample had more lines than the other patterns. Although the pattern was not identical to that of Zaachila, there are a number of approximations in *d*-spacings. It is to be hoped that the source of this sample will at least be suggested when the site received adequate investigation.

Another group of Guatemalan Highland pigments should be mentioned, although they are not Maya blue. They occurred on unfired clay figures found in a tomb at Kaminaljuyu by the late Susan Miles. The pigments were applied on a red undercoat which in turn overlay a white, calcareous primary coat. The red undercoating is reminiscent of the technique of stucco decorated pottery found at Finca Miraflores, a part of Kaminaljuyu (Kidder and Shepard, 1944). The blue pigment was micaceous in texture. The light matrix was crowded with dark irregular vermicular inclusions. A green pigment was clear in color and free of inclusions.

The samples are being held for an investigator who is interested in paint composition and painting techniques.

Possibly the availability of malachite in the Guatemalan Highlands limited the use of Maya blue, but there is need of more extensive sampling before conclusions can be reached.

Trade. The study of trade in Maya blue will carry on an approach to Maya pottery analysis that has been extensively used. Trade was an established calling among the Maya and Mexicans. The technical and artistic quality of the wares must have encouraged the business. Optical petrology together with knowledge of the geology of the areas involved have been effective means of tracing trade, a study sharpened by questions of doubters.

A different approach will be required in the study of trade in Maya blue. Varieties of Maya blue are distinguished by clay structure, the recognition of which requires analysis by X-ray diffraction. The Maya blue from Zaachila, Oaxaca, is readily differentiated by X-ray pattern from the attapulgitite of Yucatecan Maya blue, which corresponds in pattern to that of the mineral from Attapulgitus, Georgia (see Addenda 5). A related clay mineral that is readily differentiated by X-ray diffraction is sepiolite, which has been found in Maya blue from Mexico City.

Possible variations in Maya blue from the central Maya area have not yet been investigated. Trace elements may be diagnostic for varieties in this region. Trace element analysis requires sensitive methods for which spectrochemical methods have been found satisfactory. This aspect of Maya blue study will require careful collecting, recording, and preservation of samples. It will be a long program, because samples will come mainly from excavation and will require extensive and exacting analysis. The justification for such an investigation rests on the importance of the pigment in Maya culture and on the possibilities it offers for tracing trade among the Maya and between the Maya and the Mexicans of southern and central Mexico.

Invention. Van Olphen blue raised the question whether the Maya could have used a process of preparation comparable to his, since his attapulgitite-indigo complex has the three essential properties of Maya blue. In theorizing about the discovery of Maya blue we have to grant that the Maya must have been both good observers and persistent experimenters. They may well have seen natural blue attapulgitites that lost their color when dried. The desire to restore that color may have led to the addition of indigo to attapulgitite. Thorp's description of the preparation of indigo indicates several steps that are not self-evident: recognition that the dye is in the leaves, that after the dye is extracted the liquid must be agitated to produce the blue color, and that the liquid must be heated to stop fermentation. We must credit the Maya for discovering some such steps as these because indigo was known in pre-Spanish times.

The one uncertain step in preparation of a hypothetical van Olphen Maya blue by the Maya is heating attapulgitite and indigo at low temperature for an extended period of time.

This question about the mode of discovery of a method for producing Maya blue seems at present only a field for speculation, but speculation and testing may go hand in hand in the investigation of this important Maya blue problem.

TECHNICAL ADDENDA

Addendum 1. Terminology

Maya names. As a matter of convenience I have used R. H. Thompson's names of potters' materials as they appear in his 1958 paper and in the notes that accompany his samples. The difference between his orthography and that currently adopted need cause no confusion.

Clay mineral names. The name *attapulgit*e has become familiar to American archaeologists; therefore I have retained it in the text. However, the European name *palygorskite* has priority and also the sanction of professional clay mineralogists in this country as well as in Europe. I have therefore used it throughout the technical addenda.

For varieties of clay minerals I have used descriptive terms rather than adopting specific names prematurely. Clay mineral names should have been accepted by the nomenclature committee of the Clay Mineral Society before popular adoption.

Addendum 2. Methods of Analysis

The early analyses of Maya blue were directed primarily toward identification of the colorant, after the clay base had been identified by X-ray diffraction, which was also the means by which a chance particle of colorant was tentatively identified.

The methods, briefly reviewed in the introduction, proved inadequate for identification of the colorant for a number of different reasons: insensitivity to the small percentage of colorant (e.g., infrared spectroscopy), requirement of a pure sample that could not be obtained (e.g., microchemical determination of carbon), insufficient sample for the method (e.g., microcolorimetric curves), inadequacy of the method for the properties of the colorant (e.g., microextraction of the colorant), and the fact that potentialities of the method were not well enough understood at the time (e.g., nuclear magnetic resonance).

In recent analyses clays of the Thompson collection were identified by X-ray diffraction with a schedule of glycolation and heating. The variety of clay minerals shifted interest to the total picture of ceramic techniques in Yucatán, in which use of palygorskite is only one part. The X-ray diffraction patterns showed poor crystallinity, mixed layering, and alteration of the clays. The X-ray data were therefore supplemented by spectrographic analyses; they included major, minor, and trace elements for the clays and for some potters' clay-temper mixtures.

Carbonate tempering materials and clay largely free of mineral inclusions may offer a clue to predominant clay mineral composition from silica:alumina ratios. This is an exceptional example that does not have general application.

The high percentage of potassium in the Mama palygorskite suggested minor illite; however, definitive results were not obtained from the Heller heating tests (Heller, 1961). The interest of clay mineralogists in Ticul, Tepakan, and Becal clays that have similar X-ray diffraction patterns led to intensive study of these clays, in which additional X-ray diffraction analyses and rapid chemical analyses of purified samples were made. Chemical data are recorded in Addendum 4; Atterberg limits, in Addendum 5.

Addendum 3. Composition of Yucatecan Clays

Complexity of the clays prevented a simple, complete tabulation; hence, there are emendations and additions. The familiar clay mineral name montmorillonite has been used, although most of these clays are the related mineral beidelite.

"The montmorillonite" from Uayma 281 and 282 and from Valladolid 283 are comparable. They are mixed, layered with some illite, and interlayered with aluminum hydroxide. The $\text{Al}(\text{OH})_3$ prevents collapse to approximately 10 Å when heated. Illite is indicated by K_2O in the chemical analysis. Both the illite and the interlayered aluminum hydroxide prevent expansion to 17 Å on glycolation; consequently, the basal sequence of reflections is broadened and irrational.

The clay of Lerma was initially identified as a poorly crystallized kaolinite or a halloysite. The intersalation test described by Andrew, Jackson, and Wada (1960) was applied to differentiate them, but the potassium acetate treatment did not cause the 12 Å peak to expand to 14 Å. Jackson (personal conversation) suggested that fine particle size might explain negative results. Subsequently the clay was identified as a kaolinite on the basis of small hexagonal plates in an electron micrograph (Fig. 2).

The electron micrographs of the three mixed layer clays, Ticul, Becal, and Tepakan, show some fine hexagonal plates, although kaolinite was not identified by X-ray diffraction, evidently because of the low percentage. The particle size of 75 to 90 per cent of these clays is <0.25 micron, and some of the larger particles are aggregates of fine particles. Most of the clays are in this range.

Addendum 4. Quantitative Spectrochemical Analyses – Clays and Pastes in Percentages

Village	SiO ₂	Al ₂ O ₃	TiO ₂	Fe ₂ O ₃	CaO	MgO	SrO	BaO	MnO	K ₂ O	Na ₂ O	L.O.I.*
Lerma clay	41.5	28.9	0.91	4.99	0.50	1.05	.008	.003	.025	0.10	0.48	17.8
Lerma paste ¹	30.8	19.2	0.62	3.32	10.5	3.17	.018	.003	.011	0.13	0.22	20.5
Ticul clay	41.4	27.4	1.03	6.24	1.25	1.08	.014	.007	.004	0.53	0.30	18.1
Ticul paste ²	24.9	15.1	0.55	4.75	30.8	0.69	.018	.003	.005	0.29	0.22	24.8
Valladolid clay	41.6	18.9	0.51	2.82	2.32	3.72	.009	.003	.011	0.95	0.15	21.6
Valladolid paste ²	18.6	9.32	0.24	2.23	24.5	1.04	.021	.010	.006	0.76	0.15	34.9
Mama clay	37.8	16.5	0.52	3.57	9.61	3.48	.017	.015	.013	3.48	0.21	20.5
Mama paste ³	29.0	10.7	0.34	2.80	8.87	9.32	.019	.009	.039	2.62	0.16	26.6
Becal clay	43.1	25.7	0.93	6.28	0.87	1.66	.015	.016	.013	0.41	0.62	18.5
Mérida clay	45.4	20.4	0.45	3.57	0.59	2.77	.024	.006	.012	0.88	0.67	20.4

*Loss on ignition at 950°C for 1 hour.

¹Temper crystalline calcite.²Temper cryptocrystalline calcite.³Temper palygorskite.

Addendum 5. Atterberg Limits, Clays of Yucatán and Campeche

The Atterberg limits of the clays in their original, untreated state were measured by the hydrometer method in order to understand the clays as the potter used them. The clays flocked, and a true particle-size distribution curve could not be obtained.

Meaning of the Atterberg limits: *Plastic limit*—Clay contains just enough moisture to form a coherent mass. *Liquid limit*—Water content increased to the point where a small stress will cause deformation of the mass. *Plasticity index*—Difference between the liquid limit and the plastic limit.

Sample	Source	Clay Minerals	Atterberg Limits, %		
			Liquid Limit	Plastic Limit	Plasticity Index
281	Uayma	montmorillonitic	130	55	85
278	Mama	palygorskite	70	40	30
279	Ticul	mixed layer	104	46	58
276	Becal	mixed layer	123	46	77
277	Tepakan	mixed layer	100	41	59
270	Lerma	kaolinite	79	39	40

The clay mineral composition is not simple to identify because of poor crystallinity, small particle size, and partial alteration.

The following modifications of the listed clay mineral identifications were reached after extensive testing:

Ticul—Mixed layer kaolinite—montmorillonite

Becal—Mixed layer kaolinite—montmorillonite

Tepakan—Mixed layer kaolinite—montmorillonite

Lerma—Kaolinite with minor montmorillonite

In general terms the palygorskite clay requires the least water to attain a plastic state and the montmorillonitic clay the most. The mixed layer clays show the effect of their montmorillonite component as the Lerma kaolinite shows the effect of its montmorillonite content. These results are consistent with our knowledge of the water adsorption of these clay mineral structures.

The determinations were made by George S. Erickson, U. S. Geological Survey.

Addendum 6. Table I. X-Ray Powder Data¹

Sapillo, N. M. No. 21				Zaachila, Mexico				Attapulcus, Ga.			
<i>hkl</i>	<i>d</i> (Å)obs.	<i>d</i> (Å)calc.	<i>I</i> / <i>I</i> ₀ , %	<i>hkl</i>	<i>d</i> (Å)obs.	<i>d</i> (Å)calc.	<i>I</i> / <i>I</i> ₀ , %	<i>hkl</i>	<i>d</i> (Å)obs.	<i>d</i> (Å)calc.	<i>I</i> / <i>I</i> ₀ , %
110	10.44	10.37	100	110	10.42	10.40	100	110	10.54	10.43	100
200	6.36	6.362	13	200	6.38	6.390	15	200	6.42	6.411	10
130	5.395	5.395	9	130	5.385	5.403	15	130	5.418	5.416	7
640	4.466	4.468	20	640	4.464	4.471	31	640	4.479	4.481	23
121	4.262	4.260	22	121	4.262	4.240	34	121	4.258	4.244	15
				310	4.146	4.144	6	310 s	4.137	4.158	10
310s	4.129	4.127	2								
				201 s	4.004	4.033	3				
				131	3.753	3.746	14				
131	sh	3.760						131	sh	3.751	
221	3.679	3.686	15	221	3.678	3.676	64	221	3.681	3.682	7
								240	sh	3.673	
150 s	3.440	3.441	2	150 s	3.436	3.445	11	150 b	3.444	3.453	5
231	3.348	3.347	7	231	3.347	3.340	47		Q		
311	sh	3.243		311	3.250	3.241	34	311	3.246	3.247	20
400	3.179	3.181	12	400	3.191	3.195	23	400	3.205	3.206	18
321	3.096	3.094	16	321	3.104	3.092	23	321	sh	3.098	
331	2.889	2.885	4	241	2.992	2.995	3				
411	sh	2.689		411	2.698	2.691	6	411	2.698	2.698	4
251	2.679	2.679	8					251	sh	2.681	
				251	2.680	2.676	9				
421	sh	2.602		421				421			
					2.603						
12	sh	2.593		440				440 b			
440		2.591						61			
			10						2.601		
061	2.589	2.590								2.607	10
102	2.567	2.567	12	12	2.566	2.573	14			2.590	
								102	2.548		
112		2.541								2.548	
161	2.539	2.538	20	161	2.536	2.535	34	161		2.539	13 b

Plus many additional lines, mostly weak and broad, for all samples.

s = peak poorly resolved because of low ratio of peak intensity to background.

sh = peak present, but as shoulder an adjacent, more intense peak.

b = broad.

Q = peak due to quartz present.

¹From "Palygorskite: New x-ray data." C. I. Christ, J. C. Hathaway, B. P. Hostetler, and Anna O. Shepard, *American Mineralogist*, vol. 54, nos. 1 and 2, p. 198.

Addendum 7. Table II. X-Ray Crystallographic Data¹ for Palygorskite

Sample	$a(\text{\AA})$	$b(\text{\AA})$	$c(\text{\AA})$	Monoclinic Angle	$V(\text{\AA}^3)$	Symmetry	Space Group or Diffraction Aspect
Sapillo, N.M. No. 21	12.725	17.872	5.242	—	1192	orthorhombic	$P_{222}1$
This paper	± 0.009	± 0.017	± 0.004		± 1		
Zaachila, Mex.	12.781	17.885	5.199	—	1188	orthorhombic	$P_{222}1$
This paper	± 0.011	± 0.014	± 0.006				
Attapulugus, Ga.	12.823	17.925	5.199	—	1195	orthorhombic	$P_{222}1$
This paper	± 0.024	± 0.030	± 0.033		± 7		

¹The unit-cell parameters and diffraction aspects are based on the powder data given in Table I. The values of the unit-cell parameters, and their associated standard errors, were determined by computer, using the program of Evans *et al.* (1963).

Addendum 8. Table III. Unit Cell Parameters of Palygorskite

Zaachila, Mexico; this paper	Brazil; Huggins <i>et al.</i> 1962	Volhynia, U.S.S.R. quoted in Huggins <i>et al.</i> , 1962	Attapulugus, Ga.; Bradley, 1940
Orthorhombic	Orthorhombic	Orthorhombic?	Monoclinic
a_0 12.781 $\text{\AA} \pm 0.011$ \AA	a_0 12.690 \AA	a_0 12.98 \AA	a_0 12.9 \AA
b_0 17.885 $\text{\AA} \pm 0.014$ \AA	b_0 17.857 \AA	b_0 18.09 \AA	b_0 18.0 \AA
c_0 5.199 $\text{\AA} \pm 0.006$ \AA	c_0 5.207 \AA	c_0 5.16 \AA	c_0 5.2 \AA
vol. 1188.4 \AA^3			

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