CHEMICAL AND PHYSICAL ANALYSIS OF THE HOTCHKISS SITE (CCo-138)

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Introduction

The site of a large prehistoric village situated 3.5 miles east of the town of Oakley is known as the Hotchkiss Mound or site CCo-138. This site was first recognized and dug by an amateur, E. N. Johnson, in 1936, who reported the mound to the Department of Anthropology and encouraged the University of California to carry out excavations.

During June, 1938, a student summer excavation group, under the direction of R. F. Heizer, excavated in the site and recovered one hundred and ten burials from the small area on the northwestern edge of the mound which at the time was accessible for excavation. Johnson continued to dig for several years in a semisystematic way and made an effort to number his pits, to plot these on a master map, and to catalogue his materials (grave goods for the most part) with reference to pit number. He attempted, with partial success, to catalogue materials from one grave as a single lot in order that associations on a grave-by-grave basis could be determined as a matter of record rather than memory. Johnson's immense collection of artifacts was studied and recorded and will in time be analyzed and published. He saved skeletal materials and presented these, often in lots of several scores of skulls and long bones at a time, to the Robert H. Lowie Museum of Anthropology at Berkeley. These have not yet been measured, but they comprise the largest batch of well preserved skeletal material from any one Late period site in Central California, and as such constitute a particularly valuable series for anthropometric analysis.

The Saturday field class in archaeological methods, under the direction of R. F. Heizer, worked during the spring semester, 1953, at site CCo-138. At this time a 5 by 5 foot pit (designated as pit X-3) was excavated and passed through a quarter-inch mesh screen, and seven auger borings were collected by 12 inch levels. The elements in the pit and auger samples were segregated and provide the basis for discussion in the present paper.

Site CCo-138 was occupied during the Late period which is believed to cover the time span from 300 A.D. to the opening of the historic period ca. 1700 A.D. Dr. J. A. Bennyhoff has provided us with a summary of phases of the Late period as follows:

Late Phase 2	1700-1850 A.D.
Early Phase 2	1500-1700 A.D.
Late Phase 1	1100-1500 A.D.
Middle Phase 1	700-1100 A.D.
Early Phase 1	300- 700 A.D.

The dates for the several phases are partly estimated, but are based on a series of ten radiocarbon age determinations and therefore may be presumed to have some validity. Site CCo-138 has not yielded any materials of Caucasian origin and was probably abandoned by or shortly before 1800 A.D. as a result of depopulation through introduced diseases, flight of the occupants to escape missionization, or removal (in part) to mission establishments at San Francisco or San Jose. Dr. Bennyhoff believes that site CCo-138 may be the site of one of the main villages of the Julpun group which is mentioned in Spanish accounts of 1810 and 1817. If this identification is correct, it is difficult to explain why, after some years of Spanish contact, there are no materials of Caucasian manufacture in graves unless, as suggested, the site was abandoned shortly after the appearance of the Spanish in the late eighteenth century.

The land level surrounding the site lies on the sea level contour, and was in aboriginal times within the overflow delta plain of the Sacramento and San Joaquin rivers which unite only a few miles to the east. Before the area was reclaimed by building levees, it was a marshy, tule-covered swamp.

The only surface relief consists of old, stabilized sand dunes (Cook and Elsasser, 1956), and it was on one of these that site CCo-138 was established, doubtless for the reason that the elevation afforded protection from the spring river floodwaters and the marshy swamp of drier seasons.

Along the northern and eastern sides of the site can still be seen a depression which marks the channel of a shallow, slow-moving slough. To the southwest extend a series of linear sand ridges, a few feet in elevation, which would have permitted communication on foot with the nearby Marsh Creek hills area. Not only was the area a favorable one in terms of the aboriginal food economy, but also its isolated position enclosed in the tule swamps made it a spot which afforded security from surprise attack. From the immediate area of the site elk, river clams, fish, and waterfowl were readily available, and to the southwest in the hills area the inhabitants could find deer, grass seeds, and acorns in abundance.

1. Density and Concentration of Material

In previous work with physical analysis, particularly by Cook and Treganza (1950) and by Cook and Heizer (1951), the amount of any individual component in a refuse deposit has usually been expressed in terms of weight, that is, grams per kilo of mound matrix. Further consideration of this point has led us to the conclusion that a more satisfactory mode of expression, particularly for comparative purposes, is in terms of weight of component per unit volume of mound matrix.

Weight of component per unit weight of matrix would be very acceptable if the mineral composition of mounds were always similar or identical. But we know empirically from examination of numerous sites that the apparent density of the matrix itself is seldom identical when two mounds are compared. Thus Cook and Treganza (1950:234, Table 2) found that in fourteen California sites for which the data were available the apparent density ranged from 1.181 to 2.098. It is clear that a fixed amount of a certain component, say bone, would seem to be present to a much different relative amount, or percentage, in one site than in another if referred to unit weight. Furthermore, the weight itself is subject to variation due to degree of compaction, moisture content, relative particle size, and many other factors. The latter sources of error, it is true, may be substantially controlled by appropriate manipulative procedures, but this in turn requires effort and time.

What we really want is a measure of concentration. Just as in chemical operations we want to know the weight, or number of molecules, of substance x in a known volume of solution or a known volume of a gas, so we want to know the weight, or number of particles, of a component in a predetermined space, or volume, of mound material. The physical density, or specific gravity, of the latter as such is irrelevant. Thus, if the concentration of bone, for example, expressed as grams per unit volume, is the same in two mounds of equal dimensions, then the total amount of animal matter yielding the bone is identical, regardless of the mass of the mounds. On the other hand, if the bone were expressed as percentage by weight of mound matrix, the above relationship would be obscured.

For these reasons it is proposed hereafter to express quantity of components as weight per unit volume, preferably grams (or kilograms) per cubic meter of mound material.

2. Screen Size

The investigation of site CCo-138 emphasizes the desirability, indeed the necessity, of standardizing screen sizes in future work. In work published some years ago (Treganza and Cook, 1948), a careful analysis was made of an entire small site by passing all the material through a 3/8 inch sieve, and passing over one hundred small samples through a 1/8 inch sieve. The relationship between matter held by the two sizes was analyzed. Cook and Heizer (1951) used 1/8 and 1/2 inch screens. At CCo-138 a single pit was sifted in the field through a 1/4 inch screen. The 1/2 inch screen was regarded as too large, and one of 3/8 inch could not be found locally.

The result is obvious. At different times and for different jobs screens of three sizes—in addition to 1/8 inch—have been employed. Quite evidently the results obtained in the three studies are comparable only in so far as they were secured with the screen of common size, 1/8 inch.

It is urgent that in the future the same size screens be employed. There can be no question that for small samples and for thorough extraction of components occurring in fairly fine particles the 1/8 inch, or 2 millimeter, screen is the most satisfactory. This screen, therefore, should always be used, and the sampling of the site arranged with this end in view.

For mass screening in the field, where the contents of a whole 5 by 5 foot pit is passed through the sieve, the 1/8 inch (i.e. 2 mm.) size is too small. The labor would be interminable and excessive. A larger size is required. But what size? The 3/8 inch screen used by Treganza and Cook (1948) was very satisfactory but is difficult to obtain. The 1/2 inch size would be suitable for very large scale operations where tons of soil are to be sifted. On the other hand, a great amount of significant small particles is lost, probably too great an amount. The 1/4 inch size catches most of the substance wanted. Moreover a careful collection of smaller samples permits reasonably stable ratios to be established between the 1/4 and 1/8 inch screens such that the labor may be greatly reduced. Results about to be set forth obtained at CCo-138 lead us to recommend as standard procedure a combination of 1/4 and 1/8 inch screens.

3. Establishment of Working Ratios

At CCo-138, one pit (X-3) was excavated and screened in toto through the 1/4 inch screen. None of this material was put through the 1/8 inch screen. Quite separately, however, seven auger borings were sunk and a total of forty-three samples were brought into the laboratory, each one foot in depth and with a cross section equal to the area of the auger as it went into the ground. The diameter of the auger was 13 centimeters. Hence the volume of the sample was 3592 cubic centimeters. All these samples were passed through the 1/4 inch screen in the laboratory and nineteen of them were also put through the 1/8 inch screen. The next step was to compute for each component the ratio between the quantities held by the two screens. These quantities are expressed in grams and for each sample the material held by the 1/4 inch screen is included in the total for the 1/8 inch screen. Obviously any fragment held by the larger would also be held by the smaller. There are two methods of calculation which may be employed.

Method 1. For each sample and for each component the ratio of weights is taken. Then these ratios are averaged. The results are given in Table 1.

It will be noted immediately that the value for n, the number of samples, is different for each component. The reason is that with one sample for rock, three for shell, four for charcoal, and seven for obsidian, the weight of material in the 1/4 inch screen was zero and that of comparable material in the smaller screen was either zero or some finite value. In either case the ratio cannot be used (it is either infinity or indeterminate) and was discarded. Therefore the average ratio is not an entirely true index.

Table 1 also shows the standard deviation, coefficient of variation, and standard error of the mean. These values are all very high and indicate that in order to get an accurate mean ratio an extremely large series would be necessary.

Method 2. This method is purely empirical and ignores sampling as such altogether. It consists of taking the total mass of each component in all the auger borings and referring the larger to the smaller screen. Thus, for rock 1463.2 grams were held by the 1/8 inch screen and 838.8 grams by the 1/4 inch screen. The ratio is 1.74, as compared with 3.08 obtained by Method 1. The values for the other substances were all lower than by Method 1, being respectively for bone, shell, charcoal, and obsidian, 3.16, 1.77, 5.18, and 1.95.

If we are interested in the total quantity of a component in the entire site, then it is likely that Method 2, however crude, is preferable to Method 1, since those samples in which the component is relatively lacking carry less weight in the final calculation.

There remain to be accounted for those samples in which the 1/4 inch screen retained no fragments but in which there was material held by the 1/8 inch screen. In extending the computation to samples in which the material in the 1/4 inch screen was zero and that in the 1/8 inch screen was unknown, the only possible device is to assume the corresponding observed values from the nineteen samples analyzed. For bone, their value is unknown; for rock, it is 33.2 grams; for shell, 0.05 grams; for charcoal, 0.77 grams; and for obsidian, 0.15 grams.

Of the two methods, as indicated, the latter appears to give better results. In this connection, it is of interest to compare parallel results secured in previous studies. Treganza and Cook (1948), at the Peterson site, screened the entire mound through a 3/8 inch screen and in addition put one hundred and thirteen small samples through the 1/8 inch screen. Based upon per cent by weight of the totals, the ratio of material held by 1/8 inch screens to that held by 3/8 inch screens was 3.06 for rock, 3.88 for bone, 5.90 for shell, 30.00 for charcoal, and 3.06 for obsidian. That these ratios are greater than for CCo-138 is to be expected (3/8 inch instead of 1/4 inch screens) but the order of magnitude is reasonable.

Cook and Heizer (1951) studied similar ratios (based upon percentage of total weight) in a series of Sacramento Valley sites. The results (ibid, p. 294, Table 3) may be expressed in ratios of 1/8 inch screen to 1/2 inch screen, the latter being the size employed for field sifting in this investigation (see Table 2). Clearly the average numerical value is much in excess of that obtained for CCo-138 or for the Peterson site, as would be anticipated for the 1/2 inch screen. Furthermore, wide variation exists for the same component from mound to mound. This variation is partially due to sampling error and to the random occurrence of large fragments of material (such as big rocks, mammal bones, whole skulls, etc.). It is also partially referable to real differences in the content of the mounds.

The following conclusions now seem valid:

1. For all physical analysis of mounds in the future standard size screens should be employed.

2. For field or pit sampling the 1/4 inch screen should be used, despite the labor involved. The 1/2 inch screen should be used only for objects of large dimensions.

3. All small samples, column or auger borings, should be passed through the 1/4 inch screen.

4. In addition, at each site, an adequate number of these smaller samples should be put through the 1/8 inch screen.

5. From the total quantities secured with identical samples, empirical ratios may be calculated which will yield a fair estimate of the mass of each component in the whole site.

4. Distribution of Contents

The large area and relatively great depth of site CCo-138, together with the thorough sampling, make possible some analysis of the vertical distribution of various materials. In particular we are able to compare a single, completely excavated pit, 5 by 5 feet in area, with a series of seven auger borings placed at random over the surface of the mound.

The data for pit X-3 are shown in Tables 3 and 4. In Table 3 the quantities are those which were held by the 1/4 inch screen, expressed for convenience as gram material per 1000 cubic centimeters of original soil or matrix. This material was not put through the 1/8 inch screen. Consequently, in Table 4 the values in Table 3 have been calculated by multiplying the figures for each component by the conversion factor derived by Method 2 of the preceding section.

From these tables one may discern a clear tendency for all components to accumulate at a depth of from 24 to 48 inches below the surface. The concentrations diminish both above and below this level. Such an accumulation, if it were universal throughout the mound, would imply a period, roughly midway in the history of the site, when culinary and industrial activity was extremely intense, or when the population achieved a maximum.

Seven auger borings were made in the site, distributed fairly well over the entire surface. There was no apparent bias in their location, and no significant area was omitted. We may accept these borings, then, as being representative of the whole mound, as would be any other seven points which might be selected.

Since the mound in cross section slopes up from the periphery to the center, and since the original base may be considered a plane surface, it follows that the auger borings are of varying depth, even though they all reached, or nearly reached, the geometrical plane of the submound.

In order to study vertical distribution of components, two courses are open. (A) The depth may be reckoned down from the mound surface, regardless of the actual elevation of the surface above the submound. Thus the first foot of boring, wherever on the site it was placed, would be regarded as 0-12 inches, the second foot as 12-24 inches, and so on. (B) The depth may be reckoned on the scale of absolute elevation. Thus Map 1 shows contour lines of one foot each, extending 10 feet below the exact summit of the mound. Therefore, if auger boring were started at the summit, that is, on the 0 contour, the first foot of boring would correspond to a depth of 0-12 inches. But if the boring were started on the 5 foot contour, the first foot of boring would be designated by a depth of 60-72 inches, the second foot 72-84 inches, and so on.

The data are presented in Tables 5 and 6. In both tables (as in the preceding ones) the quantities are calculated to the 1/8 inch screen and are expressed in terms of grams held by that screen per 1000 cubic centimeters of matrix. Furthermore, the values for the individual auger holes are averaged so as to give a mean figure for each interval of depth. Table 5 shows the figures with reference to procedure A (above) and Table 6 shows them according to procedure B. Cursory inspection is sufficient to demonstrate certain features:

1. The actual midden does not begin to be replaced by subsoil to a serious extent until a depth of at least 5 feet below the present surface is reached (Table 5). Moreover, the midden (Table 6) reaches a generally uniform depth of fully 8 feet below the top of the mound. We may assume therefore that the base of the habitation residue lies at a level corresponding to the zone from 8 to 10 feet below the summit. There is no sharp line of demarcation, for bone, shell, and charcoal were found to an appreciable extent in two auger borings at the interval of 108-120 inches. The latter figure, 120 inches or 10 feet, may be taken as the practical or useful limit of deposit.

2. No consistent variations in distributions of components can be detected more than 5 feet from the surface or more than 8 feet below the summit contour. The values of each component fluctuate considerably in a probably random fashion, but no clear trend is present nor is there any uniform sequence of values noticeable in all five materials. We must conclude, therefore, that the heavy occurrence of rock, bone, etc., from 24 to 48 inches below the surface of pit X-3 is a purely local phenomenon and is not characteristic of the mound as a whole. This finding is of significance for future studies since it demonstrates clearly the danger of confining operations to a single point or area at a site.

The vertical distribution being fairly uniform, the horizontal distribution remains to be examined. This may be done by calculating the relative richness of the deposit in each of the seven auger borings, the latter being satisfactorily distributed over the surface of the site. The procedure is to determine first the concentration of each component—rock, bone, shell, charcoal, and obsidian—which is held by the 1/8 inch screen for each foot of depth for each boring. This value will be expressed as grams per 1000 cubic centimeters of matrix. Then the values per foot of depth are averaged for each of the seven borings. The results are given in the first (left hand) column under each component in Table 7. Next, in order to weight the individual components equally, the absolute are converted to relative figures by setting, for rock, bone, etc., the largest value as equal to 100 and computing the corresponding numbers for the smaller values. These are placed in the second (right hand) column under each component. Thus for rock the largest amount is in boring no. 1, with 31.00 grams per 1000 cubic centimenters for the boring. This is equivalent to 100. Boring no. 2 has an average concentration of 18.91 grams rock per 1000 cubic centimeters, which is equivalent to 64.3 on the 100 point scale, etc. Finally, the relative values of the five components are averaged for each boring and are placed at the extreme right in the table.

It is to be observed from Table 7 that the richest deposit comes from boring no. 1 and the poorest from boring no. 5, the two borings differing by a factor of roughly 2. More exactly, the standard deviation of the figures for the seven borings is ± 14.88 where the mean is 60.58. The coefficient of variation is therefore 24.56 per cent of the mean. In other words, in this particular site the concentration of habitation residue in one sample boring in about two cases out of three will not differ from another sample boring by more than 25 per cent. On the whole, therefore, the horizontal distribution is quite uniform.

These estimates of homogeneity have perhaps little theoretical significance for site CCo-138 itself. They are, however, of value for establishing over-all uniformity of deposit, and particularly for comparing this with other sites in a quantitative manner.

5. Total Content

We now approach the problem of computing the total amount of rock, etc., in site CCo-138. The basis of estimate may be unit quantity of the component per unit volume of mound, or per unit weight of mound material. In a previous discussion the superiority of the former method was pointed out, but for the purpose of comparison with sites investigated in previous years some estimate based upon weight may be necessary. From the data already set forth in the tables (particularly Tables 5, 6, and 7) the mean concentration of any component at any level, or for the whole site, may be calculated.

Map 1 is an accurate map of the site with the contours marked at one foot intervals. The volume may be derived from this map as a series of layers. The first layer will extend from the summit, or 0 contour, to a depth of 12 inches. The area included by the one foot contour may be measured accurately by means of a planimeter and converted from map units to field units. The figure is not a circle but may, indeed must, be considered so if even an approximation to the volume is to be secured. After calculating the assumed radius, the formula for the volume of a cone may be applied and a solution obtained.

For the levels below 12 inches the outline of the site becomes too irregular to permit the use of the formula for a cone—or indeed any other conventional geometrical figure. A purely empirical device must therefore be employed.

This device considers first that the layer from 12 to 24 inches consists of two portions. The first is the part directly underlying the layer at and above the 12 inch contour. The volume of this part will then be the product of the area (measured on the map) multiplied by 12 inches or one foot. The second portion is that sloping region lying between the one and the 2 foot contours, these contours varying widely in their distance from each other. Now this solid will have a cross section close to the form of a triangle, where the altitude will always be one foot and the base will be the distance on the map between the two contour lines. The true mean value of the latter entity cannot be determined but it can be closely approximated by taking a significantly large number of well distributed measurements. The mean area of the cross section is thus known. The volume of the solid can then be estimated by measuring on the map the length of the line representing the halfway mark between the two contours, that is, the distance around the mound at roughly the 18 inch contour. This may be done most easily by taking half the sum of the 12 and 24 inch contour lines. The result obtained here is added to that secured for the first portion of the layer for the total volume. The process is then repeated for the remaining layers.

In Table 8 are presented, by one foot contour levels, the volumes in cubic meters. With these values, and those already given for concentration of components in Tables 5 and 6, the total quantities have been calculated both for each level and for the entire mound.

For deriving the percentage composition by weight only, the auger boring samples can be used, for the material dug out of pit X-3 was not weighed in the aggregate. The simplest procedure is merely to divide by the total weight of the samples. The outcome is a reasonably close approximation to the relative amount of each component in the site. In Table 9 will be found the composition by weight and the mean density of air dried samples. In addition there are included for comparison the parallel data for several other Sacramento Valley sites, all of which represent distinctly river or marsh habitats.

In general CCo-138 conforms to the picture presented by ten other localities. A few points, however, merit brief note at this juncture. The very low apparent density of the air dried samples is associated, no doubt, with the surprisingly low rock content. The percentage of this component (1.563) is the lowest we have ever obtained with the exception of site Sac-145. On the other hand, the bone content is very high (1.067 per cent), indeed the highest for any site in our records. Charcoal and shell are within the expected range for a river environment, but obsidian is remarkably high (again the highest we have ever encountered). The explanation of these findings will be discussed subsequently.

6. Analysis of Bone Content

Further information is available with regard to the bone content of site CCo-138.

The sifting of the soil of pit X-3 through the 1/4 inch screen yielded a bone concentration of 3596 grams per cubic meter. Employing the conversion factor derived previously (3.16), the quantity which would have been held by the 1/8 inch screen is 11,363 grams per cubic meter. This value corresponds reasonably well with that for the whole site based upon the auger borings (10,780).

The bone secured at pit X-3 was brought to the laboratory and sorted according to whether each fragment was from a mammal, a bird, or a fish. The data, arranged by foot levels in the pit, are shown as per cent of each type in Table 10, together with the percentages for the entire excavation.

In all about one-half the bone is from fish, about two-fifths from mammal, and about one-tenth from bird. It is probable that substantially the same ratios extend throughout the mound. If so, it is clear that the proportion of fish and bird bone is remarkably high. Thus the average percentages of fish and bird bone at nine Valley sites (Cook and Heizer, 1951:296, Table 4) were respectively 3.45 and 3.20, nearly all the remainder being mammal.

The figures as presented in Table 10 also bring to light a peculiarity in distribution. From bottom to top in the pit the bird bone stays nearly constant in relative amount. On the other hand, mammal bone increases sharply, and fish bone decreases to correspond. If this one excavation is to be relied upon, the conclusion would be justified that there was a profound change in the food habits of the inhabitants, a wide swing from fish to mammal. This conclusion is not assured however, since we have no confirmation of such a change elsewhere in the mound and the single locality at pit X-3 may well present merely a local characteristic.

Some estimate of gross quantities is possible. From Table 8 we observe that the calculated total bone held by the 1/8 inch sieve is 174,520 kilograms. Applying the percentages from pit X-3 (for we have no other), the masses of mammal, bird, and fish bone are respectively 72,077, 17,975, and 84,468 kilograms. If we assume that one gram of dried bone represents 20 grams of living animal, then the estimated bone in site CCo-138 provided 3,490,000 kilos or 3,850 ordinary tons of fresh meat.

7. Chemical Analysis of Site Matrix

The physical analysis of site CCo-138 has been described in the foregoing sections. It is also instructive to observe some of the chemical features of such a mound, in particular those which are related to the presence and activity of man. For this purpose the mound itself may be considered as soil and methods of soil analysis may be applied. To be sure, the interest does not lie in pedology, either from the point of view of soil development or from that of the plant-supporting potentiality of the site matrix. Hence an exhaustive study of physical consistency or of elementary composition need not be attempted.

Several types of analysis are feasible and might be considered if a complete chemical examination of the site were intended. Four of these types will be discussed. First is the hydrogen ion concentration, or pH, a basic datum without which the interpretation of any other results is difficult. Second is the carbon content, taken in such a manner as to show the carbon derived from residues of organic matter, not charcoal formed by burning. Third is the phosphorous concentration as an index to human occupancy. Fourth is calcium analysis.

The pH has been determined by the conventional method, using a Beckman pH-meter. The carbon was estimated by the Walkley-Black method as described by Jackson (1958). The mild oxidation is employed which is provided by potassium dichromate and sulphuric acid, the only heat source being that liberated by the mixing of the two components. The yield for ordinary soils is quite consistently about 80 per cent of the carbon contained in the organic compounds. This is not satisfactory for many types of soil analysis but is well adapted to the present problem. It gives reliable comparative figures, and it does not attack elementary carbon to a significant extent. Since CCo-138, as well as many other habitation sites, is permeated with ash and charcoal, the latter would interfere seriously with the analysis for organic matter if it were included in the determination. On the other hand, if an analysis for charcoal _per se_ were desired, then in conjunction with the mild Walkley-Black method a complete combustion might be performed.

Archaeologists have been interested in phosphorus because this element is present in considerable quantity in human and animal excreta, as well as in fleshy residues and bone. Hence habitation areas of man or animals should be recognized by showing phosphate levels higher than adjacent areas which were not inhabited. The theory and practice of phosphate surveys have been developed by Lorch (1939, 1952) in Germany and Arrhenius (1931, 1954) in Sweden. In the United States, Haury (1950) has utilized the method at Ventana Cave. For analysis we have employed the spectrophotometric method as outlined by Jackson (1958).

Calcium is an element which has received little attention from archaeologists. It is, however, one which may, under the proper circumstances, serve as an index to type and intensity of occupation. Significant quantities are liberated to the site matrix through excreta of man and animal, and in organic residues of all kinds. It tends to cause the soil in which it is deposited to become more alkaline, and is undoubtedly of importance in producing the high pH characteristic of habitation areas. Analytically it is determined by precipitation as oxalate and colorimetric estimation with ceric sulphate (Jackson, 1958). The results of all analyses, expressed as per cent by weight of elementary phosphorus, calcium, and organic carbon, together with pH, are shown in Table 11.

Three auger borings were selected (nos. 1, 4, and 6), all fairly close to the center of the mound. A few of the samples were omitted in order to reduce the total number to be analyzed (seventeen in all). To these were added two samples (nos. 1 and 2) from each of two off-site test pits (0-12 and 12-24 in.) approximately 100 and 200 feet, respectively, southwest of the edge of the mound. These served as controls and provided samples of the existing soil of the adjacent agricultural area.

For chemical, as contrasted with physical analysis, the mound matrix must be finely screened. Therefore the material which had been passed through the 1/8 inch screen was saved and, in the case of those samples to be examined chemically, was sifted through a 30-mesh copper wire screen. The values for the elements in Table 11 are expressed as per cent, by weight, of this fine material. These percentages, of course, cannot be equated directly with those of the components derived by mechanical sorting. They can, however, be compared among themselves.

The data shown in Table 11 indicate a high level of alkalinity (pH 7.8-9.8), a very high calcium content, and a phosphorus content which reaches a concentration five to ten times as great as that found in the adjacent ground off the site. The auger hole profiles also show that the phosphorus extends in great quantity to the base of the mound. At the same time the percentage diminishes with depth, particularly in auger holes nos. 4 and 6, thus demonstrating that, within the few hundred years that the mound has been in existence, there has been little if any tendency for phosphorus to be lost by leaching. Furthermore, it is of interest that the concentration is at its maximum 1, 2, or 3 feet below the surface, not at the surface. This distribution may perhaps be due to the manner in which the original phosphorus-containing material was deposited by the human occupants. It also suggests, however, that a lapse of roughly one hundred and fifty years since the site was vacated by its aboriginal inhabitants is not enough time for vegetation to bring to and redeposit on the surface sufficient phosphorus to establish the characteristic gradient from the surface downward found under other environmental conditions.

The organic carbon is high and persists to a much greater depth than would be expected in a mature, nonoccupied soil. The calcium content is very great, a fact which itself would suggest intensive occupancy even in the absence of other evidence. Moreover, the association between these three elements within the mound matrix is very close. Thus if we correlate the percentage values of carbon and phosphorus for seventeen samples (three auger holes) we get $\underline{r}$ equal to +0.866. Similarly, for calcium and phosphorus in seventeen samples we get $\underline{r}$ equal to +0.837.

Both of these are significant values of *r*. Another useful parameter is the C/P ratio which in many soils diminishes rather rapidly with depth as the organic matter is destroyed, whereas the phosphorus in mineral form may tend to persist. In this site there is a clear negative correlation of C/P ratio with increasing depth (*r* equals -0.648), but the slope of the regression line is very gentle (the regression coefficient, *b*, equals -0.040). These findings, in the absence of any other evidence, would imply a quite heavy accumulation of organic matter within the matrix, which had not yet had time for disposal, reworking, and redistribution by the action of micro-organisms and weathering.

At this point we may revert to the physical analyses previously described. In particular we may correlate the per cent of phosphorus per unit weight of sifted soil in each sample with the grams of fish and bird bone found per unit volume of soil for the same seventeen samples. We get a value of *r* equal to +0.831, which is highly significant. The correspondence is not absolutely exact but is close enough to support strongly the thesis that the carbon, calcium, and phosphorus found in such great quantity are derived from the organic and mineral residues left on the site by former inhabitants. It also follows that in Central California habitation midden (and by extension elsewhere) one may expect to find phosphorus and calcium at concentrations five, ten, or more times as high as is characteristic for the area. Moreover the vertical distribution of these elements, particularly phosphorus, conforms to the layering of the midden residues rather than to that which would be imposed by the normal cycle of removal and redeposition through the activity of the plant cover at the surface.

The status of calcium merits further consideration. The Ca/P ratio in seventeen samples from three auger holes varies from 0.8 to 10.1, with a mean of 5.57. The variability argues a multiple origin for the calcium, and the magnitude of the mean ratio points to other sources than bone, for the Ca/P ratio of bone itself is approximately 2.4. Furthermore, the association is only moderately good between calcium and the quantity of bone found by physical analysis, for the correlation is given by *r* which equals +0.597, a value lying near the one per cent level of probability with seventeen samples. We should therefore seek other sources of calcium.

Organic residues from animal parts other than bone, and from excreta would account for some of the calcium, but these materials would also bring in phosphorus, and at a Ca/P ratio not exceeding that of bone. Hence such substances may be neglected as a source of the excess calcium. The only remaining likely possibility is that the calcium is present to a considerable extent in the form of carbonate. Although we have not yet completed analysis of this site for acid extractable CO_2, it is to be noted that the average pH of the samples is high, and furthermore it has been observed qualitatively that small samples of the site matrix, when exposed to acid, effervesce violently.

There are three possible modes of origin of carbonates, One is from the animal residues, for excreta, flesh, and bone all contain substantial quantities. Another is the sand, mud, and dirt imported inevitably by the occupants in the course of daily activities such as food gathering. A third source is mussel shell, of which we found a great deal by physical analysis of the samples from site CCo-138. The relative importance of each of these modes of origin cannot be determined by analysis for total calcium, or even for total carbonate. Nevertheless each must have contributed appreciably to the high calcium content.

To summarize briefly the chemical findings, site CCo-138 shows clearly certain characteristics diagnostic of local areas subjected recently to intensive human habitation: abnormally high concentrations of alkali (high pH), calcium, phosphorus, and organic matter (organic carbon); the persistence of each of these substances to depths not usually reached in uninhabited soil profiles; and failure of the C/P ratio to fall sharply with moderately increasing depth. Comparison with other sites of recent culture horizon is desirable, but it is clear from the study of CCo-138 that chemical criteria as well as physical analysis may be employed in conjunction with stratigraphic and industrial data for the elucidation of archaeological status.

TABLE 1

Ratio of Weights Held by 1/8 Inch Screen to Those Held by 1/4 Inch Screen as Found in Pit X-3, Site CCo-138

	No. of Samples	Mean	Standard Deviation	Coefficient of Variation	Standard Error
Rock	18	3.08	±3.278	106.4	±0.773
Bone	19	3.33	±0.820	24.6	±0.188
Shell	16	2.25	±0.986	43.8	±0.247
Charcoal	15	7.05	±6.511	92.3	±1.740
Obsidian	12	2.26	±1.651	73.0	±0.477

TABLE 2

Ratios of Percentages of Total Weight Held by 1/8 Inch to Those Obtained from 1/2 Inch Screens in Several Sacramento Valley Sites (Calculated from Data in Cook and Heizer, 1951, p. 294)

	Sac-6	Sac-106	Sac-107	Sac-151	Sac-96	SJo-43	Sac-52	Sac-145	Sac-54
Rock and clay	2.03	3.85	3.92	4.30	5.47	1.98	9.51	4.78	4.53
Bone	9.83	24.35	13.06	7.96	14.85	7.89	30.25	92.50	7.30
Shell	6.64	8.73	19.00	13.75	20.05	9.03	-	24.00	-
Obsidian	6.29	2.00	8.00	-	85.00	4.75	-	-	-

TABLE 3

Concentration of Components in Grams per 1000 cc. of Matrix for the 1/4 Inch Screen as Found in Pit X-3, Site CCo-138

Depth (in.)	Rock	Bone	Shell	Charcoal	Obsidian
0-12	12.880	1.903	0.199	0.117	0.258
12-24	7.930	2.358	0.201	0.245	0.125
24-36	16.100	6.180	0.483	0.745	0.266
36-48	14.780	7.290	0.468	0.898	0.318
48-60	7.290	4.430	0.364	0.961	0.171
60-72	4.310	2.250	0.191	0.260	0.088
72-84	0.725	0.763	0.042	0.048	0.014

TABLE 4

The Same Values as in Table 3 Converted to 1/8 Inch Screen Size by Multiplying as Follows: Rock by 1.74; Bone by 3.16; Shell by 1.77; Charcoal by 5.18; Obsidian by 1.95

Depth (in.)	Rock	Bone	Shell	Charcoal	Obsidian
0-12	22.411	6.010	0.352	0.606	0.502
12-24	13.798	7.455	0.356	1.269	0.244
24-36	28.020	19.530	0.855	3.860	0.519
36-48	25.710	23.030	0.828	4.650	0.620
48-60	12.680	14.010	0.644	3.975	0.333
60-72	7.500	7.110	0.338	1.346	0.172
72-84	1.361	2.410	0.074	0.249	0.027

TABLE 5

Concentration of Components in Grams per 1000 cc. of Matrix for the 1/8 Inch Screen for Auger Holes. Each Value is the Mean of the Number of Holes Specified. Depths are Inches Below the Actual Surface at the Point of Boring

Depth (in.)	No. of Holes	Rock	Bone	Shell	Charcoal	Obsidian
0-12	7	18.55	11.21	0.462	1.080	0.623
12-24	7	16.88	13.38	0.532	1.721	0.345
24-36	7	19.38	13.24	0.303	1.351	0.178
36-48	6	19.00	14.78	0.523	1.591	0.479
48-60	6	23.76	10.36	0.423	2.360	0.086
60-72	6	11.02	8.43	0.256	0.815	0.053
72-84	3	4.31	3.50	0.011	0.352	0.103

TABLE 6

Data as Shown in Table 5, Except That Depths Are in Inches Below the Summit of the Mound (0 Foot Contour)

Depth (in.)	No. of Holes	Rock	Bone	Shell	Charcoal	Obsidian
0-12	2	16.76	11.80	1.774	1.474	0.540
12-24	2	18.58	13.13	0.406	1.668	0.406
24-36	5	18.28	15.95	0.488	1.330	0.304
36-48	5	17.28	15.36	0.679	1.486	0.710
48-60	5	19.44	11.41	0.479	1.421	0.156
60-72	6	15.74	11.50	0.321	1.233	0.172
72-84	6	24.45	9.54	0.359	1.481	0.426
84-96	5	16.70	9.30	0.309	1.426	0.103
96-108	4	8.66	6.98	0.248	1.010	0.092
108-120	2	2.45	4.01	0.414	1.680	0.019

TABLE 7

Material held by 1/8 inch screen for each auger boring divided by the number of feet in depth, converted to grams per 1000 cc. This value is then placed upon a relative scale where for each component the maximum value is set equal to 100. These relative values for each boring are then averaged.

Boring number	Rock		Bone		Shell		Charcoal		Obsidian		Mean relative
	gm. per 1000 cc.	relative	gm. per 1000 cc.	relative	gm. per 1000 cc.	relative	gm. per 1000 cc.	relative	gm. per 1000 cc.	relative	
1	31.00	100.0	16.95	96.0	0.700	100.0	1.922	86.1	0.302	41.7	84.76
2	18.91	64.3	12.33	69.8	0.595	85.0	2.233	100.0	0.136	18.8	67.58
3	20.18	65.1	17.66	100.0	0.501	71.6	1.750	78.4	0.235	32.4	69.50
4	16.88	54.4	13.20	74.8	0.163	23.3	1.333	58.7	0.204	28.2	47.88
5	9.56	30.8	10.32	58.5	0.128	18.3	1.512	67.7	0.183	25.3	40.12
6	14.76	47.6	14.02	79.4	0.326	46.6	0.940	42.1	0.587	81.1	59.36
7	18.00	58.1	6.10	34.5	0.393	56.2	0.557	25.4	0.724	100.0	54.84

M = 60.577
SD = $\pm$14.88
C = 24.56

TABLE 8

Quantities of materials in site CCo-138. Volumes of levels calculated as described in text. Mean concentrations of components for each level below the summit taken from Table 6. Quantities expressed as kilograms.

Level	Volume in cubic meters	Total				
		Rock	Bone	Shell	Charcoal	Obsidian
0-12	161.28	2703	1903	286.1	237.7	87.1
12-24	699.05	12988	9178	283.8	1166.0	283.8
24-36	1160.67	21217	18512	566.4	1543.6	352.8
36-48	1821.54	31476	27978	1236.8	2706.8	1293.2
48-60	1884.53	36635	21502	902.6	2677.9	293.9
60-72	2153.00	33888	24759	691.1	2654.6	370.3
72-84	2411.96	58972	23010	865.9	3572.1	1027.4
84-96	2788.61	46569	25934	861.6	3976.5	287.2
96-108	3115.20*	26977	21744	1289.6	3146.3	286.6
Totals	16195.84	271425	174520	6983.9	21681.5	4282.3
gm/1000 cc or kilos/ cu. meter		16.75	10.78	0.432	1.340	0.264

*Volume estimated from the partially completed 9 ft. contour line on Map 1.

TABLE 9

Apparent density of air dried samples and percentage composition by weight of rock, bone, shell, charcoal, and obsidian for site CCo-138, together with several other Valley sites. For the latter the data are taken from previous papers (in particular Cook and Treganga, 1950, pp. 236-237, Table 3; Cook and Heizer, 1951, p. 294, Table 3).

Site	Apparent density	Per cent				
		Rock	Bone	Shell	Charcoal	Obsidian
CCo-138	1.028	1.563	1.0670	0.0390	0.1290	0.02700
Sol-3	1.625	40.280	0.2390	0.0072	0.0796	0.00593
Col-1	1.210	4.880	0.2390	0.4820	0.1810	0.00110
Sac-6	1.181	11.470	0.6238	0.0577	0.2982	0.01070
Sac-106	---	4.670	0.2486	0.0192	0.0389	0.00060
Sac-107	---	7.770	0.2313	0.0247	0.0584	0.00160
Sac-145	---	1.180	0.3519	0.0120	0.0123	0.00100

TABLE 10

Percentage of mammal, bird, and fish bone in pit X-3, CCo-138

Depth (in.)	Mammal	Bird	Fish
0-12	59.3	7.7	33.0
12-24	48.0	10.1	41.9
24-36	46.0	10.1	43.9
36-48	37.7	11.9	50.2
48-60	40.4	8.9	50.7
60-72	31.0	10.8	58.2
72-84	19.5	12.9	67.6
0-84	41.3	10.3	48.4

TABLE 11

Results of chemical analysis of samples from auger borings nos. 1, 4, and 6, and from off-site test pits nos. 1 and 2.

Location	Depth (in.)	pH	Percent organic carbon	Percent elementary phosphorus	Percent elementary calcium	Ratio carbon/ phosphorus	Gr. of bone per 1000 cc.
Auger hole 1	0-12	8.45	2.65	1.002	7.730	2.64	17.78
	24-36	9.75	1.63	0.905	8.355	1.80	22.90
	48-60	9.70	1.84	0.975	8.375	1.89	9.55
Auger hole 4	0-12	8.15	1.96	0.542	0.415	3.62	9.71
	12-24	8.45	1.59	0.574	0.473	2.77	18.07
	36-48	8.90	0.97	0.426	0.513	2.27	11.30
	60-72	9.00	0.48	0.225	1.475	2.13	1.06
	72-84	8.85	0.34	0.127	0.599	2.70	0.70
Auger hole 6	0- 6	8.25	2.14	0.628	6.355	3.41	6.09
	6-12	8.10	2.20	0.780	6.600	2.82	16.99
	18-24	8.10	3.77	0.980	7.960	3.85	22.83
	24-30	8.05	2.29	0.714	4.855	3.21	17.59
	36-42	7.90	1.94	0.565	2.283	3.43	15.67
	48-54	7.75	1.56	0.574	2.442	2.72	7.94
	60-66	8.40	0.88	0.426	1.762	2.06	3.92
	78-84	8.70	0.50	0.238	1.211	2.10	2.70
	90-94	8.30	0.34	0.192	0.743	1.74	0.33
Test pit 1	0-12	7.60	4.04	0.073	0.450	55.30	0.00
	12-24	8.00	0.58	0.062	2.980	9.20	0.00
Test pit 2	0-12	7.60	3.76	0.110	1.177	34.20	0.00
	12-24	7.90	0.80	0.107	7.332	7.40	0.00

BIBLIOGRAPHY

Arrhenius, O.

1931 Die Bodenanalyse im Dienst der Archäologie. Zeitschrift für Pflanzenernährung, Düngung und Bodenkunde, Teil B, 10 Jahrgang, pp. 427-439.

1954 Chemical Denudation in Sweden. Tellus, Vol. 6, No. 4, pp. 326-341.

Cook, S. F. and A. B. Elsasser

1956 Burials in the Sand Mounds of the Delta Region of the Sacramento-San Joaquin River System. Univ. of Calif. Arch. Survey Report No. 35, pp. 26-46. Berkeley.

Cook, S. F. and R. F. Heizer

1951 The Physical Analysis of Nine Indian Mounds of the Lower Sacramento Valley. Univ. of Calif. Publs. in Amer. Arch. and Ethnol., Vol. 40, No. 7, pp. 281-312. Berkeley.

Cook, S. F. and A. E. Treganza

1950 The Quantitative Investigation of Indian Mounds, with Special Reference to the Relation of the Physical Components to the Probable Material Culture. Univ. of Calif. Publs. in Amer. Arch. and Ethnol., Vol. 40, No. 5, pp. 223-262. Berkeley.

Haury, E. W.

1950 The Stratigraphy and Archaeology of Ventana Cave, Arizona. Univ. of Arizona Press, Tucson.

Jackson, M. L.

1958 Soil Chemical Analysis. Prentice Hall, Englewood Cliffs, N.J.

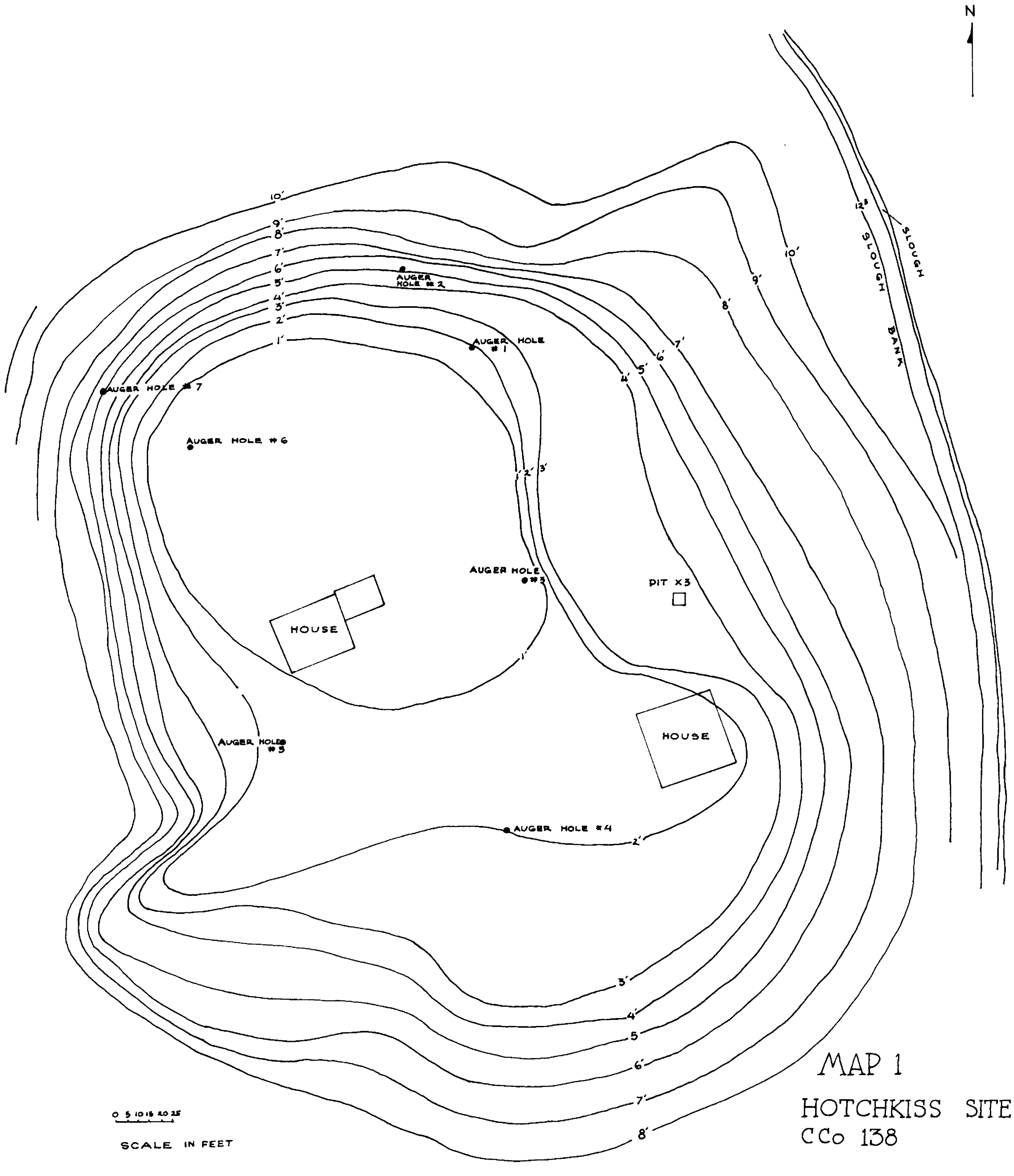
Lorch, W.

1939 Methodische Untersuchungen zur Wüstungsforschung. Arbeiten zur Landes- und Volksforschung, Band 4, 91 pp. Issued by the Anstalt für Geschichtliche Landeskunde, Friedrich Schiller Universität. Jena, Germany.

1952 Arbeitsanweisung zur einheitlichen Anwendung der Siedlunsgeschichtlichen Phosphatmethode. 12 pp. Multigraphed and privately circulated; stated to be copyrighted. Dated May 4, 1952. Tübingen, West Germany.

Treganza, A. E. and S. F. Cook

1948 The Quantitative Investigation of Aboriginal Sites: Complete Excavation with Physical and Archaeological Analysis of a Single Mound. American Antiquity, Vol. 13, pp. 287-297.



MAP 1

HOTCHKISS SITE
CCo 138