

NEUTRON ACTIVATION ANALYSIS OF EARLY BRONZE AGE  
POTTERY FROM LAKE VOULIAGMÉNI, PERAKHÓRA, CENTRAL GREECE

by

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ABSTRACT

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NEUTRON ACTIVATION ANALYSIS OF EARLY BRONZE AGE  
POTTERY FROM LAKE VOULIAGMENI, PERAKHORA, CENTRAL GREECE

Thermal-neutron activation followed by high-resolution gamma-ray spectroscopy was used to measure the concentrations of 19 trace elements in 111 samples of pottery, terra-cotta, mud-brick and clay from the Early Bronze Age settlement at Lake Vouliagmeni, Perakhora, Central Greece. Treatment of the data by cluster analysis and multivariate statistical methods yielded 6 major groups:

- 3 of locally-made Early Helladic (or EH) II pottery
- 1 consisting of all the sampled Late Helladic and Archaic (Corinthian) material plus half the EH I samples, and matching the composition of the Perlman-Asaro "Mycenae" group
- 1 of EH I and II coarse wares
- 1 smaller EH one.

The implications of these results are discussed with reference to the Aegean Early Bronze Age and in particular to the development of the Vouliagmeni site.

## RÉSUMÉ

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### ANALYSE PAR ACTIVATION NEUTRONIQUE DE CERAMIQUE

#### PROVENANT DU LAC VOULIAGMENI, VILLAGE DE

#### L'AGE DU BRONZE ANCIEN, A PERAKHORA EN GRECE CENTRALE

Les concentrations de 19 éléments à l'état de traces dans 111 échantillons de céramique, terre-cuite, torchis, et argile provenant du site de Lac Vouliagmeni, à Perakhóra en Grèce centrale (village de l'Age du Bronze Ancien), ont été déterminées par l'activation neutronique suivie de spectroscopie gamma à haute résolution. Des analyses taxométriques et statistiques ont pu distinguer 6 types de céramique:

- 3 d'origine locale fabriqués pendant la deuxième phase de l'Helladique Ancien (HA II)
- 1 qui comprend toutes les pièces testées des périodes Helladique Récent et Archaïque (Corinthienne) ainsi que la moitié des échantillons de HA I, et dont la composition correspond d'ailleurs à celle d'un groupe de Mycènes analysé par Perlman et Asaro.
- 1 de céramique grossière HA I et II
- 1 petit groupe de la période HA.

Les résultats sont discutés dans le contexte de l'Age du Bronze Ancien dans l'Egée et surtout par rapport au développement du site du Lac Vouliagmeni.

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## 1. INTRODUCTION

### 1.1 Technical Analysis of Pottery

The determination of the place of manufacture of artifacts, especially of pottery, is an important aspect of archaeology. Traditionally these assignments of provenance have been made on stylistic grounds; that is, pots made in specific shapes or painted in distinctive ways were usually assumed to have been manufactured where the largest deposit of similar wares had been found. This method of sourcing has its faults, however, particularly in regions where pottery of the same type was made at many different centres in a manner so uniform that stylistic criteria are inadequate guides to origin. A method not relying on habits of potters and painters but on characteristics of the pot fabric itself would permit archaeologists to make more definite statements about provenance.

Clays around the world are composed of roughly the same main constituents. The characterization of a particular clay bed or area requires a study of the minor or trace constituents of clay. For coarse pottery, petrographic examination of the naturally-occurring or artificially-added rock grains in the pottery fabric can be used to assign pots to probable regions of manufacture (Peacock 1970, Shepard 1965). However for fine, grain-free pottery or pottery containing

only common sand grains, one must resort to chemical or specialized physical methods.

It has been found that certain trace elements, present in amounts ranging from around one percent to less than one part per million, vary greatly in concentration between clay beds, but relatively little within a given bed (e.g., Birgül 1975). The determination of the concentrations of a number of these can establish a trace-element pattern unique to a particular area, with which the corresponding patterns of pieces of pottery can be compared. Obviously the more elements determined the more sure is the assignment of pots to clay beds, as the probability of coincidental similarities in trace-element patterns becomes exceedingly small.

Several assumptions are implicit in this methodology: that ancient potters did not transport raw clay over great distances for the manufacture of their wares, and that the pattern of trace-element concentrations remains constant both during the creation of the pot (including clay refining, possible addition of temper, and firing) and during the time the pot has lain buried (leaching and deposition of salts due to sea and groundwaters). The first must be considered a reasonable assumption, based on observation of modern-day primitive potters. As far as the second consideration is concerned, wherever raw clay and fired pottery from the same

source have been compared, agreement for all elements except the volatile ones, is remarkably good (Perlman and Asaro 1969, Catling and Millett 1969, Abascal et al. 1974, Brooks et al. 1974). The addition of most kinds of temper, usually quite pure, has the effect of lowering the concentration of all elements by a constant factor, but leaving the pattern of relative concentrations unchanged. Alternatively, refining the clay by letting larger grains settle out has the effect of raising the trace concentrations by a constant factor, again leaving the pattern unchanged (ibid.).

The effect of groundwater percolation is quite serious on elements in easily-exchangeable or soluble forms. Some studies done (Freeth 1967, Poole and Finch 1972, Bieber et al. 1975) indicate that though under certain conditions sodium, calcium, barium, manganese, zinc, and sulphur concentrations may change between raw clay and excavated potsherd, most other elements remain valid for use as indicators of place of manufacture.

A further complication arises when the locations of the clay beds used in ancient times are unknown, or when for other reasons the raw clay cannot be directly studied. In that case, archaeological considerations as to which pottery is likely to be local must be combined with many analyses, in the hope of yielding one or two average composition patterns which can tentatively be considered as those of the local

clays (see section 4). This procedure does not always work, for instance when a small site is being studied and all its pottery was imported. In most other cases a typical composition pattern can be obtained.

With these caveats in mind, provenance determination by chemical and physical analysis of pottery can and often does succeed.

The first multielement provenance studies of ancient pottery were carried out at Oxford in the late 1950's using optical emission spectroscopy (Richards and Hartley 1959) and continue to the present day (Boardman and Schweizer 1973, Prag et al. 1974). At that time the technique used was the best available, but today it suffers in comparison with neutron activation analysis and X-ray fluorescence spectrometry, both capable of greater sensitivity, precision, and simultaneous multielement analysis capability.

Neutron activation studies also began at that time (Sayre and Dodson 1957, Sayre et al. 1958, Emeleus 1958), but were restricted to the analysis of at most four or five elements. The development of the high-resolution solid-state gamma-ray detector in the early 1960's gave neutron activation the necessary tool for analysis of over twenty elements simultaneously, and it was immediately applied to the study of ancient glass (Sayre 1965) and pottery (Perlman and Asaro 1967). The technique

is based on the fact that many elements when bombarded with neutrons (usually in a nuclear reactor) produce radioisotopes which emit gamma rays of known energies characteristic of those particular isotopes. By measuring the number of gamma rays of the characteristic energies emitted by a sample of unknown composition it is possible to calculate the concentrations of certain elements in the sample. Pottery neutron activation analysis using large lithium-drifted germanium detectors has become the most accurate method available for provenance studies, provided a nuclear reactor and gamma-ray detector (both pieces of expensive equipment) are at hand. Excellent reviews of applications to 1971 are those by Sayre (1972) and Perlman, Asaro, and Michel (1972). The following more detailed explanation of the principles of neutron activation analysis is taken largely from Lyon (1964).

## 1.2 Neutron Activation Analysis

Nuclear reactions, as opposed to chemical ones, are responsible for the success of neutron activation as an analytical technique. The most common reaction employed is the neutron-gamma ( $n, \gamma$ ), in which a neutron (usually of very low energy) is captured by a target atom and one or more gamma rays are promptly emitted. The chemical identity of the target atom remains unchanged, but its nucleus, heavier by one mass unit, is usually unstable. It therefore undergoes radioactive decay at a rate dependent on its nuclear

nature. This decay can take many forms, usually the emission of a negative beta particle, but positron emission, emission of a gamma ray, or capture of an orbital electron occur frequently. Most of these processes involve the release of at least one photon, be it a gamma ray from within the nucleus or an X-ray from the surrounding electron cloud. These photons are monoenergetic and characteristic of the nuclear species which emits them. Their detection is thus an indication of the presence of that species in a sample, and their intensity is proportional to its abundance.

The number of activated atoms produced is dependent on several factors. The first is the tendency of the target atoms to interact with neutrons, termed the neutron-capture cross-section. This can vary enormously from one nuclear species to another. The intensity of the neutron source and the duration of exposure of a sample to that source also affect the yield of activated species. Usually nuclear reactors are used as sources, since they produce very high neutron fluxes. Irradiation times can vary from a few seconds to several weeks.

The rate of decay of radioactive species is expressed in terms of the half-life, or amount of time required for half the total number of atoms to decay. Half-lives of activated species range from fractions of a second to many years, so that the time elapsed between neutron bombardment and activity



measurement is often critical. Species with very short half-lives may have decayed completely away in that time. Alternatively, weak radiation from longer-lived species may be masked at first by the stronger activity from shorter-lived ones. Occasionally a material whose activated form has an inconveniently short half-life can still be determined if that activated form decays to another radioactive species with a longer half-life. This is the case with thorium-232, which is activated to thorium-233, or  $^{233}\text{Th}$ .  $^{233}\text{Th}$  decays with a half-life of 22 minutes to protactinium-233, or  $^{233}\text{Pa}$ .  $^{233}\text{Pa}$  in turn decays with a half-life of 27 days to uranium-233, so that measurement of the  $^{233}\text{Pa}$  decay can be used to determine the thorium concentration.

The contributions of the various factors to the decay rate of an activated sample can be expressed mathematically. If the decay constant  $\lambda$  of the activated species is defined in relation to its half-life  $T_{1/2}$  as:

$$\lambda = \frac{\ln 2}{T_{1/2}} \approx \frac{0.693}{T_{1/2}} \quad 1.2 - I$$

then the measured rate of decay  $R$  (in disintegrations per second) at a time  $t$  after the end of an irradiation period of duration  $T$  (both in the same time units as the half-life, such as days) is given by:

$$R = sN_0 e^{-\lambda t} (1 - e^{-\lambda T}) \quad 1.2 - II$$

where  $\epsilon$  is the efficiency of the detector,  $N$  is the number of atoms of the target element present in the sample,  $\sigma$  is the neutron-capture cross-section of the target element in  $\text{cm}^2$ ,  $\phi$  is the irradiation flux in neutrons per  $\text{cm}^2$  per second, and  $e$  is the base of natural logarithms, 2.718...

Gamma-ray spectroscopy for multielement neutron activation analysis is most conveniently accomplished using a lithium-drifted germanium detector. Gamma rays passing through the detector crystal induce the formation of ion pairs (electrons and holes) which are quickly swept to opposite faces of the crystal by a high applied electric field. This collection process results in a small voltage pulse whose intensity is proportional to the number of electron-hole pairs formed, in turn proportional to the energy of the gamma ray. These pulses are then amplified and sorted according to size. The result is a spectrum of gamma-ray peaks of different energies, the area of each peak being proportional to the intensity of its corresponding gamma ray (see Figure 4).

Direct determinations of elemental concentrations can be accomplished only with a great deal of difficulty. Neutron-capture cross-sections, neutron flux, and absolute sample activity must all be known with a high degree of accuracy, requirements difficult to achieve in practice. Instead, most activation analyses use the comparator technique,

whereby a standard sample of known composition and the unknown sample are irradiated simultaneously under the same conditions. If activity measurements are also taken under identical conditions, none of the above terms is included in the calculations. The ratio of the activities of the unknown and standard samples is the same as the ratio of the corresponding concentration of each element analysed. This can be seen by forming the ratio of unknown to standard sample decay rates  $R_1$  and  $R_2$  respectively using equation 1.2 - II:

$$\frac{R_1}{R_2} = \frac{\epsilon N_1 \sigma \phi e^{-\lambda t_1} (1 - e^{-\lambda T})}{\epsilon N_2 \sigma \phi e^{-\lambda t_2} (1 - e^{-\lambda T})} \quad 1.2 - III$$

If the rates are corrected for the difference between times of measurement  $t_1$  and  $t_2$ , this ratio simplifies to:

$$\frac{R_1}{R_2} = \frac{N_1}{N_2} \quad 1.2 - IV$$

Expressed in terms of concentrations  $C_1$  and  $C_2$  (in parts per million or percentage) it becomes:

$$\frac{R_1}{R_2} = \frac{w_1 C_1}{w_2 C_2} \quad 1.2 - V$$

where  $w_1$  and  $w_2$  are the weights of the unknown and standard samples respectively. Since  $C_2$  is known,  $C_1$  can be calculated by transforming the equation to:

$$C_1 = C_2 \times \frac{R_1/w_1}{R_2/w_2} \quad 1.2 - VI$$

This method minimize errors resulting from all the other factors (Lukens 1972), and was the method used in this study.

### 1.3 Studies of Aegean Material

Ceramic products from Classical Greece and Rome and from the Eastern Mediterranean were among the first to be studied by chemical methods, and they continue to receive much attention. The major investigations are concerned with the Greek Late Bronze Age (see Figure 1), when Mycenaean influence had spread as far west as southern Italy and east all the way round the Mediterranean coast to Egypt. The extreme stylistic uniformity of the pottery found in that wide area raised many questions about the location of the main manufacturing centres and the direction and extent of trade. Some of these questions have been answered, both by the Oxford group (Catling et al. 1963, Catling and Millett 1965a, 1965b, 1969) using optical emission spectroscopy, and by the Brookhaven and Lawrence Berkeley Laboratories (Asaro et al. 1971, Harbottle 1970, Bieber et al. 1975) using neutron activation. The latter groups are also studying Cypriot pottery of the Late Bronze Age, of the succeeding "Dark Age" (11th-9th centuries BC), and of the Phoenician Period (5th-4th centuries BC), times during which the extent of foreign influence on Cyprus is controversial (Karageorghis et al. 1972, Artzy et al. 1973, Bieber et al. 1973).

Archaic Greek Pottery (7th and 6th centuries BC) is also being investigated both by optical emission spectroscopy (Boardman and Schweizer 1973) and by neutron activation analysis (Farnsworth 1974).

In the course of these studies, pottery of many periods from all parts of Greece has been analysed to serve as comparative material, though not all these analyses have been published. However, to the author's knowledge no program of analysis has yet been undertaken on Greek Early Bronze Age pottery, other than the one here presented. Though the extent of this Bronze Age culture is not as great as that of the Mycenaean civilization, trade relations are problematic and directions of influence much debated. A study of ceramic provenance in such a restricted area demands chemical analyses of high precision and statistical analyses of considerable subtlety (Bieber et al. 1975). It is hoped that this work can provide information useful to the study of regional inter-relationships during the Greek Early Bronze Age.

## 2. ARCHAEOLOGICAL BACKGROUND

### 2.1 The Early Bronze Age in the Aegean Area

About the middle of the second millenium BC, the first European civilization appeared around the Aegean sea. This was the Minoan-Mycenaean civilization, characterized by royal palaces, highly stratified social organization, written systems of accounting, and a beautiful naturalistic art. But a thousand years earlier, in the third millenium BC, the Aegean area had been brought to the brink of civilization with the flowering of the Early Bronze Age cultures, the first to advance from simple village subsistence economy to more complex proto-urban settlements. The Early Helladic period, as the Early Bronze Age on the Greek mainland is known, is marked by communities with fortifications and large central buildings, and by increased evidence for bronze metallurgy and widespread trade. The succeeding Middle Helladic, or MH, period (2000-1550 BC) is regarded as a period if not of stagnation at least of consolidation and little progress. The Late Helladic, or LH, period is more familiarly known as the Mycenaean Age (see chronological chart, Fig. 1).

Several good summaries of the archaeology of the Early Helladic period (usually abbreviated EH) have recently been written (Caskey 1971, Vermeule 1972, Renfrew 1972). In this thesis, Renfrew's will be referred to most often as it is the most detailed.

FIGURE 1

Chronological chart of the Aegean Bronze Age, after Higgins (1967: 13). In the Cyclades the subdivisions of the Late Cycladic period are seldom used; the LM and LH systems are used instead. In Greece MH is not yet susceptible of division into phases. The terms LH and "Mycenaean" are synonymous. The dates are only approximate, especially before 2000 BC.

NEOLITHIC	DATE BC	CRETE	CYCLADES	GREECE	EGYPT	
	2800					DYNASTY
EARLY	2700	EM I	EC I	EH I	OLD	II
	2600					III
	2500					IV
BRONZE AGE	2400	EM II	EC II	EH II	DOM	V
	2300					VI
	2200					
	2100	EM III	EC III	EH III	1st INTER	VII - X
	2000					XI
MIDDLE BRONZE AGE	1900	MM I	MC I	MH	MIDDLE KING- DOM	XII
	1800	MM II	MC II			
	1700				2nd INTER	XIII - XVII
	1600	MM III	MC III			
	1500	LM I A				
LATE BRONZE AGE		LM I B		LM I	NEW KING- DOM	XVIII
	1400	LM I C		LM II		
	1300	LM III A		LH III A		
	1200	LM III B		LH III B		XIX - XX
	1100	LM III C		LH III C		
IRON AGE	1000	DARK AGES (GEOMETRIC PERIOD)			LATE PERIOD	XXI - XXII
	900					
	800					
	700					



The first of the Early Bronze Age cultures on the mainland, EH I, is also known as the Eutresis culture after an important site in Boiotia (see map, Fig. 2). There, continuous occupation from the preceding Neolithic period right through the Early Bronze Age shows that this culture had its origins essentially in the previous one. The pottery shows a fair variety in fabric: a red-slipped ware is characteristic, together with burnished monochrome ware, light coloured plain ware, and coarse ware (Renfrew 1972: 100). The "jug" or one-handled cup occurs as do deep bowls (often with lug handles), jars, and incised fine ware (Fig. 3). A kind of flanged disk decorated with incisions known as a "mainland frying pan" originated in this period, though it is also found in EH II contexts (Renfrew 1972; 536).

Apart from the pottery, few EH I finds are exceptional. There are tools of bone and stone (especially obsidian blades), clay loom-weights and spindle whorls, but practically no metal finds at all. In fact, the term "Bronze Age" for this phase is a misnomer.

The succeeding EH II phase, also known as the Korakou culture, shows dramatic advances in number of sites, extent of influence, and variety of material remains (Renfrew 1972: 107). The fine pottery, characteristically thin-walled and highly polished, is known as urfinis. Typical shapes are the odd but elegant "sauceboat", the collared jar, the askos,

FIGURE 2

Maps illustrating the position of Lake Vouliagméni in relation to other Early Helladic sites. Map II after French (1972, fig. 10, distribution of Korakou (EH II) phase "urfirnis" ware in Central Greece). The major sites are labelled as follows:

1. Aígina
2. Asine
3. Askitarió
4. Ayios Kosmás
5. Berbáti
6. Eutresis
7. Keramidáki (Corinth)
8. Korakou
9. Lake Vouliagméni
10. Lerna
11. Maníka
12. Mycenae
13. Perakhóra (Heraion)
14. Raphína
15. Tiryns
16. Zygouriés

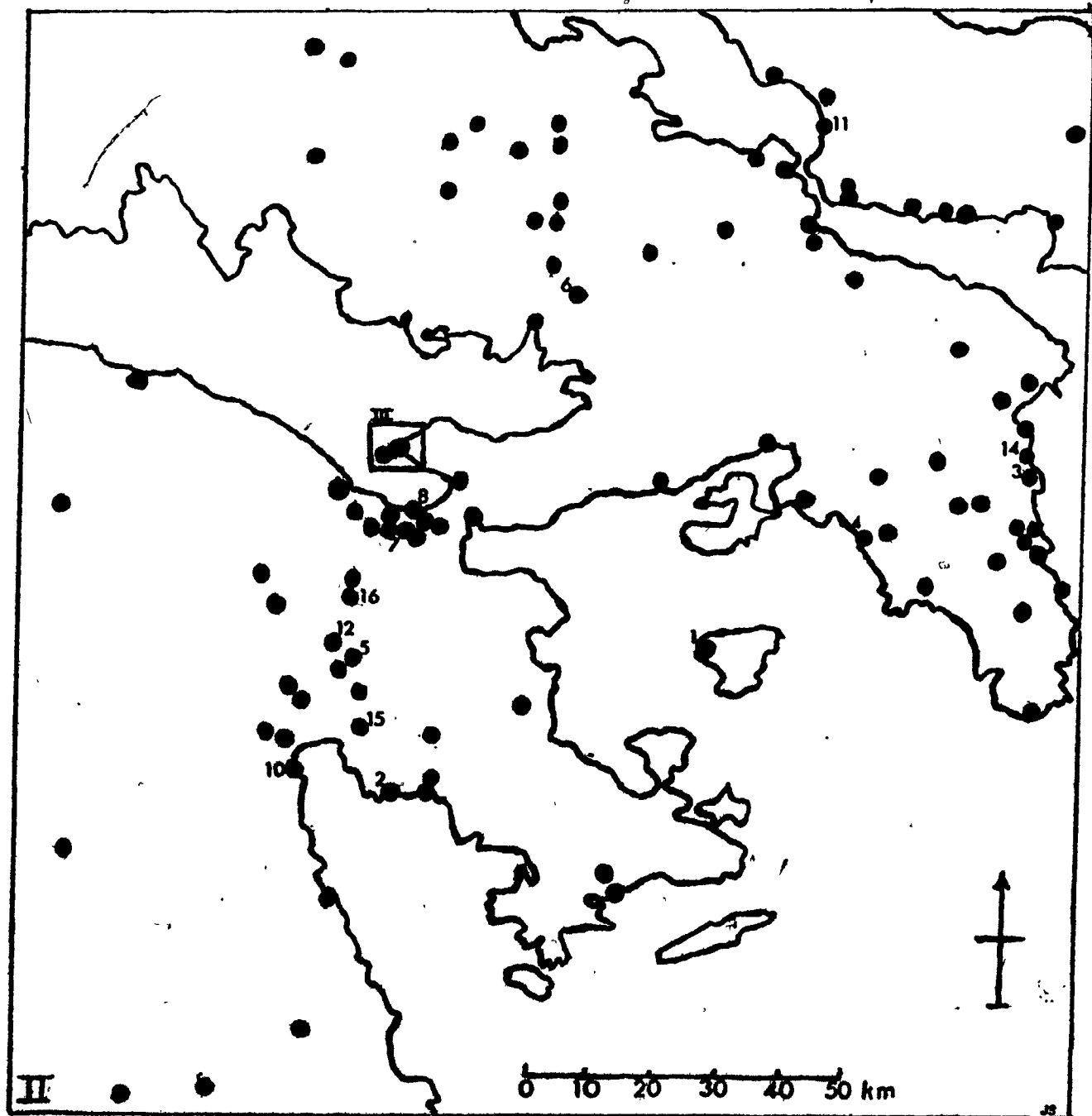
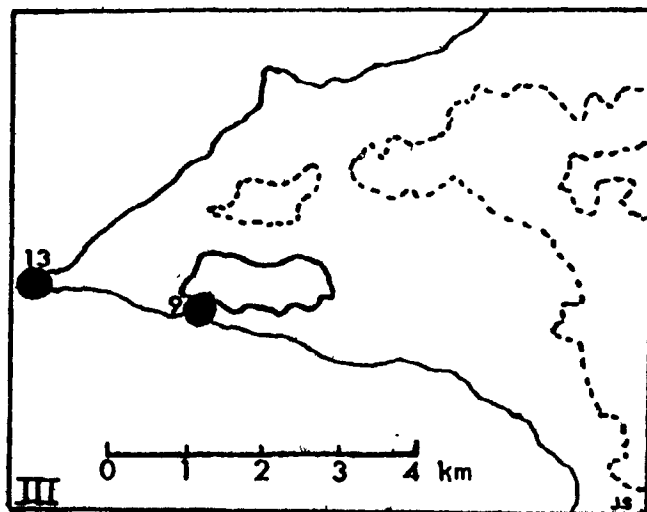
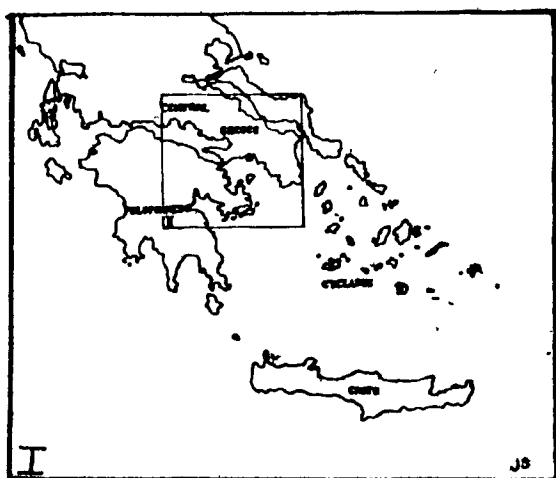
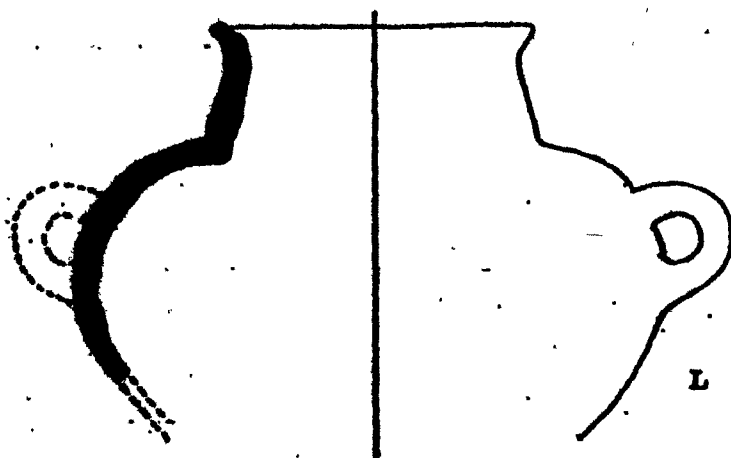
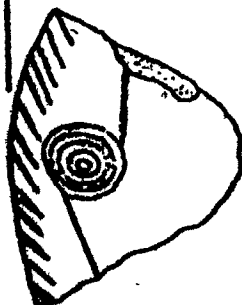
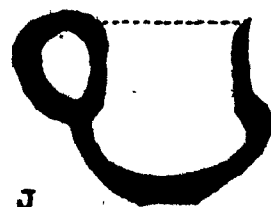
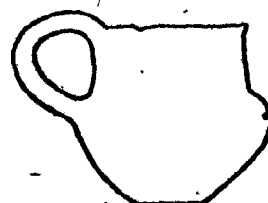
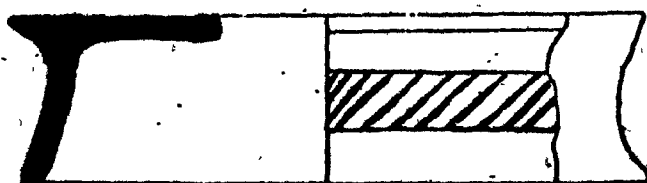
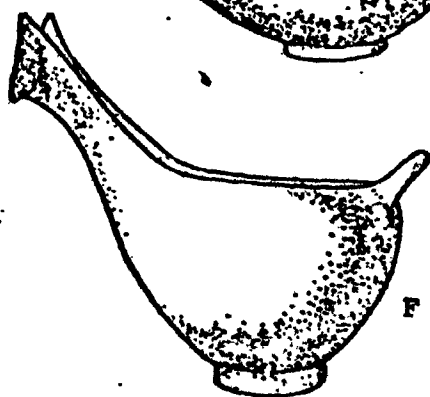
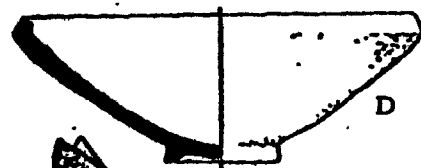
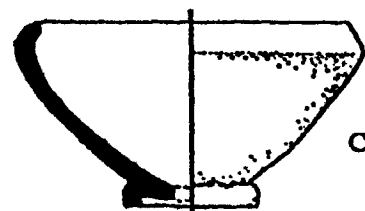
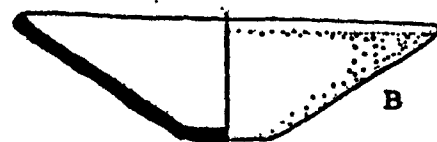
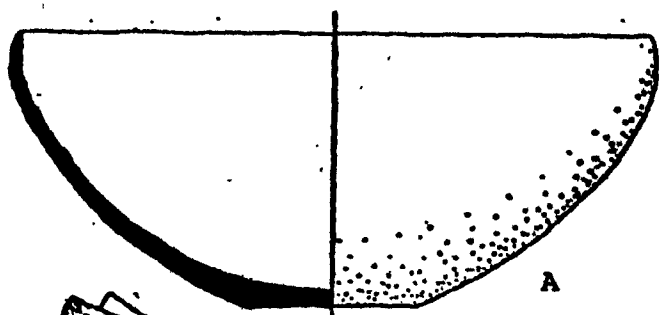


FIGURE 3

Shapes of typical Early Helladic I and II pottery vessels. A-H after Caskey (1960: 291); I after Renfrew (1972: 181); J, K after Mylonas (1959, figs. 56 and 58); and L after Caskey and Caskey (1960: 141).

- A. Deep Bowl
- B-D. Saucers
- E-H. Sauceboats, Caskey types I-IV respectively
- I. "Mainland Frying Pan"
- J. One-Handled Cup
- K. Askos
- L. Collared Jar



and the little footed bowl or saucer (Fig. 3). Some urfirnis pottery is further decorated with dark lustrous paint.

The impressiveness of the EH II culture does not lie only in its pottery, however. Over one hundred sites are known to exist. Several of them are fortified (Renfrew 1972: 107-8 lists Lerna, Askitarió, Raphína, and possibly Maníka and Aígina), and at two at least, Lerna and Tiryns, large and presumably public buildings exist. In fact, some EH II settlements (Renfrew 1972: 108 + Áyios Kosmás, Zygouriés), can be considered as small towns, with numerous houses set close together and separated by narrow alleys. Large storage jars, decorated with a roll stamp, are often found in the Peloponnese as are seal-impressions on clay, presumably put there to identify the ownership of jars containing various commodities. Loom-weights and spindle whorls of terracotta and polished and flaked stone tools are all more common, bone tools very much so. Copper and bronze tools are very well represented: flat axes and chisels, daggers and spearheads, knives, awls, borers, and tweezers are often found in hoards and graves. Gold and silver jewellery is also found, as are vessels of precious metal in the same shapes as the pottery.

Although such an expansion in settlements and material culture has been explained as being due to an influx of new people, sufficient similarities exist between the Eutresis and Korakóú cultures to call the latter indigenous. In fact, at Eutresis itself, the only site where a clear transition from

EH I to EH II can be observed, it seems to be a gradual one (Renfrew 1972: 114, see also Fossey 1969).

The subsequent EH III period ("Tiryns culture") is marked by a significant decline in the number of known sites, and in their size and richness. The pottery too is quite different. In fact, the Tiryns culture has stronger affinities with the succeeding Middle Bronze Age culture in mainland Greece than with the preceding two Early Bronze Age cultures. The site at Lake Vouliagméni, Perakhóra, has no EH III material, and this culture does not enter into discussions in this paper, so it will not be further presented. Suffice it to say, as Renfrew implies (1972: 116), that if ever prehistoric Greece was invaded by foreign peoples, the invasion came between EH II and EH III.

During the Early Bronze Age, the Cycladic islands and Crete experienced advances in culture similar to those taking place on the mainland. However, in Crete the transition from the Early to the Middle Bronze Age (Early to Middle Minoan periods) was marked by the foundation of the first Minoan palaces and by the emergence of civilization itself, at least as Renfrew defines it (1972: 81). Connections between the Cyclades and mainland Greece appear to have been extensive, at least during EH II (which corresponds to Early Cycladic II or the Kéros-Sýros culture in the islands). During the Middle Bronze Age, the Cycladic islands came under Cretan control,

and later on under Mycenaean control. We will later have occasion to discuss the possibility of imports from the Cyclades to the site at Lake Vouliagméni.

## 2.2 The Site at Lake Vouliagméni, Perakhóra

The Early Helladic settlement at Lake Vouliagméni, Perakhóra, lies along a low ridge between the lake and the Gulf of Corinth, on the south side of the Perakhóra Peninsula just north of Corinth (see map, Fig. 2). Excavations were carried out there in 1965 and 1972 by John Fossey under the auspices of the British School of Archaeology at Athens. The 1972 expedition was staffed by Classics students from McGill University, the present author included, as was a study session held in 1974. The results of the excavations can be summarized briefly here (see Fossey 1969, 1974a, 1974b, Michaud 1973).

In 1965 a trench cut through the lower, central part of the site revealed three occupation levels of the EH I period in closely stratified sequence, designated X, Y, and Z from earliest to most recent. Phases X and Y contained portions of buildings with stone foundations for rounded and straight walls respectively, accompanied by much typical EH I pottery. Phase Z consisted of a wide earth bank running along the edge of the lake, with occupation debris of transitional EH I/EH II form behind it, but no traces of buildings.



In 1972 land rights problems forced the digging to continue only on the western, higher part of the site. Here the occupation debris was found to belong only to the EH II period. This shift of the centre of activity uphill may have been caused by a sea level rise known to have taken place around this time, which probably subjected the lower part of the site to flooding (Fink and Schröder 1971). In fact, the earth bank discovered in 1965 may have served as a dyke to hold back the water.

In the main area of EH II occupation a sequence of three phases was found. The earliest of these was in fact just a rubbish dump, in a small ravine over two metres deep, filled with broken pottery. The top of this fill was levelled to take the crude stone foundations of the second phase, a small freestanding building a little less than two metres square. Inside this building, on a floor of fine grey silt, lay seven almost complete vases, including one in the form of a crouching ram. The purpose of this structure, containing no bones or traces of burial and too small to be a habitation, is as yet unknown.

It was covered up in the third phase of occupation by a much larger building, excavated only in part, with well-laid stone foundations of at least two rooms and a corridor. Its walls were made of mud-brick and its roof was apparently tiled. This building contained only a small amount of

occupation debris, and seems to have been destroyed by fire. The rubble from its collapse added at least a metre to the ground level.

From that time, about the middle of the third millenium BC, to the present day, only two more phases of occupation are evident in the two metres of natural soil which accumulated. There is a poorly-preserved Mycenaean wall with some bits of associated pottery, and there are traces of a series of Archaic wooden structures (c. 6th century BC), possibly part of a farm complex of which another part was found in 1965. They too contained a little pottery. The site was not built upon from then until the present day.

A smaller area (area "B") also excavated in 1972 revealed two superimposed, poorly-preserved buildings dated to EH II by the associated pottery.

### 3. CATALOGUE OF SAMPLED OBJECTS

#### 3.1 Introduction

The samples listed here have been numbered according to their archaeological context. The information given in each case consists of:

- a) the three-digit sample identification number (always underlined);
- b) the archaeological identification code, usually consisting of the trench, level, and object subcodes, in that order;
- c) a brief designation of the form of the object, indicating the shape and the portion preserved;
- d) the Munsell colour index (Munsell 1971) of the actual powdered sample (see note below);
- e) a short paragraph listing additional information about the object. This usually includes type and colour of the ceramic fabric, surface finish, decorative features, reference to illustrated parallels (analogous material) for the shape, and dimensions (always given in centimetres). The following abbreviations are used in this section:

d., diameter

th., thickness

l., length

w., width

h., height

max., maximum

Note:

The Munsell system of colour notation uses three variables to designate a colour. The first is the hue, or relation of the colour to primary colours. Pottery colours are covered by the hue range Red to Yellow, given in the soil-colour booklet in the steps 10R, 2.5YR, 5YR, 7.5YR, 10YR, 2.5Y, and 5Y. The other variables are the value and the chroma indices. The value is the lightness of a colour; it ranges from 0 for absolute black, to 10 for absolute white. The chroma is the strength, or purity; it varies from 0 for natural greys to over 10 for very strong colours. The hue letter is always followed by a space, and a diagonal line separates the value and chroma numbers. Thus 10R 5/8 is a strong red, 5YR 6/6 a medium brown, 7.5YR 8/4 a pink, 10YR 7/4 a beige or "buff", 2.5Y 8/6 a yellow, and 5Y 8/3 a pale grey-green.

For inclusion in Table II the above notation has been further abbreviated. The steps listed

above are denoted by the digits 3 to 9 respectively; for instance, 10R 5/8 is coded as 3 5/8, 2.5Y 8/6 as 8 8/6, and so on.

3.2 Samples of the Natural Clay (010-016)

A large quantity of the clay immediately beneath the bottom layer (levels (13) and (14)) of the pottery dump in trench AI was available for analysis. Samples of other clays from the immediate vicinity of Lake Vouliagmeni were also taken, but have not yet been analyzed. Small amounts of the natural clay were refined to various extents and fired to various temperatures before they were sampled for analysis, in an attempt to duplicate the treatment accorded to clay by the prehistoric potters. It is felt that the degree of refining of 012-014 corresponds to "semifine" pottery, that of 010 and 011 to coarse wares, and that of 015 and 016 to the liquid "slip" applied to the surface of some fine vases. Firing temperatures were intended to cover the range from that of unfired clay, through loss of bound water and loss of carbon dioxide from the carbonate ion, to the beginnings of sintering or vitrification.

<u>010</u>	AI	natural clay	10YR 7/2
		raw lump dried overnight at 100°C	

- 011 AI natural clay 7.5YR 6/4  
raw lump mixed with water, left to dry, and fired to 700 C for one hour in an electric (oxidizing) kiln.
- 012 AI natural clay 7.5YR 7/4  
raw lump mixed with water, left to settle for one hour; upper part of sediment removed, left to dry, and fired to 700 C as 011.
- 013 AI natural clay 7.5YR 7/3  
raw lump treated as 012 but fired to 900 C.
- 014 AI natural clay 2.5Y 5/6  
raw lump treated as 012 but fired to 1100 C.
- 015 AI natural clay 5YR 5/8  
upper part of sediment (as 012) centrifuged for one minute; upper part of that dried and fired to 700 C for one hour.
- 016 AI natural clay 10YR 5/6  
sediment treated as 015 but fired to 1100 C.

3.3 Objects from the Square Structure (101-108)

This collection of eight vases was found as a group in a corner of the structure making up the second phase of EH II occupation at Lake Vouliagmeni. They are thus all accessioned in level (18sq), and are given individual vase numbers.

- 101 AII (18sq) Vase no. 1 saucer: complete (mended)  
7.5YR 7/5

semicoarse buff, varying to orange and pink (10YR 7/4 to 5YR 6/6), with large (c. 0.2) dark red grains, some smaller orange-brown and many tiny dark grey and black ones; no traces of either slip or burnish inside or out; low foot-ring and inturned rim: cf. Siedentopf 1973: 4 fig. 2, 7; long-tailed T incised outside below rim; h. 6.1, max. d. 12.3; ("Saucer" is the technical term used by Caskey and Caskey (1960: 165 n.33) for these small bowls, which can be very shallow or relatively hemispherical, as this one is).

- 102 AII (18sq) Vase no. 2 saucer: complete (mended)  
10YR 7/3

semifine pale buff, varying to yellow and pink (2.5Y 8/4 to 7.5YR 7/4), with various tiny inclusions in dark red, orange-brown, brown, black, and dark grey; poorly preserved dark red-brown slip inside (2.5YR 6/6 to 7.5YR 5/4), with traces of horizontal brush marks; low foot-ring and inturned rim (ill. Michaud 1973: 275 fig. 43): cf. Caskey and Caskey 1960: 154 fig. 11, VIII.34; h. 6.2, max. d. 11.2.

- 103 AII (18sq) Vase no. 3 sauceboat: spout missing  
5Y 8/2

fine pale green, with no traces of slip or burnish inside or out; low foot-ring, deep cylindrical body, double vertical handle like an 8 in horizontal section; cf. Caskey 1960: 291 fig. 1, III; h. (as preserved) 13.8, max. d. 12.6.

- 104 AII (18sq) Vase no. 4 sauceboat: rim fragment  
with handle  
5YR 8/4

semifine orange with some dark red, orange-brown, brown, white and beige inclusions c. 0.1 and smaller, and some impressions of plant-stalks c. 0.1 long; no traces of slip inside or out; squat horizontal handle at level of rim; cf. Caskey 1960: 291 fig. 1, intermediate between types II and IV.

105 AII (18sq) Vase no. 5 bowl: rim to base preserved  
7.5YR 7/4

coarse buff, with large (0.2 - 0.5) angular grey-brown inclusions, smaller dark red ones, and others; thick cream slip inside and out; very shallow (cf. Caskey 1972: 371 fig. 6, C34 for rim), with a low foot-ring; h. 6.9, d. 70.

106 AII (18sq) Vase no. 6 bowl: rim fragment  
10YR 7/4

coarse dark red (5YR 5/8) with large (c. 0.2) white, beige, dark red, grey and black inclusions; unslipped, but smoothed on outside; lug handle just below thickened rim, cf. Säflund 1965: 147 fig. 112, 19; d. greater than 50.

107 AII (18sq) Vase no. 7 "salt pot": complete  
7.5YR 7/4

semicoarse buff, poorly fired, with small (c. 0.1) angular dark grey and black inclusions; many traces of red slip (2.5YR 4/6) inside and out; flat oblong dish divided into two compartments, with small vertical ribs and horizontal lugs applied outside; h. 4.6, l. 16.4, w. 8.1.

108 AII (18sq) Vase no. 8 ram vase: complete  
5YR 6/6

semicoarse orange, with large (c. 0.2) dark red inclusions and smaller white, brown, grey and black ones; plastic vase in form of crouched ram, with the opening on its back, off centre; similar heads have occasionally been found on sauceboat spouts, cf. Weinberg 1969: l. 13.6, h. 6.6, w. 5.2.

3.4 Miscellany from the Pottery Dump (111-116)

These six samples were taken from objects of particular archaeological interest found in the lower levels of trench AI; levels (12) and (13) correspond to the dump



proper, and (9A) to its levelling in preparation for the large building of the third phase of occupation.

Object subcodes enclosed by triangles indicate objects separately recorded as small-finds. The subcode UT is short for "Unaccessioned Tile"; i.e., tile fragments only separately recorded after the excavation, during study. The waster fragments were also separately recorded then, and given capital letters for identification.

111    AI (12)                      incised sherd                      7.5YR 7/4

semifine, well-fired buff with a few tiny (less than 0.1) orange-brown, dark red, and black inclusions; no traces of slip either inside or out; a few deep incised lines outside, many lighter scratches inside, all made before firing; 8.2 by 7.5.

112    AI (13)                      bowl(?): impressed base 7.5YR 7/4

semifine buff, dense and well-fired, with very small dark red, dark grey, and black inclusions; very fine stalk impressions visible on fresh break; traces of red slip (5YR 6/4-6/6) inside and out; impression of a woven mat on the bottom, probably the mat on which the pot was resting while it was being formed; cf. e.g., Blegen 1928: 177 fig. 109; base d. 6.0.

113    AI (12)  sealings on fired clay lump 10YR 7/1

semifine pale buff, hard and well-fired, with a few very small black inclusions; stamped four times with the same seal (circular, d. 2.55, of complex non-symmetric design); lump dimensions 5.4 by 4.2 by 1.9.

114    AI (9A)                      plastic vase fragment: head of fish  
10YR 7/3

semifine pale buff, hard, dense and well-fired, with specks of dark grey, brown and black inclusions; reddish slip (2.5YR 4-5/6) outside; preserved l. 4.6, h. 3.5, w. 3.2.

115 AI (13) UT.3 tile: large portion including edge  
10YR 7/3  
  
semifine pale brown with small (c. 0.1) grey-brown  
stone inclusions; unslipped; along edge, three parallel  
rows of impressed slanted triangles, similar to the  
decoration on a pithos rim from Eutresis (cf. Goldman  
1931: 96 fig. 124,2); l. 11, w. 12, th. 3.7-3.9 at  
edge, 2.4 elsewhere.

116 AI (12) waster B 2.5Y 8/2  
  
extremely hard, semifine greenish clay with small  
(c. 0.1) black or dark grey inclusions, and patches  
of bluish grey-green (7.5Y 8/2?) on surface; large  
mass (18 by 16 by 7) of collapsed overfired pottery  
from a kiln accident, twisted and stuck together.

3.5 Objects from an Occupation Layer (151-160)

All ten objects in this group come from level (17)  
in trench AII, which is part of the third phase of EH II  
occupation, immediately preceding the final destruction of  
the site. The sherds chosen for sampling were typical in  
colour and fabric of most wares found in occupation levels,  
except for 160, an example of the rare "fine mottled ware".

151 AII (17) 2 bowl(?): handle fragment 5Y 8/2  
  
coarse green with tiny black, white, and grey  
~~inclusions~~; unslipped; lug or strap handle attached  
to plain bowl rim; th. 0.7.





152 AII (17) 4 jar: rim fragment 2.5Y 7/2  
  
semifine green with tiny black inclusions; unslipped;  
neck of jar with flaring rim, d. 12; cf. Sjöflund 1965:  
151 fig. 119b, 4.

- 153 AII (17) 5 jar(?): handle fragment 5Y 8/1  
semifine green with tiny black inclusions; unslipped;  
handle circular in section, d. 1.8.
- 154 AII (17) 13 bowl: rim fragment 7.5YR 7/4  
semifine buff with a few dark red inclusions; bowl  
with thickened, flat-topped rim, d. 46; dark red  
(10R 5/6) thick matt worn slip inside; cf. Sjöflund  
1965: 147 fig. 112, 10.
- 155 AII (17) 30 large bowl(?): wall fragment  
5YR 6/4  
semifine pink with tiny dark grey and dark red  
inclusions; wall or possibly rim fragment of large  
bowl (or pithos?), d. 55, with two horizontal applied  
bands of "piecrust" decoration on outside; light  
brown (7.5-10YR 8/3) matt slip inside and out.
- 156 AII (17) 31 bowl: rim fragment 10YR 7/4  
coarse red with large (c. 0.2) dark grey angular inclusions;  
flat rim, d. 60, cf. Sjöflund 1965: 147 fig. 112, 23a.
- 157 AII (17) 33 bowl: rim fragment 7.5YR 6/4  
coarse red with large dark grey inclusions; thickened  
rim with flat top, d. 33; thick matt cream slip (2.5Y  
8/2) inside and out; cf. Sjöflund 1965: 149 fig. 117, 5.
- 158 AII (17) 35 bowl: rim and handle fragment  
10YR 6/3  
coarse red with large (c. 0.2) dark grey inclusions;  
plain bowl rim (d. 40) with beginnings of round handle  
emerging from top, width 1.8; thick matt cream slip  
(2.5Y 8/2) inside and out; cf. Fossey 1969: 66 bowl 2.
- 159 AII (17) 36 bowl: rim fragment 7.5YR 6/4  
coarse red with small dark red and grey inclusions;  
incurving rim, d. 32, with applied "piecrust" decoration  
outside along ~~slip~~ thick matt cream slip (2.5-5Y 8/2)  
inside and out; cf. Sjöflund 1965: 149 fig. 116, 8.

- 160 AII (17) 52 sauceboat: rim fragment 2.5Y 7/2  
fine grey-pink mottled ware, very smooth surfaces,  
varying in colour from 7.5YR 8/4 to N 8/0, th. 0.3-0.4;  
for fabric cf. Caskey and Caskey 1960: 150 and 153.

3.6 Fragments of Mud-Brick (201-206)

Six of the many pieces of sun-dried mud-brick were sampled, with colours varying from orange to green. Most were recorded as small-finds during excavation and so given numbers enclosed in triangles, but a couple were only separately recorded during study as "unaccessioned terra-cotta" or UTC.

- 201 AII (11)  mud-brick fragment 2.5Y 7/2  
bright yellow with small black inclusions; 5.2 by 4.9 by 3.7.
- 202 AI (5E)  mud-brick fragment 7.5YR 7/4  
pale orange, quite pure; 6.0 by 4.5 by 2.8.
- 203 AII (7)  mud-brick fragment 10YR 8/3  
pale orange-buff with light red inclusions, among others; 5.3 by 4.6 by 2.4.
- 204 AI (5E)  mud-brick fragment 2.5Y 7/2  
pale yellow-green with fine stalk impressions; 4.5 by 3.5 by 3.0.
- 205 AII (18sq) UTC 8.1 mud-brick fragment 2.5Y 8/2  
pale yellow with small black inclusions; a flat surface, with traces of burning; 5.7 by 4.6 by 3.3.

206 AII (18sq) UTC 8.2 mud-brick fragment 7.5YR 7/4  
semifine orange-brown; a flat surface; 3.2 by 3.2  
~~by 2.7.~~

3.7 Vases from Area "B" (301-304)

The four outstanding objects from the small excavation (designated "B") on the hilltop just north-west of the main excavation ("A") were also sampled. They are EH II in date, though their chronological ~~relationship~~ with the three phases of occupation of the main excavation is not yet clear.

301 BII/III (3) 51: B Vase no. 4 jug: rim to belly  
preserved at handle  
10YR 7/4

semifine buff-brown, with a red slip (5YR 4/3) outside; globular upper body, constricted neck, conical rim, possibly a spout, strap handle fragments at rim and shoulder; preserved h. 7.0; cf. Goldman 1931: 103 fig. 136.

302 BII/III (2) B Vase no. 1 saucer (mended):  
only chips missing  
10YR 7/3

fine pale yellow-buff (2.5Y 8/2 to 7.5YR 8/4) with flakey worn black(?) slip inside; d. 13.6, h. 6.0; cf. Caskey and Caskey 1960: pl. 50, VIII.22.

303 BII baulk (1) 1: B Vase no. 3 sauceboat: rim to  
base preserved at back  
7.5YR 7/4

semifine buff with a few small (c. 0.1) light red and red-brown angular inclusions; thin matt slip inside and out, dark red to dark brown (5YR 6/6 to 5YR 4/4), with brush marks; quite squat, ring base, high horizontal handle; roughly shaped outside, smoother inside; preserved h. 11.0; cf. Caskey 1960: 291 fig. 1, intermediate between types II and IV.

304 BIII (3) 37: B Vase no. 2 askos: rim with handle  
10YR 7/3

semifine orange with a few small (0.5-1.5) white and grey inclusions; dull orange slip (10YR 8/3) inside and out; handle round in section leaving horizontally from edge of rim; d. of opening 9.0, th. 0.45; cf. Caskey and Caskey 1960: pl. 51, VIII.28.

3.8 Representative Sherds from the Pottery Dump (401-422)

Sherds from pots of typical shape and fabric were selected for sampling. Among the most common shapes were plates (401-407), bowls with "piecrust" applied decoration (408-413), and jars (415, 416), in fabrics ranging from buff to green.

401 AI (12) 707 plate: rim fragment 7.5YR 6/4  
coarse red with many inclusions up to 0.1 in size; unslipped; flat or slightly concave shape, with plain rim: cf. Caskey 1972: 364 fig. 3, B28; d. 60, th. 0.9.

402 AI (12) 711 plate: rim fragment 7.5YR 7/6  
semicoarse orange-red with several inclusions up to 0.06 in size; unslipped; plain rim, as 401; d. 30, th. 0.6.

403 AI (12) 713 plate: rim fragment 10YR 7/4  
semifine buff with a few inclusions up to 0.02 in size; unslipped; plain rim, as 401; d. 22, th. 0.6.

404 AI (12) 747 plate: rim fragment 10YR 7/4  
semifine buff with a few inclusions up to 0.02 in size; unslipped; plain rim, as 401; d. 35, th. 0.7.

- 405 AI (12) 753 plate: rim fragment 2.5Y 7/2  
coarse green with several inclusions up to 0.08 in size; unslipped; plain rim, as 401, possibly from a large bowl; d. 60, th. 0.8.
- 406 AI (12) 507 plate: rim fragment 10YR 7/3  
semicoarse buff with some small dark red inclusions; unslipped; thickened, rounded rim: cf. Caskey 1972: 371 fig. 6, C34; d. 50, th. 0.6.
- 407 AI (12) 545 plate: rim fragment 10YR 7/3  
semicoarse buff with some inclusions up to 0.1 in size; unslipped; slightly incurving, rounded rim: cf. Caskey 1972: 371 fig. 6, C5; d. 24, th. 0.7.
- 408 AI (12) 706 large bowl: rim fragment 10YR 5/2  
semifine reddish (with a grey core) with a few inclusions up to 0.1 in size; unslipped; thickened, incurving rim with scalloped "piecrust" outside; cf. Siedentopf 1973: 10 fig. 8; d. 30, th. 0.8.
- 409 AI (12) 719 large bowl: rim fragment 7.5YR 7/6  
semicoarse orange with a few inclusions up to 0.1 in size; unslipped; smoothly inturning rim with "piecrust" decoration applied below lip, outside; cf. Fossey 1969: 58 fig. 3, 2 (top); d. 30, th. 0.5.
- 410 AI (12) 733 large bowl: rim fragment 10YR 8/2  
semicoarse yellow with many inclusions up to 0.2 in size; unslipped; thickened rim with "piecrust" decoration outside below lip; cf. Säflund 1965: 147 fig. 112, 22; d. 40, th. 1.2.
- 411 AI (12) 756 large bowl: rim fragment 7.5YR 6/2  
coarse pale green with many inclusions up to 0.2 in size; unslipped; thickened rim with "piecrust" decoration applied outside; cf. Säflund 1965: 149 fig. 117, 5; d. 35, th. 2.5.

- 412 AI (12) 558 large bowl: rim fragment 7.5YR 6/4  
coarse red with many large (c. 0.2) inclusions and a thick green slip inside and out; "piecrust" decoration along outside of lip; cf. Säflund 1965: 149 fig. 116, 8 (but yet more incurving than his); d. 30, th. 1.0.
- 413 AI (12) 563 large bowl: rim fragment 7.5YR 8/2  
semifine buff with only a few very small (c. 0.05) inclusions; unslipped; "piecrust" decoration outside below gently inturned, thickened rim; cf. Siedentopf 1973: 9 fig. 7, 76 (but deeper than his); d. 60, th. 1.8.
- 414 AI (12) 567 thick pan: rim fragment 7.5YR 7/4  
semicoarse dull orange with many small (c. 0.1) dark red inclusions; unslipped; very shallow, with thick rounded vertical rim; cf. Caskey 1972: 367 fig. 4, B66 (but a little more upright than his); d. 30, h. 4.5, th. 1.5.
- 415 AI (12) 547 jar: fragment of rim with handle 10YR 7/2  
semicoarse yellow with many small black inclusions; unslipped; base of vertical handle of twisted-rope type attached to slightly outturned, rounded rim; cf. Goldman 1931: 113 fig. 151, 3; d. 8, th. 0.6.
- 416 AI (12) 569 jar: fragment of rim with handle 10YR 7/2  
semicoarse yellow with many small black inclusions; unslipped; base of vertical handle of twisted-rope type attached to slightly outturned, rounded rim; cf. Goldman 1931: 113 fig. 151, 3; almost identical in form and fabric to 415; d. 10, th. 0.5.
- 417 AI (12) 576 saucer: rim fragment 2.5Y 7/2  
fine yellow-green; unslipped; pointed, sharply inturned rim; cf. Siedentopf 1973: 4 fig. 2, 7; d. 15, th. 0.3.



- 418 AI (12) 579 jar: rim fragment 5Y 8/1  
fine yellow-green; unslipped; rounded, smoothly  
outturned rim; cf. Caskey and Caskey 1960: 141  
fig. 7, IV.6; d. 9, th. 0.4.
- 419 AI (12) 542 large bowl: rim fragment 7.5YR 7/4  
semicoarse red-orange, with some medium (c. 0.15)  
inclusions; dark red slip inside; gently inturned,  
flattened rim; cf. Säflund 1965: 151 fig. 120, 10;  
d. 30, th. 1.0.
- 420 AI (13) 1604 bowl: rim fragment 7.5YR 7/4  
semifine orange, with a few small dark red inclusions;  
red slip inside and over lip; flat, smoothly inturned  
rim with lug handle below lip; cf. Caskey and Caskey  
1960: 141 fig. 7, IV.2; d. 42, th. 0.6.
- 421 AI (12) 609 bowl: rim fragment 10YR 6/1  
fine grey, slipped inside in red and outside in  
mottled shades of orange, brown, grey and black;  
hard clay, outer surface pitted, also showing  
burnishing marks; plain rim, but twisted (due to  
a kiln accident?).
- 422 AI (12) 843 bowl: rim fragment 10YR 7/4  
semicoarse buff, with many small black inclusions;  
unslipped; flat inturned rim, with uneven "piecrust"  
along outside of lip; twisted shape, scarred inside  
(due to a kiln accident?); d. 20?, th. 1.5.

3.9 Late Helladic ("Mycenaean") and Archaic ("Corinthian")  
Pottery (501-526)

These sherds were found in the upper levels of the  
excavation more or less associated with the Mycenaean wall

and the post-holes of the Archaic period. The dates and attributions given were kindly supplied by the excavator. In this section, FM stands for the Furumark Motive Number (see Arne Furumark, The Mycenaean Pottery: Analysis and Classification; Stockholm 1941). Sample 510 is an EH II sherd of unusual nature which had found its way into an upper level.

- 501 AI (4) 1 Corinthian skyphos: base fragment 2.5Y 7/1  
fine grey, with traces of black and red-orange paint on the bottom inside and on the wall outside.
- 502 AI (4) 2 Corinthian bowl or skyphos: base fragment 10YR 8/3  
fine buff, with thin flakey black glaze inside and out.
- 503 AI (4) 3 Corinthian miniature bowl: rim fragment 7.5YR 7/7  
fine orange, unslipped; apparently hand-made; d.8.
- 504 AI (4) 19 Corinthian skyphos: base fragment 10YR 8/4  
fine buff with orange surface; smooth shiny black glaze inside and out.
- 505 AI (4) 20 Corinthian pyxis lid: rim fragment 10YR 8/3  
fine yellow-buff; painted design on upper surface: red bands bordering a band of black checkerboard; Middle or Late Protocorinthian (c. 700-640 BC).
- 506 AI (4) 30 Corinthian skyphos: base fragment 7.5YR 7/5  
fine orange, with red paint in the "radiating base lines" pattern, and red circle underneath base.

- 507 AI (5A) 25 Mycenaean vessel: fragment of spout  
5Y 7/1  
  
fine green ("Minyan"); a matt brown horizontal stripe of paint around the rim, with attached brown vertical stripes.
- 508 AI (5C) 6 Mycenaean closed vessel(?): wall fragment  
10YR 8/3  
  
fine buff, with one wide and three narrow bands of red lustrous paint (5YR 6/8) on the outside; th. 0.5; LH IIIA or IIIB.
- 509 AI (6) 1 Mycenaean kylix: base fragment 7.5YR 7/4  
  
fine yellow-orange, with black paint on upper surface; LH IIIA or IIIB.
- 510 AI (7) 277 EH II vessel: wall fragment 10YR 7/1  
  
fine grey, with mottled dull red, brown, yellow and grey surfaces, slipped and polished (cf. Caskey and Caskey 1960: 153); possibly from sauceboat; th. 0.3-0.4.
- 511 AII (2) 1 Corinthian skyphos: base fragment 2.5Y 8/2  
  
fine beige; interior dull black glaze; exterior dull black glaze under base ring inside which two concentric circles and filled centre in red paint; d. 4.0.
- 512 AIII (1) 5 Corinthian large closed vessel: base fragment  
7.5YR 8/4  
  
heavy base ring (d. 8.0) in fine buff, with red paint on outside.
- 513 AIII (1) 12 Corinthian pyxis lid: rim fragment 10YR 7/3  
  
fine buff with traces of white or pale pink slip on upper surface; d. 12.0.

- 514 AIII (3) 8 Corinthian pyxis lid: fragment 7.5YR 7/4  
fine buff-orange, with filled centre and compass-drawn concentric circles in dark red paint on upper surface; Late- or Subgeometric (c. 750-650 BC).
- 515 AIII (3) 37  
This sample was taken but not analysed. The number remains in the catalogue to simplify the coordination of analytical and archaeological records.
- 516 AIII (4B) 7 Mycenaean kylix: base fragment 7.5YR 7/4  
fine orange-brown, with traces of red paint on upper surface; LH IIIA or IIIB; d. 9.0.
- 517 AIII (5) 2 Mycenaean conical bowl: rim fragment  
10YR 8/4  
fine buff with yellowish slip inside and out; painted with a black band on the inside and a broad red band on outside of rim and top of shoulder; LH IIIA or IIIB; d. 56.
- 518 AIII (5) 6 Mycenaean deep bowl(?): rim fragment  
7.5YR 8/5  
possibly rather an amphora; uplifted horizontal handle attached at rim; fine buff with traces of black and red paint on outside; LH III.
- 519 AIIIS (4) 1 Mycenaean vessel: wall fragment 2.5Y 7/3  
pale grey with tiny black inclusions; unslipped; a single band of dull brown paint 0.6 broad; th. 0.4-0.6; LH IIIC?
- 520 AIIIS (4) 3 Mycenaean deep bowl: rim fragment 10YR 8/3  
fine pale yellow, with high-quality black lustrous paint inside and out; d. 18, th. 0.4-0.5; LH IIIA or IIIB.

- 521 AI (3) 51 Corinthian lamp: spout fragment 7.5YR 7/4  
fine buff, with black glaze inside body and spout;  
semi-open type; 5th century BC?
- 522 AII (6B) 1 Mycenaean open vessel: wall fragment  
7.5YR 8/4  
fine buff, with a cream slip inside and out; a black  
band of paint inside, and a black band with red cross-  
hatching outside (FM 78); LH I or II.
- 523 AII (6B) 6 Mycenaean vessel: wall fragment 7.5YR 8/4  
fine buff, with a cream slip inside and out; on the out-  
side, two parallel wavy red lines painted between  
two parallel straight horizontal red lines (FM 53.9);  
LH I or II.
- 524 AII (6B) 11 Mycenaean open vessel: handle fragment  
7.5YR 7/4  
fine buff, with a cream slip inside and out; a stripe  
of brown paint on the inside and a stripe of black on  
the outside; lower junction of high-swung handle.
- 525 AII (6B) 14 Mycenaean deep bowl: handle fragment  
7.5YR 8/3  
fine buff, with a cream slip inside and out; cracked  
black paint on the inside, and black vertical stripes  
under the handle on the outside; rim and beginning of  
vertical strap handle; probably LH IIIC.
- 526 AII (6B) 36 Mycenaean bowl(?): rim fragment 2.5Y 8/2  
fine buff, with a thin dull line around the outside  
of the rim; possibly from a shallow, carinated bowl;  
LH II or III.

3.10 Early Helladic I Pottery from the 1965 Excavation (601-623)

Most, though not all, of this material was published in the Annual of the British School at Athens for 1969. The descriptions given here may differ slightly from the published ones as a result of further examination of the pottery.

- 601 VP65 YZ pot 4 "frying pan": rim fragment 10YR 6/2  
coarse grey-brown with burnished black slip inside; incised with simple strokes, spirals, and connecting tangents; of mainland type as opposed to Cycladic (Renfrew 1972: 536); ill. Fossey 1969: 68 top right.
- 602 VP65 Z J1 jar: rim fragment 5YR 7/3  
fine dark red, unslipped but burnished; thick flaring rim; ill. Fossey 1969: 66 top left.
- 603 VP65 Z J10 jar: shoulder fragment 7.5YR 7/6  
fine orange-buff; pattern of small stamped triangles on shoulder, combined with deep incised lines and smaller, shallower incisions; ill. Fossey 1969: 66 top centre.
- 604 VP65 Z J11 jug: fragment of neck and shoulder  
10YR 6/1  
coarse grey with small black inclusions (similar to 608); incised lines in groups of three on shoulder; ill. Fossey 1969: 66 centre.
- 605 VP65 Z B2 bowl: rim fragment 10YR 7/4  
fine buff, with traces of smoothing lines on outside; heavy loop handle rising above rim; ill. Fossey 1969: 66 top right.
- 606 VP65 Z B3 bowl: rim fragment 10YR 7/3  
fine buff, with thin red slip (5YR 6/6) inside and out, burnished; flat-rimmed shallow bowl with a hole pierced a little below the rim; ill. Fossey 1969: 66 top right.

- 607 VP65 Z P1 "frying pan"?: rim fragment  
10YR 7/3  
  
coarse orange, unslipped, with a few black and dark red inclusions; decorated with impressed spirals and joining tangents, together with stamped triangles; possibly a bowl or pyxis rim, but if a "frying pan" it is of Syros type (Renfrew 1972: 528); ill. Fossey 1969: 66 bottom right.
- 608 VP65 Z P2 "frying pan": rim fragment 2.5Y 6/2  
  
coarse grey with small black or dark grey inclusions (similar to 604); decorated with impressed spirals, joining lines, and tiny stamped triangles; ill. Fossey 1969: 66 bottom right.
- 609 VP65 Z M1 ladle(?): bowl fragment 7.5YR 7/4  
  
fine pink, with good-quality dark red slip (2.5YR 4/6) covering the outer surface; d. 6; cf. Blegen 1928: 96 fig. 84.
- 610 VP65 Y B27 bowl: rim fragment 7.5YR 6/8  
  
semifine red with a few tiny black and white inclusions; a dull, dark red slip inside (2.5YR 7/6) and out (10R 6/6); a disorderly double row of deep point impressions along the flattened rim; d. 32, th. 0.9; cf. Goldman 1931: 111 fig. 146, 8.
- 611 VP65 Y P2 "frying pan": rim fragment 10YR 6/2  
  
coarse grey-brown, neither slipped nor burnished; decorated with radial strokes, deeply incised, on upper surface and along edge; of mainland type, as 601 (Renfrew 1972: 536); ill. Fossey 1969: 63 bottom right.
- 612 VP65 Y P1 "frying pan": rim fragment 2.5Y 6/2  
  
coarse grey-brown, with grey burnished slip outside; on the upper surface, incision forming three concentric circles, the inner and outer in zig-zag form, the middle of short radial strokes; of mainland type (Renfrew 1972: 536); ill. Fossey 1969: 63 bottom right.

- 613 VP65 Y M1 "scoop"(?): complete profile preserved  
10YR 6/2  
coarse red with large (c. 0.2) grey-brown inclusions;  
burnished inside and out; possibly rather a narrow-  
mouthed jug; ill. Fossey 1969: 63 bottom left  
(restored as a scoop).
- 614 VP65 Y J6 jar: rim fragment 10YR 7/3  
fine buff, neither slipped nor burnished; outturned  
lip; knob decoration applied on outside at constriction  
of neck; ill. Fossey 1969: 61 top right.
- 615 VP65 Y J1 small jar: rim fragment 7.5YR 8/4  
fine buff, with dark red burnished slip on the outside  
and over the lip to the inside of the rim; ill. Fossey  
1969: 61 top left
- 616 VP65 X B20 bowl: rim fragment 2.5Y 8/1  
fine buff, with burnished slip, dark red (2.5YR 4/6)  
inside and red-brown (5YR 5/6) outside; wide bowl  
with flattened rim and trumpet-ended handle; ill.  
Fossey 1969: 58 middle right.
- 617 VP65 X J19 small jar: profile preserved from rim  
to belly  
10YR 6/4  
fine buff-orange, unslipped but fire-blackened outside;  
high collar neck; ill. Fossey 1969: 56 lower left.
- 618 VP65 X J20 small jar: complete from neck down  
10YR 6/4  
fine buff-pink, with thin dark orange (2.5YR 6/8)  
matt slip outside; attachment for handle preserved  
on belly; ill. Fossey 1969: 56 lower middle.
- 619 VP65 X J21 small jar: complete from shoulder down  
2.5Y 8/2  
fine pale green, without slip or burnish; ill. Fossey  
1969: 56 lower right.



620 VP65 X J22 small jar: complete from base of  
neck down  
5YR 8/1

fine pale pink, varying to pale green, without slip  
or burnish; traces of shaping marks on lower exterior;  
ill. Fossey 1969: 56 lower right.

621 VP65 X M3 small "spoon": complete profile  
preserved  
7.5YR 7/4

fine pink, with red slip (2.5YR 6/6) inside and out;  
beginning of vertical ring handle preserved on rim;  
ill. Fossey 1969: 58 bottom left.

622 VP65 X M5 "fruitstand"(?)<sup>✓</sup>: central portion  
7.5YR 7/5

semifine orange with a few tiny dark red, and white  
(calcareous) inclusions; red matt slip (2.5YR 5/8)  
on the inner surface of the shallow side; vessel  
flares both upwards and downwards, with a double  
horizontal strap handle and incised slashes around  
constriction; probably six bored holes spaced around  
vessel on shallow side; ill. Fossey 1969: 58 bottom  
right.

623 VP65 X M4 lentoid pyxis: most of body preserved  
10YR 7/2

coarse grey-brown with some light-coloured inclusions;  
slightly flattened base, d. 8; traces of burning on  
outside; ill. Fossey 1969: 58 bottom middle.

4. ARCHAEOLOGICAL PROBLEMS TO BE INVESTIGATED  
AND REASON FOR CHOICE OF SAMPLES

A natural question arising from consideration of the great amount of pottery recovered during excavation of only a small part of the site is whether most of the pottery was manufactured locally or imported from other production centres. That some of it was of local manufacture is clearly shown by the presence of waster fragments, twisted pieces of pottery spoilt by overfiring, several of which were found in the rubbish dump at Vouliagméni. These useless pieces must have been made right at the site, as no one would bother importing or exporting them. If the composition of one of these pieces (e.g. sample 116) matched the composition of the bulk of the other sherds sampled, this would indicate that most of the pottery was of local manufacture. Most of the wasters are made of a black-speckled green fabric, but a couple of sherds which may also be wasters (421, 422) are grey and buff respectively, indicating that differing colours may imply either the existence of a variety of clay beds available to the local potters or the use of various firing techniques with the same clay(s) rather than necessarily different geographic origins.

Two other checks can be made to determine the chemical "fingerprint" of locally-made pottery. The first

is the composition of the natural soil, actually quite a good clay, found underneath the rubbish dump. Samples of this clay were analysed after being refined to various extents and fired to various temperatures (010-016). The second is the composition of some of the many lumps of hard earth found mostly in the destruction debris above the final EH II phase but also among the ruins of the small square structure. These lumps are very probably remains of the sun-dried mud-brick used as wall material above a stone foundation for these buildings. The large quantity required, simplicity of manufacture, and crude nature of these mud-bricks argue for their being made locally. Six mud-brick samples of various colours were analysed (201-206).

Having established the mean composition of Vouliagméni pottery, one can then tackle several other questions. Did the inhabitants of the Lake Vouliagméni site in EH I times, also make their own pottery from the same clay source(s), or did the local ceramics industry start only in EH II? Twenty-three samples of EH I pottery were analysed (601-623), including typical sherds from all three phases of occupation, and pieces of "frying pans" and of other unusual wares.

Can the locally-made pottery be assigned a certain fabric type such as "black-speckled green fabric" or "pink to red with dark grains", or at least a restricted range of colours? Pottery from an occupation level of the final

EH II phase (samples 151-160) was accordingly selected to span the range of common fabric types. Various fabric types were also sampled for several common shapes of pottery found in the rubbish dump (401-422).

The composition of objects of particular archaeological significance is also of interest in that specific pottery forms and decorative motifs can be assigned local provenance with a fair degree of certainty. The most important deposit was of course the group of vases found in their original positions within the small square structure (101-108). These objects were the best-preserved of any material from the excavation. The enigmatic nature of the building in which they were found makes information gathered from these associated finds particularly valuable. That two of the vases (107, 108) are unique increases the importance of knowing their provenance. The finer vases (301-304) from the smaller 1972 excavation site "B", and unusual pieces from the rubbish dump (111-115) are also of special archaeological interest.

Articles which are found to be imports can perhaps be assigned a specific origin by comparison of their trace-element composition patterns with those of later wares, published in the studies mentioned in section 1.3. This comparison with other composition data is especially important in the study of the Late Helladic and Archaic pottery (501-526). At Vouliagmeni both these periods seem to be represented

only by isolated buildings, making it highly unlikely that pottery manufacture was carried out locally. The sherds chosen for sampling were ones which could be easily identified and precisely dated, and some for which a geographic origin in Corinth can very safely be deduced on archaeological grounds. The latter, by their nature, provide yet another source of control.

## 5. EXPERIMENTAL PROCEDURE

The analytical procedures employed in this study were adapted from those of the Lawrence Berkeley Laboratory (Perlman and Asaro 1969) and the Brookhaven National Laboratory (Abascal et al. 1974). They were modified for use at McGill University with the help of Dr. O. Birgül, a visiting professor there during 1974.

### 5.1 Sampling

The pottery sherds were sampled in the Perakhóra museum during the summer of 1974. Most of them had previously been washed in dilute hydrochloric acid and rinsed in tap water. Solid tungsten carbide drill bits of 1.5 mm diameter were used to extract about 300 mg of sample in powdered form from various places along the edges of the sherd. This was accomplished in the following manner: an ordinary slow-speed (900 rpm) electric hand drill was fastened horizontally to the edge of a table. With the side of the drill bit, some edges of the sherd were ground clean in preparation for the actual sampling. After the bit had been rinsed with distilled water and acetone and then wiped clean, the hand-held sherd was pressed against it so that the rotating bit entered to a depth of 1 to 2 cm parallel to the sherd's surfaces. The pottery powder was

allowed to fall onto a clean index card, from which it was poured into a washed polyethylene sample vial with a snap top. Usually four or five holes resulted from the sampling.

## 5.2 Encapsulation and Irradiation

Quartz tubing of 3 mm inner diameter was cut into 5 cm lengths and sealed at one end. Each piece was then washed thoroughly in distilled water and acetone and left to dry overnight. About one hundred milligrams of pottery powder was weighed into the tube, which was then sealed, labelled with an indelible marking pen, wrapped in aluminum foil, and labelled again. The wrapped samples were then 2.5 cm long and 0.5 cm in diameter. They were sent in this form to Chalk River Nuclear Laboratories, where they were packed ten per self-serve capsule, and irradiated in the NRX reactor for 24 hours at a flux of about  $10^{13}$  neutrons per square centimeter per second. The samples were returned to this laboratory for activity measurements about a week after irradiation.

Empty tubes labelled and handled in the same way as the samples showed no significant interfering gamma radiation.

### 5.3 Standardization

Together with eight samples, two tubes containing a standard pottery prepared by Perlman and Asaro (1969) were packed as far apart as possible in each self-serve capsule. The composition of this standard pottery has been accurately determined, so that the calculation of trace element concentrations in the samples (see below, section 5.6) is greatly simplified. Problems of determining the neutron flux, the ratio of thermal to fast and epithermal neutrons, the irradiation time, and the neutron-capture cross-sections were eliminated, as was the necessity of knowing absolute gamma-ray intensities and detector efficiency for each radioactive species formed.

The Brookhaven team (Abascal et al. 1974) use as standards six United States Geological Survey rocks, which have been extensively analysed by many methods in many laboratories (Flanagan 1973). The composition of these standards is more accurately known than that of the Perlman-Asaro standard, but as only ten samples fit in each capsule under the irradiation conditions here employed, it was felt that the slight loss of absolute accuracy was justified by the greater number of samples which could be simultaneously analysed using the Perlman-Asaro standard.



#### 5.4 Gamma-ray Detection and Pulse-height Analysis

Immediately upon receipt, the samples were unpacked and taped to the Radiochemistry laboratory's standard sample holders in a reproducible position. Activity measurements were taken with the sample holder on shelf 2 (about 43 mm from the centre of the detector crystal), the samples for 4000 seconds each, the standards for 20,000 seconds. Measurements were retaken two to three weeks after that for 10,000 and 20,000 seconds respectively.

The gamma-ray detector used has the following characteristics: a 30 cm<sup>3</sup> lithium-drifted germanium crystal with a resolution of 2.8 keV at 1.33 MeV and a peak-to-Compton ratio of 16 to 1. The pulses were fed from the preamplifier through an amplifier to a Nuclear Data ND2200 pulse-height analyser. Dead time was on the order of 15% for the first activity measurement and 5% for the second. The resulting spectrum of gamma-ray energies was transferred automatically at the end of the measurement period onto magnetic tape in the form of 4096 channels of binary information, together with the four-digit "tagword" or identification number, the duration of the measurement, and the time of day at its end. Energy calibration of the system was achieved using standard sources of <sup>133</sup>Ba, <sup>137</sup>Cs, and <sup>60</sup>Co.

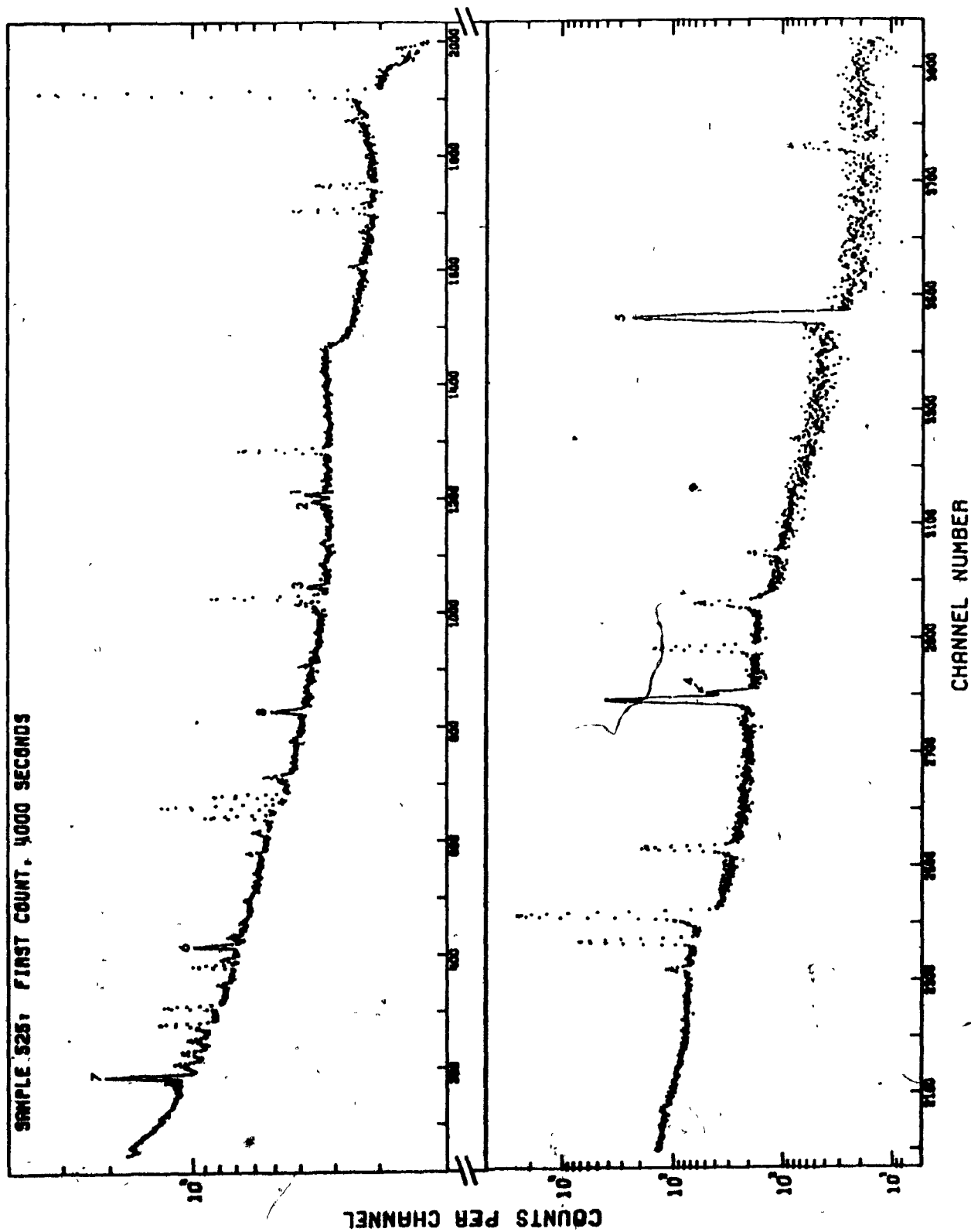
Typical spectra obtained from the first and second activity measurements are presented in Figure 4, (a) and (b) respectively.

FIGURE 4

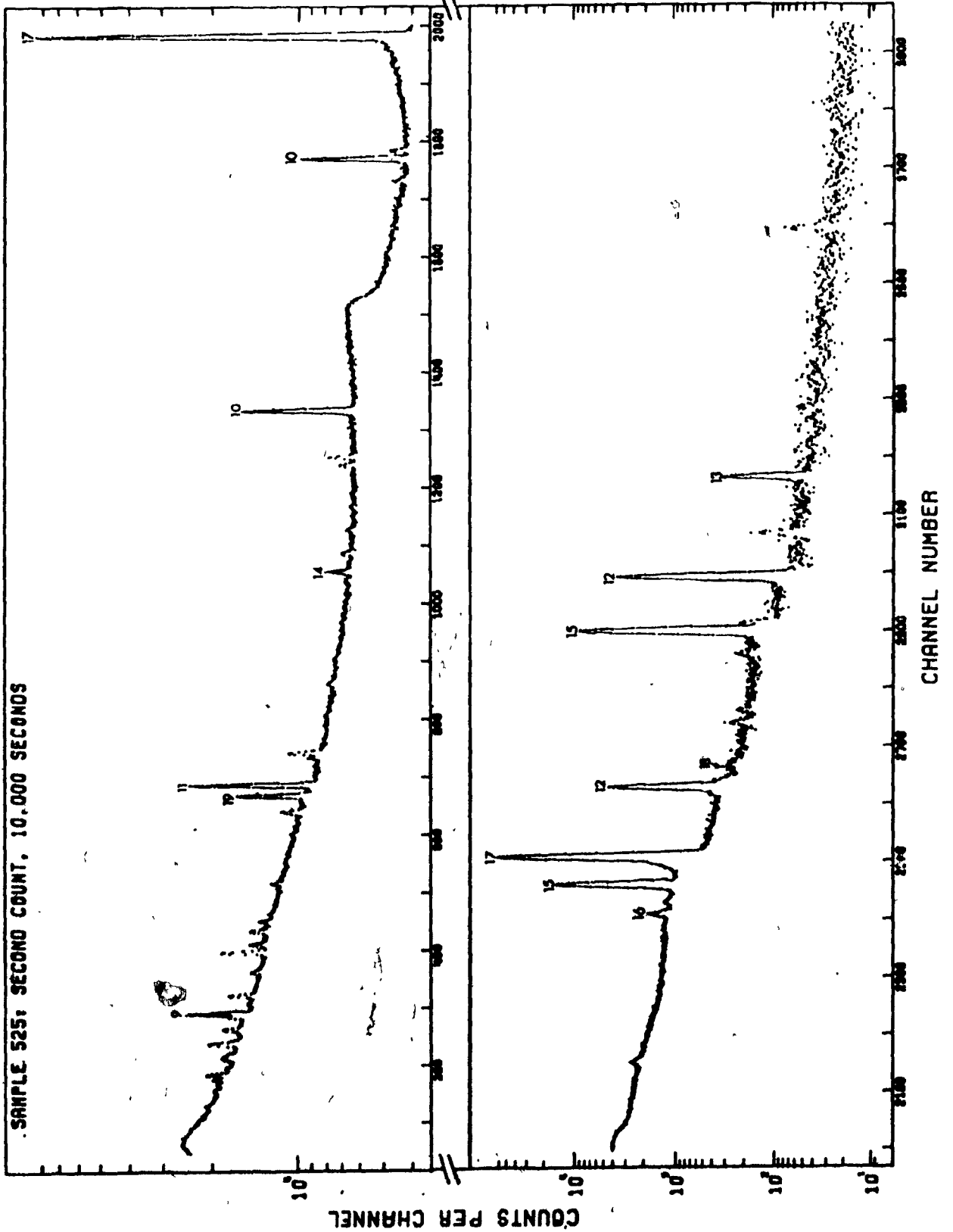
Typical gamma-ray spectra of samples, obtained from activity measurements made one and three weeks after irradiation respectively. Gamma-ray peaks used in the calculation of trace-element concentrations are numbered as follows:

- | (a)          | (b)          |
|--------------|--------------|
| 1. Antimony  | 9. Cerium    |
| 2. Arsenic   | 10. Cesium   |
| 3. Barium    | 11. Chromium |
| 4. Calcium   | 12. Cobalt   |
| 5. Lanthanum | 13. Europium |
| 6. Lutetium  | 14. Hafnium  |
| 7. Samarium  | 15. Iron     |
| 8. Ytterbium | 16. Rubidium |
|              | 17. Scandium |
|              | 18. Tantalum |
|              | 19. Thorium  |

SAMPLE 525, FIRST COUNT, 4000 SECONDS



SAMPLE 525: SECOND COUNT, 10.000 SECONDS



### 5.5 Spectrum Analysis

The magnetic tape was read and analysed using the computer program GAMANAL (Gunnink et al. 1968), slightly modified for use at McGill. This program scanned each spectrum to locate all the significant peaks, and then calculated the net area of each peak, resolving doublets and triplets where necessary. Energies were assigned to the peaks using a third-degree polynomial function fit to the energy calibration spectrum. The final result was a list of peaks, with channel number, peak height, area, energy, and percent standard deviation of the area. For each sample at the end of the output this information was reprinted in a table containing only the peaks of interest (selected by their assigned energies).

### 5.6 Determination of Trace-element Concentration

Before they could be compared, the sample and standard peak areas had to be corrected for decay time and for differences in weight and duration of activity measurement. In fact, the quantities compared were net specific activities (per hundred milligrams per 4K or 10K seconds, for the first and second measurements respectively), corrected to the midnight preceding the beginning of the series of measurements. The ratio of corrected sample activity to corrected standard activity was multiplied by the known

element concentrations in the standard (Perlman and Asaro 1971: 187) to give the element concentrations in the sample (see also section 1.2).

A list of the elements determined together with other relevant data is given in Table I.

#### 5.7 Discussion of Experimental Procedure

In principle, the usefulness of the analysis increases both with increasing number of elements determined and with increasing precision of these determinations. Of course, in practice compromises between these two factors are necessary.

The technique of neutron activation analysis is sensitive enough for the determination of about thirty or forty elements present down to trace amounts. Certain very common elements cannot be determined by this method, because they either do not activate well with thermal neutrons or have sufficiently short half-lives that they decay away almost immediately -- among these are silicon, oxygen, carbon, hydrogen, and aluminum. This is actually an advantage, as the above elements are the major constituents of most clays and pottery, are not useful as indicators of specific clay sources, and fortunately do not interfere with the determina-

TABLE I

Elements determined, with half-lives and gamma-ray energies of the radioactive species used in the determination of their concentrations with reference to Perlman-Asaro standard pottery. Half-lives and gamma-ray energies are taken from Wakat (1971); standard-pottery composition from Perlman and Asaro (1971: 187). Elements in the top half of the table are determined from the first activity measurement, the rest from the second.

Element	Determined from	Half-life (d=days, y=years)	Gamma-ray energies (keV)	Composition given by Perlman and Asaro for their standard pottery (ppm, except Fe in %)
Antimony	$^{122}\text{Sb}$	2.8 d	564.1	$1.71 \pm 0.05$
Arsenic	$^{76}\text{As}$	1.10 d	559.1	$30.8 \pm 2.2$
Barium	$^{131}\text{Ba}$	12 d	496.2	$712. \pm 32.$
Calcium	$^{47}\text{Ca}$	4.53 d	1297.1	--
Lanthanum	$^{140}\text{La}$	1.68 d	1596.2	$44.9 \pm 0.45$
Lutetium	$^{177}\text{Lu}$	6.7 d	208.4	$0.402 \pm 0.036$
Samarium	$^{153}\text{Sm}$	1.96 d	103.2	$5.78 \pm 0.12$
Ytterbium	$^{175}\text{Yb}$	4.21 d	396.1	$2.80 \pm 0.36$
Cerium	$^{141}\text{Ce}$	33 d	145.4	$80.3 \pm 3.9$
Cesium	$^{134}\text{Cs}$	2.05 y	604.6 795.8	$8.31 \pm 0.55$
Chromium	$^{51}\text{Cr}$	27.8 d	320.1	$115.1 \pm 3.8$
Cobalt	$^{60}\text{Co}$	5.26 y	1173.2 1332.5	$14.06 \pm 0.15$
Europium	$^{152}\text{Eu}$	12.7 y	1407.9	$1.291 \pm 0.034$
Hafnium	$^{181}\text{Hf}$	42.5 d	482.0	$6.23 \pm 0.44$
Iron	$^{59}\text{Fe}$	45 d	1099.3 1291.6	$1.017 \pm 0.012$ (%)
Rubidium	$^{86}\text{Rb}$	18.66d	1078.8	$70.0 \pm 6.3$
Scandium	$^{46}\text{Sc}$	83.9 d	889.2 1120.6	$20.55 \pm 0.33$
Tantalum	$^{182}\text{Ta}$	115 d	1188.9	$1.55 \pm 0.044$
Thorium	$^{233}\text{Pa}$	27 d	311.9	$13.96 \pm 0.39$

tion of other more sensitive elements. There are, however, trace elements of possibly greater value in characterizing clays, which also are not suitable for analysis by neutron activation: lead is the most important of these.

The week-long wait between the end of irradiation and the receipt of the samples prevented the determination in this study of various short-lived activated elements which are determined by other laboratories. Among these are manganese, potassium and sodium, all with half-lives of less than one day. Though they have occasionally been considered unreliable on geochemical grounds (see section 1.1), they would seem nevertheless to be essential in certain instances in distinguishing among very similar pottery groups (Bieber et al. 1975: 11).

Elements with half-lives between one day and two weeks suitable for neutron activation analysis include those given in the top half of Table I, and also gold, titanium, and uranium. Of these, titanium (measured from  $^{47}\text{Sc}$ ) and gold were not detected in this program of analysis. Uranium was detected only in about half of the samples, usually with a 40% standard deviation, and so was not reported. The remaining eleven elements in Table I were determined from the second activity measurements, made three to four weeks after irradiation. By this time measurements of longer duration could be made, and as the high background activity due to the



shorter-lived radioactive species had died down, the longer-lived activated elements could be more accurately determined. Values for nickel (measured from  $^{58}\text{Co}$ ) and zinc content are also occasionally reported by the Lawrence Berkeley Lab (Perlman and Asaro 1969) but these elements were not detected in the present study.

Calcium is an element only weakly activated in a neutron flux. However, it occurs in some ceramics as a major constituent of up to 20% by weight, in which case it can be easily detected. Unfortunately, the Perlman-Asaro standard pottery contains no calcium, so that indirect standardization was used. The magnitude of the 1297-keV peak of  $^{47}\text{Ca}$  was compared with that of the 1291-keV peak of  $^{59}\text{Fe}$ , both corrected for decay to seven days after irradiation. To arrive at an absolute value for calcium concentration, a sample tube containing known amounts of standard pottery and of anhydrous calcium oxide was irradiated. A comparison of the magnitudes of the calcium and iron peaks in that sample revealed that peaks of equal size indicated a calcium content of 15.9%, with a standard deviation of 12% of that value. The precision of this value was sufficient for the purposes of this study. The final results are presented in Table II.

#### 5.8 Estimation of Analytical Precision

The ideal way to estimate the precision of the

TABLE II

Trace-element concentrations of the pottery  
samples from Lake Vouliagméni, Perakhóra,  
Central Greece.

TABLE II TRACE-ELEMENT CONCENTRATIONS OF THE POTTERY SAMPLES FROM LAKE VOULIAGHENI, PERAKHORA, CENTRAL GREECE

ALL VALUES GIVEN IN PARTS PER MILLION EXCEPT CA AND FE, GIVEN IN PERCENTAGE  
A ZERO ENTRY INDICATES THAT AN ELEMENT WAS NOT DETECTED IN A PARTICULAR SAMPLE; A BLANK, THAT IT WAS NOT DETERMINED  
THE COLOUR NOTATION IS EXPLAINED IN SECTION 3.1

ID	COLOUR	FABRIC	FORM	RB	CS	CA(%)	BA	SC	LA	CE	SN	EU	YB	LU	TH	HF	TA	CR	FE(%)	CO	AS	SB
010	7 7/2	MEDIUM	CLAY	88.	7.61	14.5	181.	13.1	19.0	36.3	3.60	0.88	1.92	0.284	7.2	2.67	0.44	163.	3.13	19.2	6.6	0.63
011	6 6/4	MEDIUM	CLAY	73.	5.96	15.6	212.	13.8	21.2	41.2	3.92	0.73	2.43	0.333	6.0	3.26	0.41	139.	3.24	17.2	7.1	0.64
012	6 7/4	SEMIFINE	CLAY	98.	6.77	21.1	239.	15.7	24.8	48.3	4.65	1.10	2.44	0.341	8.5	3.47	0.72	220.	3.93	24.3	8.1	0.92
013	6 7/3	SEMIFINE	CLAY	78.	7.49	20.1	208.	15.7	25.8	47.6	4.38	1.01	2.45	0.327	8.0	3.33	0.41	215.	3.92	24.3	9.6	0.75
014	8 5/5	SEMIFINE	CLAY	67.	8.51	20.7	256.	15.8	24.0	45.1	4.34	1.02	2.43	0.324	8.0	3.43	0.54	200.	3.91	25.1	8.8	0.97
015	5 5/8	EXTRAFINE	CLAY	169.	16.55	0.0	206.	22.5	27.6	51.2	4.24	1.06	2.43	0.374	9.2	3.45	0.66	267.	6.31	37.3	15.5	1.10
016	7 5/6	EXTRAFINE	CLAY	150.	12.03	11.2	266.	22.7	27.5	52.0	4.07	0.97	2.44	0.331	10.7	3.46	0.64	268.	6.36	39.0	13.5	1.16
101	6 7/5	MEDIUM	SAUCER	56.	6.03	8.9	737.	21.2	22.0	43.6		0.98	2.30	0.336	6.1	3.16	0.21	261.	5.26	39.2	12.7	0.93
102	7 7/3	SEMIFINE	SAUCER	25.	4.25	8.0	1352.	19.7	23.1	45.0		1.00	2.13	0.308	7.3	3.40	0.42	556.	5.18	45.8	11.0	0.73
103	9 8/2	FINE	SAUCEBOAT	20.	5.92	10.3	737.	20.7	26.5	58.1		0.52	2.35	0.328	9.6	4.31	0.44	277.	5.15	26.9	4.8	1.43
104	5 8/4	SEMIFINE	SAUCEBOAT	14.	4.20	17.5	1655.	15.0	20.4	39.0		0.92	1.89	0.251	5.6	2.59	0.24	424.	3.97	36.6	6.9	0.64
105	6 7/4	COARSE	BOWL	48.	3.80	6.0	1086.	22.6	18.7	38.1		1.03	2.43	0.350	5.7	3.92	0.61	370.	5.07	32.0	14.4	1.00
106	7 7/4	COARSE	BOWL	56.	5.70	5.12	109.	18.3	33.0	66.0	5.43	0.89	2.53	0.378	11.8	5.04	0.73	185.	4.78	28.5	0.0	0.69
107	6 7/4	MEDIUM	SALT POT	56.	4.62	9.2	733.	19.6	20.4	40.1		1.06	2.41	0.312	6.7	3.48	0.28	385.	4.70	33.5	5.8	0.56
108	5 5/5	MEDIUM	RAM VASE	77.	4.11	7.5	1502.	18.6	23.2	44.7	3.64	0.99	2.18	0.321	7.3	3.64	0.74	532.	5.14	37.0	6.8	0.79
111	6 7/4	SEMIFINE	SHERD	22.	6.41	14.4	466.	16.4	21.7	39.1		0.11	1.97	0.296	6.0	2.92	0.36	260.	4.10	29.9	8.1	0.68
112	6 7/4	SEMIFINE	BOWL BASE	118.	5.50	12.0	1113.	18.1	23.8	45.5		1.02	2.10	0.288	7.3	2.97	0.39	364.	4.65	34.8	10.2	0.89
113	7 7/1	SEMIFINE	SEALINGS	89.	6.16	17.1	470.	14.4	18.5	34.6		0.84	1.82	0.247	5.3	2.53	0.41	278.	3.65	29.1	8.0	0.56
114	7 7/3	SEMIFINE	FISH VASE	87.	7.67	17.5	506.	16.3	23.5	39.8	3.40	0.92	2.59	0.281	6.5	2.47	0.43	306.	4.08	29.7	0.0	0.87
115	7 7/3	SEMIFINE	TILE	78.	5.45	12.8	1003.	17.0	21.1	40.2		1.01	2.22	0.283	6.7	3.04	0.74	254.	4.23	25.0	7.2	0.77
116	8 8/2	SEMIFINE	WASTER	23.	8.29	16.8	171.	18.1	21.4	38.2		0.99	2.02	0.270	7.4	2.95	0.25	380.	4.56	33.9	5.8	0.74
151	9 5/2	MEDIUM	BOWL(?)	23.	9.18	14.8	856.	15.6	25.4	46.8	4.27	1.10	2.62	0.391	8.0	3.53	0.64	217.	3.90	24.8	7.4	0.62
152	8 7/2	SEMIFINE	JAR	49.	7.25	8.3	633.	23.8	26.4	53.6	4.75	1.17	2.69	0.350	9.1	3.96	1.23	527.	6.00	42.6	5.6	0.71
153	9 5/1	SEMIFINE	JAR(?)	27.	7.34	11.9	566.	18.9	25.4	50.1	4.44	1.08	2.68	0.345	8.9	4.02	0.59	232.	4.70	27.1	9.4	0.74
154	6 7/4	SEMIFINE	BOWL	45.	3.64	7.8	2216.	20.4	19.6	37.1	4.03	1.00	2.45	0.330	6.2	3.39	0.51	131.	4.92	30.0	60.7	1.92
155	5 6/4	SEMIFINE	BOWL	98.	4.58	1.9	286.	21.9	22.4	47.9	4.97	1.24	4.00	0.499	7.8	5.63	0.58	102.	4.59	19.2	9.1	1.87
156	7 7/4	COARSE	BOWL	65.	2.30	0.8	1112.	19.7	18.9	42.2	4.29	1.06	3.09	0.528	5.9	5.01	0.75	238.	4.09	23.4	7.8	1.08
157	6 6/4	COARSE	BOWL	115.	3.20	2.1	1065.	22.5	21.5	46.2	5.06	1.28	3.15	0.478	6.6	4.83	0.56	210.	4.66	21.3	17.6	1.62
158	7 6/3	COARSE	BOWL	55.	2.87	5.1	1109.	23.6	26.2	51.9	5.72	1.44	3.78	0.547	7.5	5.28	0.70	209.	4.75	24.4	11.0	1.37
159	6 6/4	COARSE	BOWL	67.	4.09	4.5	479.	20.2	23.6	47.2	5.08	1.23	3.20	0.495	7.8	5.66	0.77	164.	4.44	23.0	8.7	1.53
160	9 7/2	FINE	SAUCEBOAT	68.	0.90	7.6	1328.	26.8	32.9	69.0	5.32	1.40	3.02	0.388	12.6	3.85	1.12	292.	6.42	36.7	11.8	0.70
201	5 7/2	SEMIFINE	MUDBRICK	27.	5.69	13.7	951.	15.2	22.3	46.1	4.12	1.10	2.47	0.298	8.4	3.85	0.44	242.	3.81	21.6	8.8	0.84
202	6 7/4	FINE	MUDBRICK	97.	7.05	10.3	609.	12.6	19.5	37.2	3.46	0.83	2.03	0.300	6.5	3.36	0.59	177.	3.08	18.8	7.8	0.73
203	7 8/3	MEDIUM	MUDBRICK	81.	3.78	7.8	785.	21.5	22.3	45.5	4.68	1.19	2.66	0.407	7.3	4.27	0.61	474.	4.96	32.9	13.0	1.13
204	8 7/2	SEMIFINE	MUDBRICK	39.	5.12	14.3	1238.	17.7	22.8	44.9	4.11	1.05	2.28	0.355	7.2	3.57	0.47	350.	4.47	30.3	9.3	0.83
205	9 8/2	SEMIFINE	MUDBRICK	59.	3.53	8.6	864.	24.0	20.6	43.8	4.23	1.17	2.44	0.336	6.5	3.41	0.46	429.	5.44	41.5	5.5	0.80
206	6 7/4	SEMIFINE	MUDBRICK	83.	8.82	19.9	748.	12.0	19.2	39.6	3.35	0.79	1.67	0.230	6.1	2.50	0.46	169.	3.07	22.2	5.2	0.64
301	7 7/4	SEMIFINE	JUG	42.	8.65	13.0	1232.	15.6	38.8	65.0		1.68	3.03	0.422	11.1	4.83	1.41	330.	4.99	26.3	25.2	0.93
302	7 7/3	FINE	SAUCER	70.	4.75	9.2	902.	21.1	23.5	47.9	4.64	1.20	2.53	0.349	9.1	3.80	0.77	501.	5.32	37.7	6.4	0.73
303	6 7/4	SEMIFINE	SAUCEBOAT	14.	1.38	6.5	1513.	25.1	24.4	53.3	4.81	1.23	2.89	0.373	7.8	3.41	0.72	539.	6.09	45.9	5.6	0.73
374	7 7/3	SEMIFINE	ASKCS	72.	2.89	0.0	1450.	22.2	33.9	69.4	5.30	1.25	2.81	0.367	10.3	3.78	0.79	462.	5.78	38.4	4.8	0.67
401	6 6/4	COARSE	PLATE	74.	4.72	5.6	299.	19.7	20.0	40.0	3.48	0.95	1.94	0.296	6.2	2.87	0.56	110.	5.04	48.9	4.2	0.82
402	6 7/6	MEDIUM	PLATE	78.	5.99	17.3	560.	17.9	18.6	35.2	3.53	0.87	2.08	0.264	5.9	2.59	0.47	215.	4.14	29.2	6.3	0.78
403	3 7/4	SEMIFINE	PLATE	76.	5.63	14.3	509.	12.6	17.4	32.2	3.12	0.82	1.62	0.214	5.2	2.01	0.76	291.	3.38	29.2	7.2	0.65
404	7 7/4	SEMIFINE	PLATE	68.	4.32	16.5	730.	13.4	20.5	36.1	3.64	0.92	1.90	0.266	6.2	2.65	0.25	169.	3.38	25.3	7.1	0.85
405	8 7/2	COARSE	PLATE	107.	8.07	6.2	385.	23.4	38.0	69.2	8.71	2.39	5.88	0.710	8.8	5.88	0.60	122.	4.38	19.6	0.0	2.26
406	7 7/3	MEDIUM	PLATE	79.	8.64	10.5	450.	14.4	21.1	40.7	4.08	1.07	2.60	0.367	6.4	3.44	0.51	151.	3.48	19.6	12.5	1.85
407	7 7/3	MEDIUM	PLATE	103.	6.60	11.3	445.	19.5	26.5	46.5	5.11	1.31	2.72	0.394	7.4	3.75	0.50	416.	4.74	33.9	8.1	0.96
408	7 5/2	SEMIFINE	BOWL RIM	109.	7.76	1.3	281.	17.9	25.2	52.6	4.36	1.02	2.41	0.395	10.0	5.11	0.56	428.	4.79	36.5	8.0	0.72
409	6 7/6	MEDIUM	BOWL RIM	83.	4.52	8.9	582.	16.6	19.7	37.4	3.47	1.00	2.05	0.279	6.6	2.82	0.44	161.	3.85	24.5	6.9	0.76
410	7 8/2	MEDIUM	BOWL RIM	36.	6.00	15.7	465.	15.9	24.4	42.0	4.32	1.14	2.65	0.363	7.4	3.40	0.58	182.	3.97	24.4	11.5	1.46

TABLE II (CONTINUED)

ID	COLOUR	FABRIC	FORM	RB	CS	CA(X)	BA	SC	LA	CE	SH	EU	YB	LU	TH	HF	TA	CR	FE(X)	CO	AS	SB
411	6 6/2	COARSE	BOWL RIM	82.	3.90	5.2	332.	20.0	17.5	61.5	4.27	1.23	3.64	0.557	7.9	5.16	0.55	95.	4.07	16.5	5.2	1.82
412	6 6/4	COARSE	BOWL RIM	120.	6.42	4.3	373.	23.0	28.2	57.0	7.29	2.01	5.22	0.790	9.0	6.76	0.72	92.	4.36	16.5	20.2	2.82
413	6 8/2	SEMI FINE	BOWL RIM	51.	4.20	16.4	940.	18.0	22.9	41.6	4.23	1.03	2.19	0.369	7.4	2.84	0.67	331.	4.49	32.1	13.6	0.84
414	6 7/4	MEDIUM	PAN RIM	108.	8.05	14.0	584.	15.8	21.0	39.2	3.64	0.81	1.64	0.304	7.0	2.35	0.56	363.	4.18	33.9	0.0	0.64
415	7 7/2	MEDIUM	JAR RIM	108.	7.17	13.5	796.	19.5	24.3	46.4	4.25	0.98	2.22	0.339	8.3	2.75	0.81	350.	4.91	37.7	6.6	1.70
416	7 7/2	MEDIUM	JAR RIM	94.	8.70	12.6	743.	18.5	22.0	33.6	4.15	1.10	2.33	0.324	6.7	3.16	0.58	175.	4.33	31.8	38.8	1.68
417	8 7/2	FINE	SAUCER	55.	11.54	13.2	291.	20.2	29.5	56.0	4.92	1.17	2.48	0.329	9.7	3.36	0.56	293.	5.09	34.2	6.2	0.93
418	9 8/1	FINE	JAR RIM	114.	6.05	13.0	481.	21.8	32.4	62.1	5.44	1.23	2.74	0.404	11.6	3.73	0.86	260.	5.42	33.2	0.0	1.01
419	6 7/4	MEDIUM	BOWL RIM	91.	6.23	13.4	344.	15.2	23.6	44.2	4.36	1.06	2.67	0.350	7.7	3.67	0.98	198.	3.88	27.5	4.9	0.61
420	6 7/4	SEMI FINE	BOWL RIM	91.	10.60	16.1	260.	13.1	19.4	34.3	3.67	0.85	2.63	0.321	6.0	2.53	0.37	171.	3.25	22.4	7.2	0.90
421	7 6/1	FINE	BOWL RIM	116.	8.91	2.2	571.	15.3	40.9	79.7	6.38	1.55	3.19	0.417	11.5	6.25	1.44	330.	4.31	36.0	12.3	1.13
422	7 7/4	MEDIUM	BOWL RIM	74.	7.40	15.4	489.	16.3	17.6	34.5	3.35	0.68	1.79	0.253	5.6	2.42	0.55	148.	3.90	25.6	39.3	1.17
501	8 7/1	FINE COR	SKYPHOS	72.	5.50	6.1	1874.	26.5	36.4	61.4	5.23	1.32	2.67	0.414	12.7	3.38	0.40	297.	6.42	37.9	0.0	1.03
502	7 8/3	FINE COR	SKYPHOS	139.	8.45	10.1	1249.	24.1	34.6	66.5	4.70	1.29	2.82	0.472	12.1	3.73	0.95	288.	6.15	33.8	0.0	0.48
503	6 7/7	FINE COR	MIN-BOWL	174.	10.50	7.2	1014.	24.3	38.5	70.6	4.95	1.22	3.00	0.427	11.8	3.60	1.11	283.	6.04	31.9	0.0	0.00
504	7 8/4	FINE COR	SKYPHOS	182.	9.08	11.2	1132.	23.0	36.1	65.9	5.94	1.20	2.75	0.390	11.4	3.28	0.56	271.	6.06	32.2	0.0	1.76
505	7 8/3	FINE COR	PYXIS LID	165.	9.90	9.2	782.	24.7	35.9	65.9	5.36	1.40	2.72	0.428	11.7	3.70	0.84	276.	6.28	34.0	0.0	0.64
506	6 7/5	FINE COR	SKYPHOS	176.	13.94	5.6	842.	26.7	37.8	79.4	5.84	1.39	3.05	0.432	13.0	4.35	1.23	631.	6.83	43.1	0.0	1.49
507	9 7/1	FINE MYC	SPOUT	70.	9.16	11.8	739.	26.5	38.4	73.3	5.32	1.45	3.13	0.450	12.8	4.51	1.06	281.	6.61	32.2	0.0	0.00
508	7 8/3	FINE MYC	SHERD	137.	7.31	10.0	1026.	24.6	39.9	69.7	6.16	1.39	3.09	0.476	12.1	4.47	0.91	320.	6.19	32.9	0.0	1.15
509	6 7/4	FINE MYC	KYLIX	157.	9.80	8.4	885.	23.3	33.9	67.1	5.89	1.22	2.72	0.372	11.6	2.76	0.42	241.	5.80	29.0	0.0	0.92
510	7 7/1	FINE EM	SHERD	161.	21.70	0.0	985.	23.7	33.4	62.5	4.93	1.23	2.75	0.385	12.1	2.99	0.79	285.	5.76	34.8	0.0	1.07
511	8 8/2	FINE COR	SKYPHOS	161.	9.82	10.6	757.	22.5	36.2	66.1	6.13	1.34	2.84	0.413	12.2	3.50	0.82	251.	5.57	30.1	0.0	1.13
512	6 8/4	FINE COR	BASE	132.	8.93	9.3	835.	23.3	35.5	64.4	5.57	1.31	2.97	0.452	12.7	3.36	0.99	278.	5.70	32.6	0.0	0.56
513	7 7/3	FINE COR	PYXIS LID	145.	7.93	7.0	662.	18.7	31.0	56.7	4.49	1.17	2.57	0.372	9.5	4.03	0.85	301.	4.77	29.2	9.6	1.05
514	6 7/4	FINE COR	PYXIS LID	97.	6.35	9.5	1030.	20.7	34.2	54.3	5.13	1.32	2.96	0.413	10.9	3.40	0.85	254.	5.45	32.8	18.7	0.90
516	6 7/4	FINE MYC	KYLIX	136.	7.50	8.7	1086.	22.5	35.3	64.4	5.47	1.31	3.67	0.417	12.1	3.75	1.05	275.	5.61	30.9	0.0	0.51
517	7 8/4	FINE MYC	BOWL	122.	8.09	9.9	732.	22.4	35.6	64.5	5.59	1.29	2.68	0.447	11.4	3.13	0.43	257.	5.53	36.6	0.0	1.10
518	6 8/5	FINE MYC	BOWL	143.	6.54	7.7	1208.	19.7	31.6	61.3	5.27	1.23	2.78	0.375	10.2	4.23	0.86	258.	5.31	27.8	0.0	1.05
519	8 7/3	FINE MYC	SHERD	86.	5.42	7.6	1090.	21.4	30.2	67.0	4.86	1.37	2.92	0.419	12.4	4.66	1.02	240.	5.79	33.6	0.0	1.43
520	7 8/3	FINE MYC	BOWL	135.	5.75	8.5	1154.	21.3	33.5	63.0	5.86	1.25	2.70	0.386	11.3	4.32	0.66	272.	5.50	26.0	0.0	0.91
521	6 7/4	FINE COR	LAMP-SPOUT	206.	12.20	0.0	913.	24.5	35.6	73.1	6.57	1.44	3.23	0.439	12.0	4.05	0.95	632.	6.20	37.4	47.1	1.61
522	6 8/1	FINE MYC	SHERD	130.	9.02	9.2	744.	22.3	34.1	67.4	5.30	1.23	2.45	0.466	11.4	4.62	0.90	237.	5.53	27.0	5.9	0.91
523	6 8/4	FINE MYC	SHERD	155.	9.36	7.1	759.	22.1	33.7	53.0	5.14	1.22	2.55	0.366	11.5	3.94	0.76	243.	5.51	27.0	6.7	0.96
524	6 7/4	FINE MYC	HANDLE	139.	10.52	0.0	714.	22.0	31.4	54.1	5.17	1.10	2.36	0.347	11.5	3.54	0.63	271.	5.60	25.3	4.2	0.90
525	6 8/3	FINE MYC	BOWL	179.	29.63	8.8	729.	24.9	36.6	60.1	5.00	1.17	3.09	0.414	12.3	3.54	1.02	281.	5.40	31.4	15.8	1.84
526	8 8/2	FINE MYC	BOWL(?)	51.	8.91	13.4	2046.	20.7	31.5	55.0	4.72	1.21	2.79	0.356	10.7	3.32	0.76	299.	5.45	28.6	0.0	0.95
601	7 6/2	COARSE	FRYINGPAN	67.	4.56	5.2	839.	19.6	27.8	61.3	6.26	1.56	3.50	0.713	9.0	5.25	2.08	102.	4.02	86.4	19.3	1.92
602	5 7/3	FINE	JAR	68.	3.55	2.0	1110.	21.8	23.0	52.0	2.84	1.22	2.68	0.371	5.6	5.10	1.16	99.	5.11	22.6	7.4	0.43
603	6 7/5	FINE	JAR	128.	9.14	11.0	758.	21.4	32.3	59.3	5.30	1.12	2.55	0.399	11.1	3.58	0.84	233.	5.16	25.2	12.1	0.80
604	7 6/1	MEDIUM	JUG	122.	5.10	2.3	918.	24.2	24.6	54.7	4.63	1.15	3.24	0.461	8.1	4.49	0.94	141.	5.41	34.5	9.0	0.87
605	7 7/4	FINE	BOWL	77.	5.07	1.8	878.	13.4	32.8	66.2	5.37	1.22	2.51	0.370	11.6	5.52	1.17	258.	3.93	30.2	13.8	0.72
606	7 7/3	FINE	BOWL	156.	7.67	8.6	714.	23.1	33.4	65.0	5.52	1.39	2.99	0.404	11.6	3.36	1.07	243.	5.62	25.9	9.2	0.72
607	7 7/3	MEDIUM	FRYINGPAN	94.	7.21	2.2	820.	15.6	30.6	60.9	5.08	1.26	2.85	0.365	9.6	3.13	1.02	335.	4.21	32.0	9.4	0.82
608	8 5/2	MEDIUM	FRYINGPAN	89.	6.26	5.6	862.	20.4	26.9	59.5	5.65	1.49	3.44	0.491	8.7	4.40	0.72	142.	4.40	23.8	13.3	1.07
609	6 7/4	FINE	LADLE(?)	154.	8.71	11.0	596.	24.8	35.8	69.3	5.26	1.37	2.84	0.435	12.8	4.10	0.54	254.	5.96	32.9	10.3	1.24
610	6 6/8	SEMI FINE	BOWL	116.	6.01	6.4	785.	20.8	31.6	61.1	5.04	1.24	2.57	0.387	10.4	3.16	0.85	209.	5.27	26.4	11.8	0.98
611	7 6/2	COARSE	FRYINGPAN	51.	3.94	4.1	1250.	21.0	17.8	39.0	4.04	1.06	3.02	0.430	6.1	4.16	0.49	104.	4.48	14.0	17.6	1.39
612	9 6/2	COARSE	FRYINGPAN	74.	5.17	6.1	446.	18.8	24.3	46.8	4.61	1.05	2.59	0.381	7.5	3.76	0.61	94.	3.88	17.8	11.7	0.65
613	7 5/2	COARSE	SCOOP(?)	108.	6.80	6.8	783.	25.1	24.5	50.6	4.39	1.22	2.47	0.348	7.9	3.26	0.39	203.	5.95	32.8	14.9	0.60
614	7 7/3	FINE	JAR	124.	6.82	7.2	1190.	19.0	30.6	59.6	4.97	1.23	2.53	0.387	10.3	3.40	0.99	239.	4.98	25.0	10.6	0.74
615	6 8/4	FINE	JAR	144.	9.46	9.2	768.	22.4	33.2	68.0	5.33	1.24	2.75	0.384	11.5	3.69	0.98	248.	5.28	27.2	7.8	1.01
616	8 8/1	FINE	BOWL	53.	9.10	12.4	364.	21.8	31.9	62.3	5.17	1.24	2.52	0.389	11.6	3.89	1.19	236.	5.28	29.2	5.3	0.82
617	7 6/4	FINE	JAR	179.	8.23	3.8	936.	21.6	28.8	59.7	4.69	1.11	2.58	0.365	12.4	3.63	1.40	282.	6.45	26.4	41.3	1.09
618	7 5/4	FINE	JAR	168.	8.25	3.8	639.	22.2	31.4	66.3	4.63	1.08	2.88	0.366	13.2	4.67	1.04	271.	5.46	32.0	23.8	1.09
619	9 8/2	FINE	JAR	134.	6.94	9.1	675.	22.6	32.2	62.6	5.26	1.20	2.88	0.413	11.2	4.50	0.98	242.	5.42	28.2	5.0	0.67
620	5 8/1	FINE	JAR	89.	4.97	8.9	610.	23.8	34.8	67.7	5.45	1.28	2.92	0.380	12.5	3.55	0.94	245.	5.49	29.4	7.6	0.75
621	6 7/4	FINE	SPOON	154.	23.00	9.0	535.	22.4	30.6	55.7	5.05	1.11	2.56	0.384	11.0	3.56	0.84	306.	5.19	30.4	11.0	1.30
622	6 7/5	SEMI FINE	FRUITSTAND	109.	6.02	10.3	409.	17.8	28.4	54.2	4.24	1.04	2.26	0.337	11.0	3.20	1.05	214.	4.42	32.0	9.5	0.89
623	7 7/2	COARSE	PYXIS	96.	4.32	2.4	652.	16.0	27.5	59												

analytical method would have been to analyse the same pottery sample about a dozen times during the program of analysis and then, for each element determined, to calculate the standard deviation of the concentration values obtained. Limitations of space within the irradiation capsules made this procedure less appealing, so that instead almost the same information was obtained using the Perlman-Asaro pottery standards. Originally, two standards had been placed in every capsule to act as a check on the uniformity of the neutron flux during irradiation. Since almost all the possible sources of error affected the standards to the same extent as they affected the samples, the standards were used for estimation of analytical precision.

Possible sources of error were due to several factors. During the irradiation itself, only non-uniformity of the neutron flux and self-shielding within the capsule could have caused the sample and standard to receive differing neutron doses. Slight variations in the position of sample tubes during activity measurements, together with the inherent uncertainty of these measurements due to the statistical nature of radioactive decay, also contributed to the total uncertainty. A third possible source of error was the weighing of the pottery powder into the tubes.

The treatment accorded to the sample and standard pottery tubes differed only in the duration of their activity.

measurements. Because for a given sample the precision of an activity measurement is directly proportional to the square root of its duration, measurement periods for the standards were several times longer than for the samples. Therefore, to the estimated precision calculated from the pairs of pottery standards was added a factor resulting from the shorter measurements of sample activity.

The actual calculations were done as follows: for each element, the pair of activity values from the pottery standards (corrected for differences in weight and interval between irradiation and measurement) was used in the usual formula for estimating the standard deviation of a small statistical sample (e.g., Bevington 1969):

$$s^2 = \frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2 \quad 5.8 - I$$

where  $s$  is the standard deviation,  $N$  the number of observations (2 in this case),  $x_i$  the value of the  $i$ 'th observation, and  $\bar{x}$  the mean value. Expressed as a percentage of the mean value, for  $N = 2$  this formula simplifies to:

$$s = 100\% \times \frac{\sqrt{\frac{1}{2} (x_1 - x_2)^2}}{\bar{x}} \quad 5.8 - II$$

This standard deviation was averaged for each element over the total of 17 capsules used in this programme of analysis. The average represented the contribution to the total uncertainty of all factors except the shorter activity measure-

ment of the samples.

This latter factor was estimated using values of activity-measurement uncertainty taken from the results of the spectrum-analysis program. Since these values varied slightly, increasing as the delay between irradiation and measurement increased, averages were taken over the 16 samples in two capsules irradiated simultaneously and analysed consecutively. Expressed in percentage form for each element, the squares of these standard deviations were added to the squares of the ones calculated above, and the square root of the sum was taken. (The sum of squares rather than the direct sum was taken because only variances, or squares of standard deviations, can be directly added.) The final uncertainties are given in Table III.

Table III gives the uncertainty in the reported values for elemental concentrations, relative to the composition of the Perlman-Asaro standard pottery. In fact, the reported values for that pottery are accompanied by their own standard errors. For the purpose of internal comparisons among various samples analysed in this project, the values in Table III are the correct uncertainties. For comparison with pottery analysed using other standards, or analysed by methods other than neutron activation, the uncertainties reported by Perlman and Asaro must be added to those given

TABLE III

AVERAGE ANALYTICAL PRECISION  
FOR ELEMENTS DETERMINED (IN PERCENTAGE)

Rb	18.1	Lu	6.1
Cs	7.2	Th	6.2
Ca	9.1	Hf	11.1
Ba	27.0	Ta	20.3
Sc	2.4	Cr	3.7
La	3.2	Fe	2.2
Ce	5.4	Co	2.5
Sm	3.2	As	17.7
Eu	5.1	Sb	21.6
Yb	6.5		



in Table III. For the element calcium, not present in the standard pottery, the standard deviation value of 11% arising from the measurement of the  $^{47}\text{Ca}$  and  $^{59}\text{Fe}$  activities in the special sample tube irradiated as a calcium standard (see section 5.7) is to be added to the value quoted in Table III if comparison with pottery analysed elsewhere is desired.

## 6. RESULTS AND DISCUSSION

### 6.1 Theory of Grouping Procedures

In the form of Table II, the results of over one hundred pottery analyses reveal very little of the variety of typical ceramic compositions found at the Vouliagmeni site. Had only a few analyses been done or only a couple of elements determined, visual inspection of Table II could have sufficed to extract all the information contained in the data.

The use of computerized data processing is made necessary by the requirement that the results be objective, reproducible, and quickly obtained. In this study two approaches were used: cluster analysis and multivariate statistics. The initial formation of groups by the clustering of individual samples, followed by the refinement of these groups using discriminant analysis, was found to be the most efficient means of handling the data.

#### 6.1.1 Cluster Analysis

The set of techniques known collectively as cluster analysis was developed in the late 1950's by mathematical biologists who wanted to derive objective classifications of specimens or species using as much morphological, physiological,

and genetic information from each one as possible (Sokal and Sneath 1963). These methods were soon applied also by archaeologists to the classification of artifacts, at first by form (Hodson, Sneath and Doran 1966), and later by the results of chemical analysis (Hodson 1969). Today they are almost de rigueur for larger-scale analytical programmes such as this one. The following explanation is derived primarily from Sneath and Sokal (1973).

The aim of cluster analysis is the production of classifications. Given information about a number of objects, an analysis arranges these objects into groups so that similar objects are found in the same group. The final result, the classification of the objects, usually allows useful conclusions to be drawn concerning relationships among them.

Essential to the use of cluster analysis is an understanding of the concept of similarity, either between two objects, or between an object and a group of objects, or between two groups. The similarity between two objects is a measure of what they have in common. This concept has been given numerical meaning so that it may be treated mathematically. Identical objects are said to be 100% similar and totally dissimilar objects are said to have zero similarity, with a continuous range existing between those extremes. Complementary to the notion of similarity is that of dissimilarity or distance. Two objects are relatively similar if they are "close to each

other" in some way; i.e., if the "distance" between them is small. This "distance" can be defined in many different ways depending on the objects being studied. The only requirement is that given information about a pair of objects, a mathematical formula for distance will yield a single, non-negative number. In this study the information given consists of the set of trace-element concentrations for each pottery sample; i.e., Table II. Similar samples are those which have similar patterns of trace-element concentrations. The most useful distance formula for use with trace-element concentrations has been found to be squared Euclidean distance (Bieber et al., 1975). This measure is the sum of the squares of the differences in the concentration of each element in the two samples; in mathematical terms:

$$D_{A,B} = \sum_{i=1}^m (A_i - B_i)^2$$

where  $D_{A,B}$  is the squared Euclidean distance between samples A and B, m the number of elements determined, and  $A_i$  and  $B_i$  the concentrations of the i'th element in samples A and B respectively. Geometrically, this measure represents the square of the distance between the two samples when they are plotted as points in m-dimensional space, with one dimension for each element.

Although not easy to visualize in ten or fifteen dimensions, this distance is a natural extension of ordinary

distance in two or three dimensions, and small squared distances between samples in fifteen dimensions imply similar compositions just as they do in a simple two-dimensional plot such as one showing lanthanum and lutetium concentrations.

In practice, a minor refinement is made to the distance formula. In place of the raw concentration data, the common logarithms of these data are used in the calculation of distance. This is done for two main reasons. First of all, it eliminates the distorting effect of scale on the distances. If log-concentration data are used, the difference by a fixed factor of the concentration of a trace element between two samples has the same effect on the distance formula no matter what the original values were. Thus, the difference between 1 and 2 parts per million (or ppm) of an element in two samples has the same effect as the difference between 10 and 20 ppm. Also, differences in measurement units for different elements are not important. In this way iron can be measured in percent, europium in ppm, and chromium in hundreds of ppm, without giving some elements more influence on the distance formula than others.

Secondly, work by geologists and soil scientists on trace elements in rock and soil has revealed that these elements are usually found in a log-normal distribution; that is, the logarithms of their concentrations are distributed in a statistically "normal" manner (Moore and Russell 1967). Adherence to this distribution, which has also been found in archaeological ceramics (Al Kital et al. 1969), is a necessary

prerequisite for the successful use of most multivariate statistical treatments. Since the data are used for the multivariate analyses in logarithmic form, it would seem preferable to use them in the same form for the cluster analyses.

A further transformation of the data is also occasionally employed. This is the conversion of the log data to standardized form, by subtracting the mean and dividing by the standard deviation for each element. Every element then has the same amount of "spread", or dispersion. This transformation seems to make little difference to the results of the cluster analyses but is usually done automatically before the multivariate analyses are performed. It may in addition save a little computer calculation time.

Armed with a measure of distance between two samples, one can proceed to the actual cluster analysis. The first step is the formation of the distance matrix, a table of the distances between every pair of samples calculated using the formula given above. A clustering procedure then produces from this table groups of samples which are reasonably similar to each other; i.e., which have low inter-point distances. The clustering procedures used in this study are all of the hierarchical agglomerative type (Sneath and Sokal 1973: 214). These begin the analysis with each sample in a separate "cluster" consisting of one point. The first step joins the two "clusters" (single

points in this case) which are closest to each other. That pair replaces the two previous single-point clusters in the analysis. The next step joins the two clusters again with the smallest distance between them. These may be two other single-point clusters, or the first two-point cluster and a third single point. At each step the two most similar clusters are joined to form a single larger cluster. The analysis ends when all the samples have been joined into one cluster. At no time during the analysis can a sample be moved from one cluster to another using this procedure.

The results of a clustering procedure are most conveniently presented as a dendrogram, or clustering tree (see, e.g., Fig. 5). At the left side the tips of the branches represent the individual samples. These branches join to form clusters as one moves to the right (in the direction of increasing distance between samples within the same cluster), until at the far right all have been joined to form the final single cluster. The farther to the right that two samples join, the greater is the original distance between them. The clusters at any particular step in the analysis can be obtained by slicing the tree with a vertical line at a particular value of the distance coefficient. Each branch encountered is a separate cluster at that stage.

Though the distance between two samples has been defined using the formula given above, the distance between

two clusters has not yet been defined. In fact, several different distance criteria have been found to be useful. Of these, minimum-linkage and average-linkage are the most commonly employed. The first of these uses as the distance between two groups the distance at the point of their closest approach; i.e., the minimum distance between all pairs of samples taken one from each group. Average-link clustering uses the average of all these "pairwise" distances, and accounts for cluster shape better than the minimum-distance method does. The first method is subject to "chaining", the formation of elongated clusters by the successive addition of single samples to one or two groups. As F. R. Hodson has noted, "Groups that are suggested seem reasonable, but relatively few groups are suggested" (1970: 305). Its value lies in the preliminary creation of a few very distinct groups which can be elaborated upon using the second method, average-link clustering. The danger with the latter method is that it will indicate the formation of groups even when no really distinct groups exist. The clustering programs used in this study are the 1972 revised version of the package called CLUSTAN Ia, available from the University of St. Andrews, Scotland (Wishart 1969).

An additional feature in Wishart's package of cluster analyses is the possibility of relocation of individual samples. After every step in the clustering procedure (of program RELOC), samples can be re-assigned by their distances as individual points from all the clusters present. Each sample is pulled



out of its cluster and then placed into the cluster to which it is closest. Often the sample is put back into its parent group, but occasionally some relocations are made. A large number of relocations indicates that the original groupings were far from optimum. In any case, slight improvements are usually made. Since a sample can belong to one group at one phase in the clustering and to another later on, dendrograms are not suitable for displaying relocation results. Instead, tables are prepared at each step in the clustering listing the original clusters, the re-assigned samples, and the stable clusters after relocation.

The relocation program also has options for creating a "residue" of samples which do not belong to any group (except the single-point group consisting of themselves alone), and for assigning to the residue also groups containing fewer than a certain minimum number of samples. These options work best when the relocation program is started not from the initial classification consisting solely of one-point clusters, but from a grouping obtained using another clustering program.

The final selection of groups from the cluster dendrogram cannot be left solely to the computer, as it must take into account archaeological and other considerations. Therefore, human judgement, albeit arbitrary, is normally used. The kind of results that would be desirable has been expressed in section 4. It may be that the groupings do not form in that manner; at any rate a few large groups accompanied by

some smaller ones and some samples which do not fit into any group is a reasonable expectation. The decisions as to whether or not two small groups should be joined in the final consideration, or whether or not several individual samples belong to a given large group, may depend on either archaeological factors or criteria related to the precision of the chemical analysis. However, certain multivariate statistical techniques may help with these decisions by providing additional information on cluster shapes and relationships. These methods are discussed in the next section.

#### 6.1.2 Mahalanobis Distance and Discriminant Analysis

Given a fairly large group of similar samples, a statistical test can be carried out to determine with what probability a given sample belongs to that group. This test uses a measure known as generalized or Mahalanobis distance (Sneath and Sokal 1973: 127 and 405). This distance is the squared Euclidean distance between a single sample and the centroid (or average) of a group, divided by the group variance (or spread) in the direction of that sample. It can be visualized as the distance between the point and the group after the space they are in has been distorted (by a linear transformation) to make the group spherical in  $m$  dimensions, where  $m$  is the number of variables used in the procedure. The statistic known as Hotelling's  $T^2$  can be used with the Mahalanobis distance to calculate the probability that the

group will include that point (Bieber et al. 1975). Given a large and possibly diffuse group, a list of the samples whose probability of belonging to that group is below a certain fixed level (usually taken as 90% or 95%) can be produced.

In practice, Mahalanobis distance can only be calculated when the number of group members is greater than the number of variables (in this case, elements) used. This limits the use of this test to large groups if the whole suite of elements determined is to be used, or forces the exclusion of several elements from the analysis. Both of these approaches were tried in this study.

The technique of "stepwise discriminant analysis" was also found to be quite useful. This method of analysis takes sets of samples which are already separated into groups and uses them to assign new samples to one of those groups. It does this by computing a set of linear classification functions based on the data supplied for those groups. Then the functions are used, together with the prior probability that a sample belongs to each given group (usually all these probabilities are initially taken as being equal), to calculate the posterior probabilities of group membership. These probabilities are only relative, in contrast to those of the Mahalanobis-distance method, which are absolute. They can therefore serve only as guides for group selection. Every

sample is assigned to a group, even if it really does not belong to any group. The value of this program lies in its ability to assign samples which fall between closely-spaced groups to one group or the other.

Programs BMD07M and BMD10M in the UCLA package of Biomedical Computer Programs (Dixon 1973) were used in this study for discriminant analysis and Mahalanobis distance respectively. Program BMD07M gives a plot of the sample points using the first two "canonical variables" (linear combinations of the original variables calculated from the discriminant functions) to show the optimal two-dimensional picture of the separation of groups. This plot, together with a similar one produced by the Mahalanobis distance program, is very useful as a means of seeing the overall distribution of the samples into groups, and can suggest further treatment of the data.

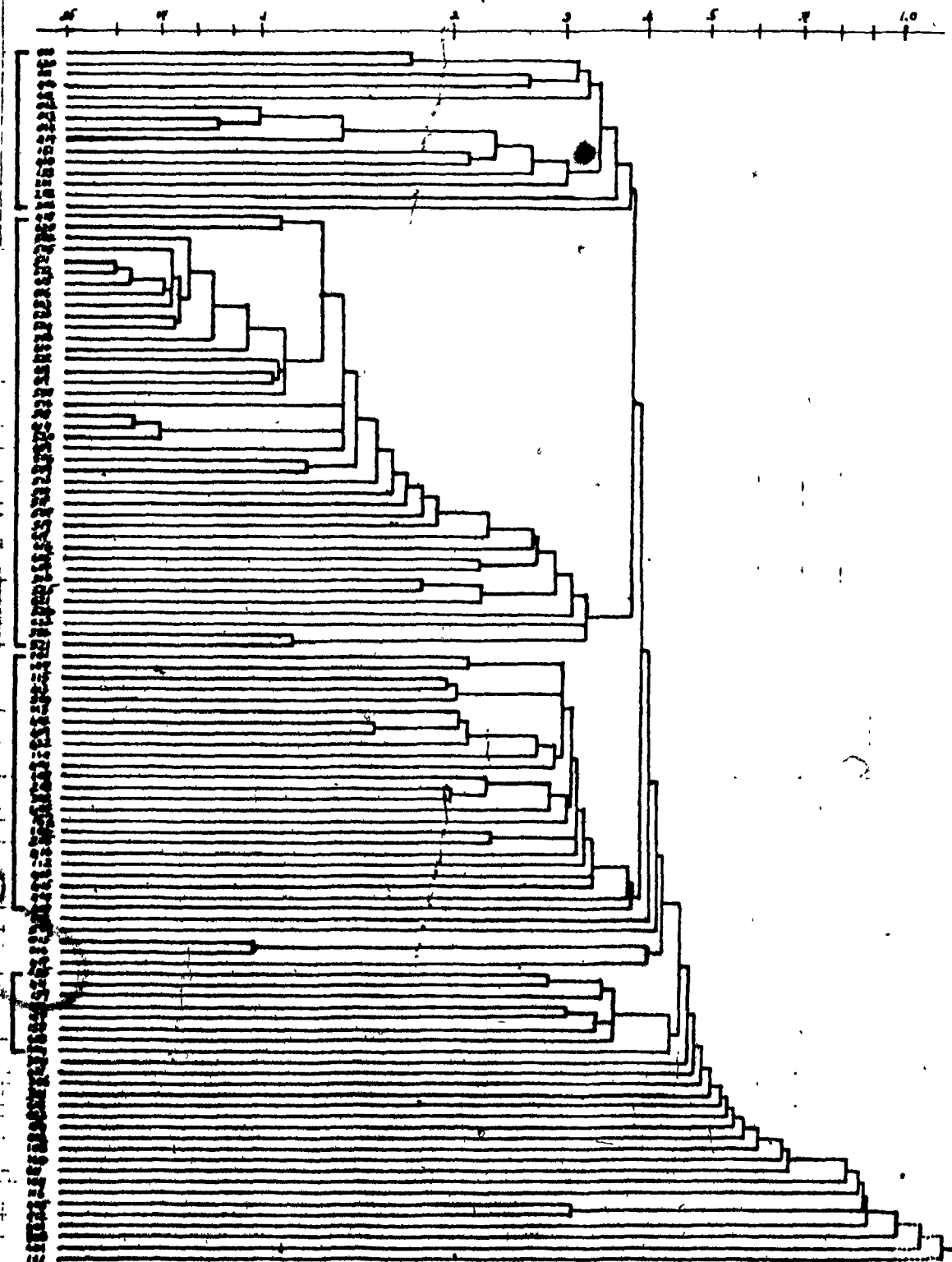
## 6.2 Formation of Major Groups

The initial clustering treatments used as variables the fifteen elements without missing values in Table II (after logarithmic transformation), calcium, samarium, arsenic, and antimony being omitted. The dendrogram resulting from minimum-link clustering with the squared-Euclidean-distance measure of dissimilarity is presented in Figure 5. Four groups

FIGURE 5

Dendrogram from minimum-link clustering of the pottery samples, using the standardized concentrations (in logarithmic form) of 15 elements, calcium, samarium, arsenic, and antimony being omitted.

DISTANCE COEFFICIENT



were immediately evident, bracketed in the figure. From top to bottom they are as follows: the first of size 15, from 010 to 206; the second of size 40, from 418 to 521; the third of size 24, from 101 to 408; and the last, a smaller one of size 8, from 155 to 604. Poorly-clustered samples lie between the third and fourth groups and below the fourth group. The second group is quite tight; i.e., it forms at a low level of the distance coefficient. The fourth one on the other hand, is loose. Substructure within the groups is not clear.

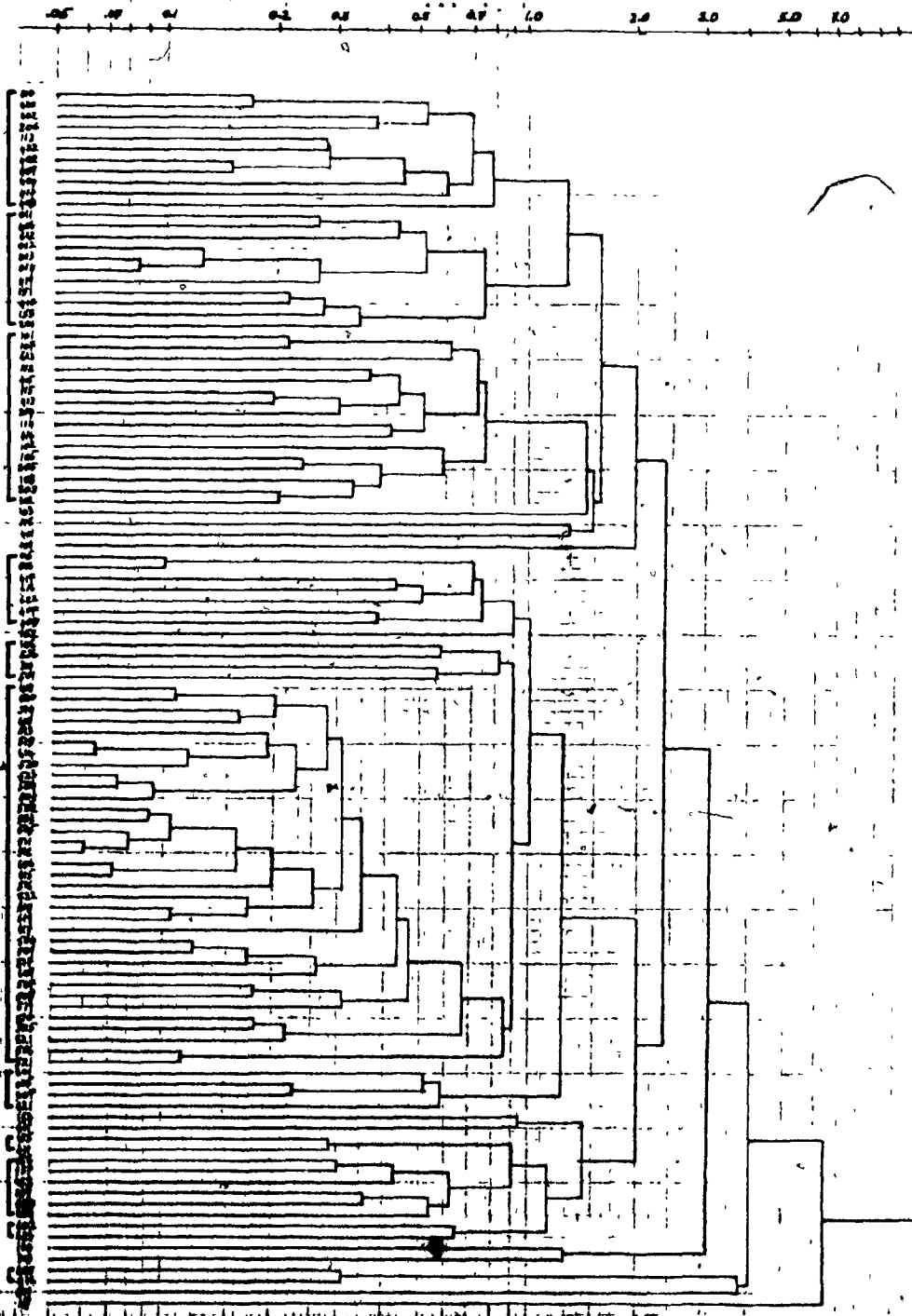
Clustering by average-link under the same conditions produced what may seem at first to be radically different results (Figure 6). Many more groups are in evidence, but in fact these are subdivisions of the four groups of the minimum-link clustering. Again reading from top to bottom, the bracketed groups are 010 to 403 of 11 members, 011 to 201 of 11 members, 101 to 302 of 16 members, followed by a few poorly clustered samples; then in the second half of the dendrogram, 015 to 408 of 7 members, the single sample 152, 106 to 501 of 4 members, 418 to 521 of 35 members, 301 to 421 of 4 members, the pair 155 and 411, 156 to 604 of 6 members, and among the poorly clustered samples at the bottom, the pairs 602 and 623, and 405 and 412. These are the groups formed at the arbitrary cutoff dissimilarity value of 0.9 on the abscissa, a value which seemed to yield reasonably clear groups. At higher levels of dissimilarity the first three of the above groups join, as do

FIGURE 6

Dendrogram from average-link clustering of the pottery samples, using the standardized concentrations (in logarithmic form) of 15 elements, calcium, samarium, arsenic, and antimony being omitted.



# DISTANCE COEFFICIENT



the next four, and the 6-member group near the bottom absorbs the pair-group on either side of it. These three "supergroups" compare well to the clusters of Figure 5. The first one corresponds to the first and third groups of the minimum-link clustering, the second to the second, and the third to the last. That they are in fact well-formed and meaningful groups is shown below.

The relocation-clustering program was applied both to the eleven groups of the average-link dendrogram and to the four groups of the minimum-link dendrogram. A few relocations were made at each clustering step, but at the three-group level the results were practically identical both with each other and with the arrangement described above. These three large clusters (omitting the poorly-clustered residue of samples) were plotted using the canonical variables from multiple discriminant analysis; the results are shown in Figure 7. Samples in the first group are indicated by L, those in the second by F, and those in the third by R.

It may be worth noting that average-link clustering using the raw data of Table II rather than the standardized data after logarithmic transformation yielded a grouping very similar to the ones described above, as did clustering with relocation starting from two different arbitrary groupings. Since the results were so similar they are not included here, but they tended to support the validity of the classification.

FIGURE 7

Discriminant-analysis plot of the first two canonical variables for the pottery samples, showing the division into three large clusters (group centroids are indicated by asterisks).

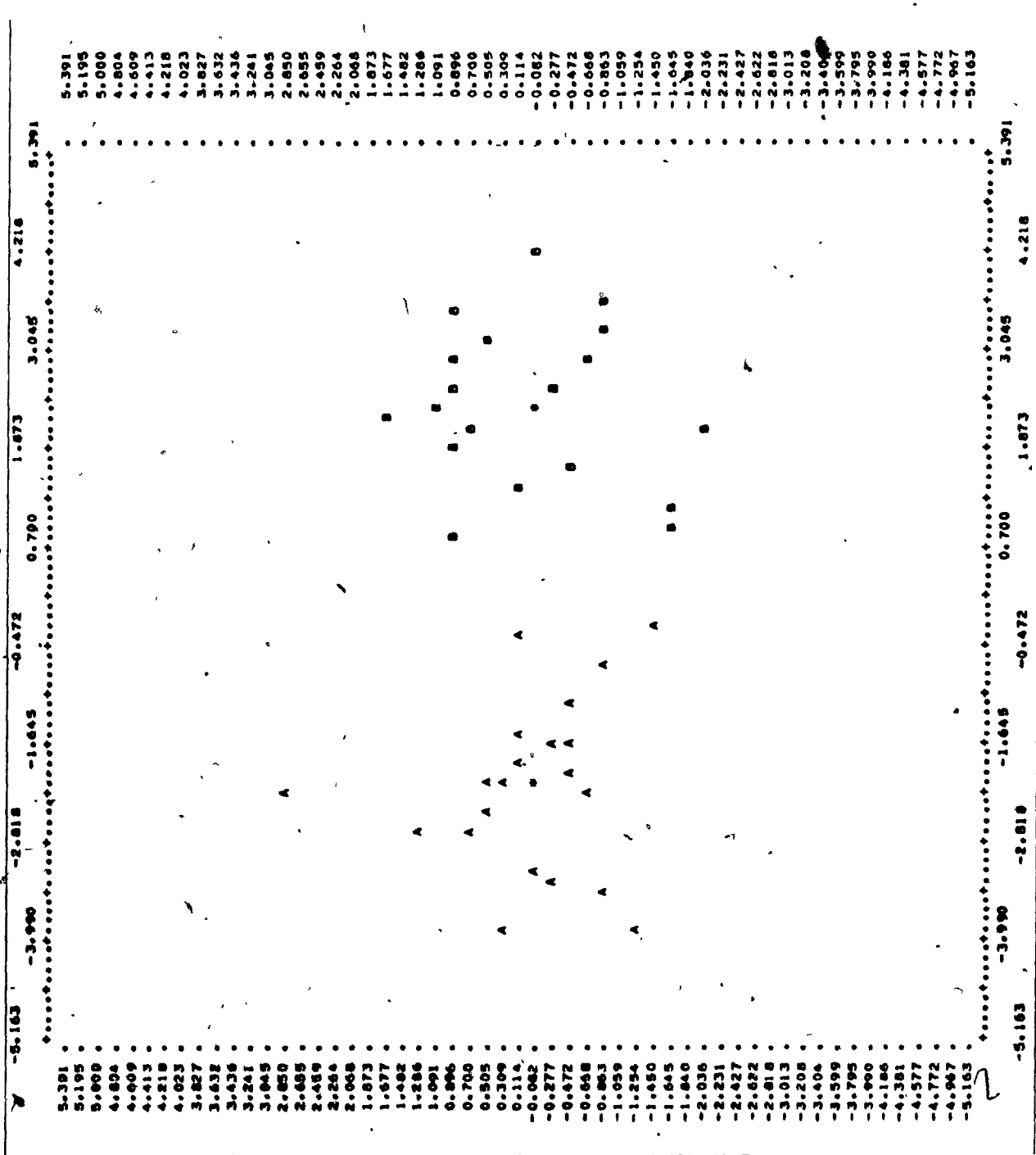
[illegible][illegible]

These three main divisions also made sense archaeologically. The first ("L") contained five clay samples 010-014, the six mud-brick samples 201-206, many of the objects from the square structure, and most of the samples from the pottery dump. These, then, are the objects which were made locally, all of EH II date. The second ("F") consisted of all the Archaic and Mycenaean pottery and over half of the EH I material. That the Archaic and Mycenaean pottery was imported is nearly certain, so the chances are high that much of the EH I pottery was too. The third group ("R") is more enigmatic, but seems to consist of very coarse pottery from both EH I and EH II occupation levels.

Finer structure within these groups could then be explored. Group "L" had been split into two clusters in Figure 5 but into three in Figure 6. As the clay samples 010-015 were all grouped together by minimum-link clustering but were split up using average-link clustering, it was at first thought that group "L" was more likely to split into two subgroups. The best bipartite split was found using the relocation program, and the sample points were plotted using the discriminant analysis program, yielding Figure 8. Though this looked promising, a tripartite division produced in the same manner was clearer. The subgroups "A" and "B" in Figure 9 correspond roughly to "A" of Figure 8, and "C" corresponds to "B". The division shown in Figure 9 was accepted as the final one, presented in Table IV. Three samples which fell between the

FIGURE 8.

Discriminant-analysis plot of the first two canonical variables for cluster "L", showing a subdivision into two groups (group centroids are indicated by asterisks).



FINISH CARD ENCOUNTERED. JOB TERMINATED

FIGURE 9

Discriminant-analysis plot of the first two canonical variables for cluster "L", showing a subdivision into three groups (group centroids are indicated by asterisks).



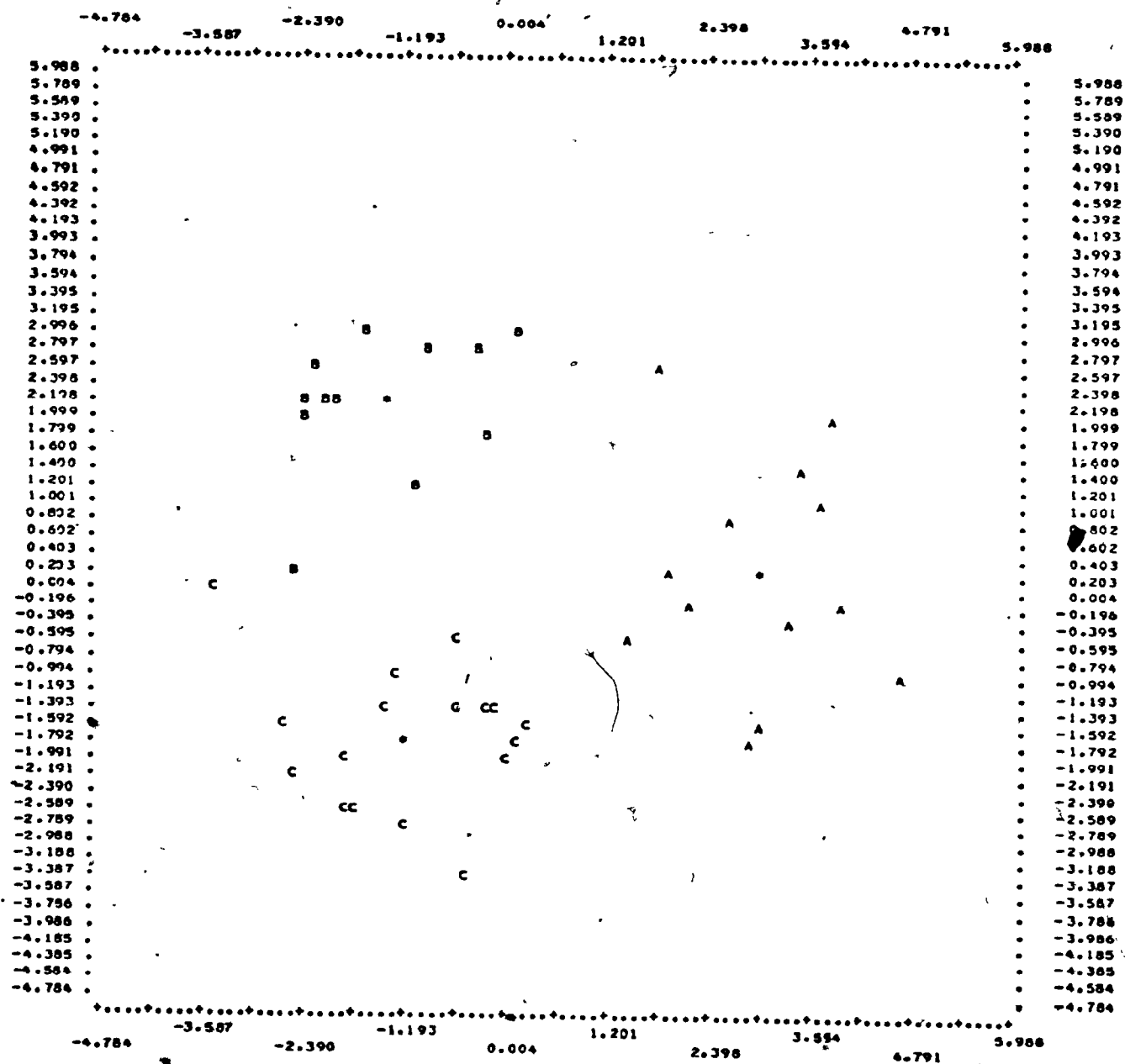


TABLE IV

## THE MAJOR POTTERY GROUPS

"L"			"F"		
<u>ALOCAL</u>	<u>BLOCAL</u>	<u>CLOCAL</u>	<u>FINEST</u>		<u>ODD</u>
010	012	101	(304)	520	(106)
(011)	013	102	418	(521)	301
113	014	105	(501)	522	421
114	151	107	502	523	605
202	153	108	503	524	607
206	201	112	504	525	
402	406	115	505	(526)	
403	(407)	(152)	(506)	603	
404	408	154	507	606	
409	410	203	508	609	
414	417	204	509	610	
420	419	205	510	614	
422	622	302	511	615	
		413	512	616	
		415	513	617	
		416	514	618	
		613	516	619	
			517	620	
			518	621	
			519		

"R"

<u>ROUGH</u>	<u>UNCLUSTERED SAMPLES</u>
155	015, 016
156	103
157	104
518	111
159	116
411	160
602	303
604	401
608	405, 412
611	601
612	
623	

groups in Figure 9 are listed in Table IV enclosed in parentheses.

The largest main group, "F" of Figure 7, could not be subdivided as neatly as group "L". It seemed to be composed of a substantial core surrounded by many small clusters of two or more samples. The boundary separating the core and the surrounding clusters could be placed rather arbitrarily so as to include a larger or smaller number of samples in that core. The order in which the last samples joined the cluster differed between the single-link and the average-link analyses. To make matters worse, the application to this problem of the "Identification of Outliers" program BMD10M, which uses Mahalanobis distance to define the limits of a group for any set probability of inclusion, gave yet a different separation of the outlying samples from the core group.

In fact, information from the other clusters set an upper limit to the size of the core group. Several members in the fourth group of Figure 6 had already been assigned to the "B" subgroup. The fact that the fourth group could be so easily broken up indicated that the core group should not be extended as far as to include those samples. The relocation-clustering program confirmed this by scattering some of them among other groups and placing the rest in the residue of unclustered samples. Table IV reflects those relocations: the seventh group of Figure 6 has acquired sample 106, the members of the core group which joined at the highest dis-

similarity are enclosed in parentheses, and the list of unclustered samples has grown to 12 members, four of which form two pairs.

Group "R" of Figure 7 was found to be remarkably stable; i.e., in most of the clustering procedures it formed quickly, remained unaltered through many clustering steps, and joined with other groups only towards the end of the procedure. It was therefore left as a single, albeit loose, group composed of the samples listed in Table IV.

### 6.3 Chemical Basis for Group Differentiation

Which specific elements account for the separation of the 111 samples into 6 groups? Table V, giving the average composition of each group, helps to answer this question. The group ALOCAL is characterized by low values of almost all the trace elements in comparison to the other groups. Only the calcium concentration is exceptionally high. In addition, it is a "tight" group; that is, the spread of values (measured by the standard deviation) is low. BLOCAL has higher values of most elements than ALOCAL, except for rubidium and of course calcium. The barium values are very similar. CLOCAL has about double the barium concentration of the previous two groups, and also high scandium, iron, and cobalt values. Its calcium concentration is again slightly lower, but it can be said that all the local pottery was made from calcareous clay.

TABLE V

The six major pottery groups, with means,  
standard deviations, and standard errors  
of the means for each group.

TABLE V THE SIX MAJOR POTTERY GROUPS, WITH MEANS, STANDARD DEVIATIONS, AND STANDARD ERRORS OF THE MEANS FOR EACH GROUP  
ALL VALUES GIVEN IN PARTS PER MILLION EXCEPT CA AND FE, GIVEN IN PERCENTAGE

ID	COLOUR	FABRIC	FORM	RB	CS	CA(X)	BA	SC	LA	CE	SM	EU	YB	LU	TH	HF	TA	CR	FE(X)	CO	AS	SB
ALOCAL																						
110	7 7/2	MEDIUM	CLAY	88.	7.61	14.5	181.	13.1	19.0	16.3	3.60	0.88	1.92	0.284	7.2	2.67	0.44	163.	3.13	19.2	6.6	0.63
111	6 6/4	MEDIUM	CLAY	73.	5.96	15.6	212.	13.8	21.2	41.2	3.92	0.93	2.43	0.333	6.0	3.28	0.41	124.	3.24	17.2	7.1	0.64
113	7 7/1	SEMIFINE	SEALINGS	89.	6.16	17.1	470.	14.4	18.5	34.6		0.84	1.82	0.247	5.3	2.53	0.41	278.	3.65	29.1	8.9	0.56
114	7 7/3	SEMIFINE	FISH VASE	87.	7.07	17.5	506.	16.3	23.5	39.9	3.40	0.92	2.29	0.281	6.5	2.47	0.43	306.	4.08	29.7	0.0	0.87
202	6 7/4	FINE	MUDBRICK	97.	7.05	10.3	607.	12.6	19.5	37.2	3.46	0.83	2.03	0.300	6.8	3.36	0.59	177.	3.08	18.8	7.8	0.73
206	6 7/4	SEMIFINE	MUDBRICK	81.	8.82	19.9	744.	12.0	19.2	35.6	3.35	0.79	1.67	0.230	6.1	2.50	0.46	169.	3.07	22.2	5.2	0.64
402	6 7/6	MEDIUM	PLATE	78.	5.99	17.3	503.	17.9	19.6	35.2	3.53	0.87	2.08	0.264	5.9	2.55	0.47	215.	4.14	29.2	6.3	0.78
103	7 7/4	SEMIFINE	PLATE	70.	5.63	14.3	509.	12.6	17.4	32.2	3.12	0.87	1.62	0.214	5.2	2.01	0.76	291.	3.38	29.2	7.2	0.65
104	7 7/4	SEMIFINE	PLATE	65.	4.32	16.3	730.	13.4	23.5	16.1	3.64	0.92	1.50	0.266	6.2	2.65	0.25	169.	3.38	25.3	7.1	0.65
109	6 7/6	MEDIUM	BOWL RIM	83.	4.52	0.9	502.	16.6	19.7	37.4	3.47	1.00	2.05	0.279	6.6	2.82	0.44	161.	3.85	24.5	6.9	0.76
114	6 7/4	MEDIUM	PAN RIM	108.	8.05	14.0	584.	15.8	21.0	36.2	3.64	0.81	1.64	0.304	7.0	2.35	0.36	363.	4.18	33.9	0.0	0.64
420	6 7/4	SEMIFINE	BOWL RIM	91.	10.80	16.1	260.	13.1	19.4	34.3	3.67	0.85	2.03	0.221	6.0	2.53	0.37	171.	3.25	22.4	7.2	0.60
122	7 7/4	MEDIUM	BOWL RIM	74.	7.40	15.4	489.	16.3	17.6	34.0	3.35	0.68	1.79	0.253	5.6	2.42	0.55	148.	3.70	25.6	39.3	1.17
MLOCAL:13 SAMPLES MEAN VALUE				84.	6.92	15.2	495.	14.4	19.6	36.7	3.51	0.96	1.97	0.275	6.2	2.62	0.47	212.	3.56	25.1	8.4	0.76
STANDARD DEVIATION				11.	1.77	3.0	180.	1.9	1.6	2.7	0.20	0.08	0.29	0.035	0.6	0.36	0.12	73.	0.42	5.0	9.7	0.16
STD. ERROR OF MEAN				3.	0.49	0.8	50.	0.5	0.5	0.7	0.06	0.02	0.07	0.010	0.2	0.10	0.03	20.	0.12	1.4	2.7	0.05
BLOCAL																						
112	6 7/4	SEMIFINE	CLAY	98.	6.77	21.1	239.	15.7	24.8	48.3	4.69	1.10	2.44	0.341	8.5	3.47	0.72	220.	3.93	24.3	8.1	0.62
113	6 7/3	SEMIFINE	CLAY	78.	7.49	20.1	208.	15.7	25.8	47.6	4.38	1.01	2.45	0.327	8.0	3.33	0.41	213.	3.92	24.5	9.6	0.75
114	5 5/6	SEMIFINE	CLAY	67.	5.51	20.7	256.	15.8	24.0	45.1	4.34	1.02	2.43	0.324	8.0	3.43	0.54	200.	3.91	25.1	8.8	0.67
151	6 8/2	MEDIUM	BOWL(?)	23.	4.13	14.8	850.	15.6	20.4	46.9	4.27	1.00	2.62	0.391	8.0	3.53	0.64	217.	3.90	24.8	7.4	0.62
153	6 8/1	SEMIFINE	JAR(?)	27.	7.34	11.9	506.	10.9	25.4	50.1	4.44	1.08	2.60	0.345	8.5	4.02	0.59	232.	4.70	27.1	9.4	0.74
201	6 7/2	SEMIFINE	MUDBRICK	27.	5.69	13.7	531.	15.2	22.7	46.1	4.12	1.10	2.47	0.298	8.4	3.85	0.44	242.	3.81	21.6	8.8	0.64
106	7 7/3	MEDIUM	PLATE	79.	6.64	10.5	450.	14.4	21.1	40.7	4.08	1.07	2.65	0.347	6.4	3.44	0.51	151.	3.48	19.6	12.5	1.05
107	7 7/3	MEDIUM	PLATE	103.	6.62	11.3	445.	19.5	20.5	40.5	5.11	1.21	2.72	0.374	7.4	3.75	0.50	416.	4.74	33.9	8.1	0.60
108	7 5/2	SEMIFINE	BOWL RIM	109.	7.76	1.3	241.	17.9	20.2	52.6	4.36	1.00	2.41	0.355	10.0	5.11	0.56	423.	4.79	36.5	8.0	0.72
410	7 6/2	MEDIUM	BOWL RIM	36.	6.00	15.7	485.	15.9	24.4	42.0	4.32	1.14	2.65	0.363	7.4	3.40	0.58	182.	3.57	24.4	11.5	1.46
117	6 7/2	FINE	SAUCER	55.	11.54	13.2	291.	20.2	29.5	56.0	4.92	1.17	2.48	0.329	9.7	3.36	0.66	293.	5.09	34.2	8.2	0.93
419	6 7/4	MEDIUM	BOWL RIM	91.	6.23	13.4	344.	15.2	23.6	44.2	4.36	1.06	2.67	0.350	7.7	3.67	0.93	198.	3.88	27.5	4.9	0.61
122	6 7/5	SEMIFINE	FRUITSTAND	109.	6.02	10.3	409.	17.8	29.4	54.2	4.24	1.04	2.26	0.337	11.0	3.20	1.05	214.	4.42	32.0	9.5	0.89
BLOCAL:13 SAMPLES MEAN VALUE				69.	7.29	13.7	445.	14.8	25.1	47.7	4.43	1.09	2.43	0.351	6.4	3.66	0.62	247.	4.20	27.3	8.7	0.67
STANDARD DEVIATION				32.	1.70	2.3	231.	1.9	2.3	4.5	0.30	0.08	0.14	0.030	1.2	0.49	0.19	84.	0.49	5.2	2.0	0.33
STD. ERROR OF MEAN				9.	0.47	1.5	64.	0.5	0.6	1.3	0.08	0.02	0.04	0.008	0.3	0.14	0.05	23.	0.14	1.4	0.6	0.09
CLOCAL																						
101	6 7/5	MEDIUM	SAUCER	56.	6.03	8.9	737.	21.2	22.2	43.6		0.98	2.30	0.336	6.1	3.16	0.21	261.	5.26	39.2	12.7	0.63
102	7 7/1	SEMIFINE	SAUCER	75.	4.25	6.01	352.	19.7	23.1	45.0		1.00	2.13	0.304	7.3	3.40	0.42	556.	5.15	45.8	11.0	0.73
103	6 7/4	COARSE	BOWL	48.	3.80	6.01	161.	22.6	18.7	38.1		1.03	2.43	0.350	5.7	3.92	0.41	370.	5.07	32.0	14.4	1.00
107	6 7/4	MEDIUM	SALT POT	56.	4.62	9.2	731.	19.6	20.4	40.1		1.06	2.41	0.312	6.7	3.48	0.24	385.	4.70	33.5	5.8	0.56
109	5 6/6	MEDIUM	PAN VASE	77.	4.11	7.51	502.	14.0	21.2	44.7	3.64	0.99	2.18	0.321	7.3	3.64	0.74	532.	5.14	37.0	6.8	0.79
112	6 7/4	SEMIFINE	BOWL BASE	119.	5.50	12.0	113.	14.1	23.8	45.5		1.02	2.10	0.258	7.3	2.97	0.39	364.	4.65	34.8	10.2	0.66
115	7 7/1	SEMIFINE	TILE	78.	5.45	12.0	103.	17.0	21.1	40.2		1.01	2.22	0.283	6.7	3.04	0.74	254.	4.23	25.0	7.2	0.77
112	6 7/2	SEMIFINE	JAR	49.	7.25	8.3	633.	23.8	20.4	57.6	4.75	1.17	2.69	0.350	6.1	3.96	1.23	527.	6.00	42.6	5.6	0.71
154	6 7/4	SEMIFINE	BOWL	45.	3.64	7.82	216.	20.4	19.6	37.1	4.03	1.00	2.45	0.330	6.2	3.39	0.51	131.	4.92	30.0	60.7	1.92
201	7 9/3	MEDIUM	MUDBRICK	81.	3.78	7.8	746.	21.5	22.3	45.5	4.68	1.19	2.88	0.405	7.3	4.27	0.61	474.	4.96	32.9	13.0	1.13
204	6 7/2	SEMIFINE	MUDBRICK	39.	5.12	14.3	1248.	17.7	22.8	44.9	4.11	1.05	2.28	0.355	7.2	3.57	0.47	350.	4.47	30.3	4.3	0.83
205	5 5/2	SEMIFINE	MUDBRICK	59.	3.53	6.6	664.	24.0	20.0	42.9	4.23	1.17	2.44	0.336	6.5	3.41	0.46	422.	5.44	41.5	5.5	0.80
302	7 7/3	FINE	SAUCER	70.	4.75	9.2	927.	21.1	21.5	47.9	4.64	1.20	2.53	0.344	6.1	3.40	0.77	501.	5.32	37.7	6.4	0.73
413	6 8/2	SEMIFINE	BOWL RIM	51.	4.27	16.4	540.	18.0	22.9	41.6	4.23	1.03	2.19	0.304	7.4	2.84	0.67	331.	4.49	32.1	13.6	0.64
415	7 7/2	MEDIUM	JAR RIM	138.	7.17	13.5	706.	19.5	24.3	46.4	4.25	0.98	2.22	0.335	8.3	2.79	0.91	353.	4.91	37.7	6.8	1.70
416	7 7/2	MEDIUM	JAR RIM	94.	8.73	12.6	743.	18.5	22.0	33.4	4.18	1.10	2.33	0.324	6.7	3.16	0.58	175.	4.33	31.8	38.8	1.68
513	7 6/2	COARSE	SCOOP(?)	109.	6.89	6.8	783.	23.1	24.5	50.6	4.39	1.22	2.47	0.348	7.9	3.26	0.39	203.	5.95	22.8	14.9	0.60
CLOCAL:17 SAMPLES MEAN VALUE				68.	5.22	10.0	1020.	20.4	22.4	43.7	4.28	1.07	2.27	0.332	7.2	3.42	0.58	364.	5.00	35.1	14.3	0.67
STANDARD DEVIATION				27.	1.51	3.0	393.	2.4	1.9	4.9	0.32	0.09	0.20	0.029	1.0	0.41	0.24	124.	0.51	5.2	14.3	0.41
STD. ERROR OF MEAN				6.	0.37	0.7	95.	0.6	0.5	1.2	0.10	0.02	0.05	0.007	0.2	0.10	0.06	31.	0.12	1.3	3.5	0.10

TABLE V (CONTINUED)

ID	COLOR	FABRIC	FORM	RR	CS	CA(X)	BA	SC	LA	CE	SM	EU	YB	LU	TH	HF	TA	CR	FE(X)	CO	AS	SB
FINEST																						
304	7	7/3	SEMIFINE	ASKOS	72.	2.89	0.01450	22.2	33.9	69.4	5.30	1.25	2.81	0.367	10.3	3.78	0.79	462.	5.78	38.4	4.8	0.67
418	9	8/1	FINE	JAR RIM	114.	6.05	13.0 481.	21.8	32.4	62.1	5.44	1.23	2.74	0.404	11.6	3.73	0.86	260.	5.42	33.2	0.0	1.01
501	8	7/1	FINE	COR SKYPHOS	72.	3.50	6.11804	26.5	36.4	61.4	5.23	1.32	2.67	0.414	12.7	3.38	0.40	297.	6.42	37.9	0.0	1.03
502	7	8/3	FINE	COR SKYPHOS	139.	8.45	10.11249	24.1	34.6	66.5	4.70	1.29	2.82	0.472	12.1	3.73	0.95	288.	6.15	33.8	0.0	0.48
503	6	7/7	FINE	COR MIN. ROWL	174.	10.50	7.21014	24.3	38.5	70.6	4.99	1.22	3.00	0.427	11.8	3.60	1.11	283.	6.04	31.9	0.0	0.00
504	7	8/4	FINE	COR SKYPHOS	182.	9.68	11.21132	23.0	36.1	65.9	5.94	1.20	2.75	0.390	11.4	3.28	0.55	271.	6.06	32.2	0.0	1.76
505	7	8/3	FINE	COR PYXIS LID	165.	9.90	9.2 782.	24.7	35.9	65.8	5.36	1.40	2.72	0.429	11.7	3.70	0.84	276.	6.29	34.0	0.0	0.64
506	6	7/5	FINE	COR SKYPHOS	176.	13.94	5.6 842.	26.7	37.8	79.4	5.84	1.39	3.05	0.432	13.0	4.15	1.23	631.	6.83	43.1	0.0	1.49
507	9	7/1	FINE	MYC SPOUT	72.	9.16	11.8 739.	26.5	38.4	73.3	5.32	1.45	3.13	0.450	12.8	4.51	1.06	281.	6.61	32.2	0.0	0.00
508	7	8/3	FINE	MYC SHERD	137.	7.31	10.01026	24.6	39.9	69.7	6.16	1.39	3.09	0.476	12.1	4.47	0.91	320.	6.19	32.9	0.0	1.15
509	6	7/4	FINE	MYC KYLIX	157.	9.20	8.4 845.	23.3	33.9	67.1	5.89	1.22	2.72	0.372	11.6	2.76	0.42	241.	5.80	29.0	0.0	0.92
510	7	7/1	FINE	EM SHERD	161.	21.70	0.0 985.	23.7	33.4	62.5	4.91	1.23	2.75	0.385	12.1	2.99	0.79	285.	5.76	34.8	0.0	1.07
511	8	8/2	FINE	COR SKYPHOS	161.	9.82	10.6 757.	22.5	36.2	66.1	6.13	1.34	2.84	0.413	12.2	3.50	0.82	251.	5.57	30.1	0.0	1.13
512	6	8/4	FINE	COR BASE	132.	8.93	9.3 835.	23.3	35.5	64.4	5.57	1.31	2.97	0.452	12.7	3.38	0.99	278.	5.70	32.6	0.0	0.99
513	7	7/3	FINE	COR PYXIS LID	145.	7.91	7.0 662.	18.7	31.0	56.7	4.49	1.17	2.57	0.372	9.5	4.73	0.85	301.	4.77	29.2	9.6	1.05
514	6	7/4	FINE	COR PYXIS LID	97.	6.35	9.51030	20.7	34.2	54.3	5.13	1.32	2.96	0.413	10.9	3.40	0.85	254.	5.45	32.8	18.7	0.90
516	6	7/4	FINE	MYC KYLIX	136.	7.50	8.71086	22.5	35.3	64.4	5.47	1.31	3.67	0.417	12.1	3.75	1.05	275.	5.61	30.9	0.0	0.51
517	7	8/4	FINE	MYC BOWL	122.	8.09	9.9 732.	22.4	35.6	64.0	5.59	1.29	2.68	0.447	11.4	3.13	0.43	257.	5.53	36.6	0.0	1.10
518	6	8/5	FINE	MYC BOWL	143.	6.54	7.71208	19.7	31.6	61.3	5.27	1.21	2.78	0.375	10.2	4.23	0.86	258.	5.31	27.8	0.0	1.05
519	8	7/3	FINE	MYC SHERD	86.	5.42	7.61090	21.4	30.2	67.0	4.86	1.37	2.92	0.419	12.4	4.66	1.02	249.	5.79	33.6	0.0	1.43
520	7	8/3	FINE	MYC BOWL	135.	5.75	8.51154	21.3	33.5	63.0	5.85	1.25	2.70	0.386	11.3	4.32	0.66	272.	5.50	26.0	0.0	0.91
521	6	7/4	FINE	COR LAMPSPOUT	206.	12.20	0.0 913.	24.5	35.6	73.1	6.57	1.44	3.23	0.439	12.0	4.09	0.98	632.	6.20	37.4	47.1	1.61
522	6	8/4	FINE	MYC SHERD	139.	9.02	9.2 744.	22.3	34.1	67.4	5.30	1.23	2.45	0.466	11.4	4.62	0.90	237.	5.53	27.0	5.9	0.91
523	6	8/4	FINE	MYC SHERD	155.	9.36	7.1 759.	22.1	33.7	53.0	5.14	1.22	2.55	0.366	11.5	3.94	0.76	243.	5.51	27.0	6.7	0.96
524	6	7/4	FINE	MYC HANDLE	139.	10.52	0.0 714.	22.0	31.4	54.1	5.17	1.10	2.36	0.347	11.5	3.54	0.63	271.	5.60	25.3	4.2	0.90
525	6	8/3	FINE	MYC BOWL	179.	29.63	8.8 729.	24.9	36.6	60.1	5.00	1.17	3.09	0.414	12.3	3.54	1.02	291.	5.40	31.4	15.8	1.84
526	8	8/2	FINE	MYC ROWL(?)	51.	8.91	13.42046	20.7	31.5	55.0	4.72	1.21	2.70	0.356	10.7	3.32	0.76	299.	5.45	28.6	0.0	0.95
603	6	7/6	FINE	JAR	128.	9.14	11.0 758.	21.4	32.3	59.3	5.30	1.12	2.55	0.399	11.1	3.58	0.84	233.	5.16	25.2	12.1	0.80
606	7	7/3	FINE	BOWL	156.	7.67	8.5 714.	23.1	33.4	65.0	5.52	1.39	2.99	0.404	11.6	3.36	1.07	243.	5.62	25.9	9.2	0.72
609	6	7/4	FINE	LADLE(?)	154.	8.71	11.0 596.	24.8	35.8	69.3	5.86	1.37	2.84	0.435	12.8	4.10	0.54	254.	5.96	32.9	10.3	1.24
610	6	8/8	SEMIFINE	BOWL	116.	6.01	6.4 785.	20.8	31.6	61.1	5.04	1.24	2.57	0.387	10.4	3.18	0.85	209.	5.27	26.4	11.8	0.98
614	7	7/3	FINE	JAR	124.	6.82	7.21190	19.0	30.6	59.6	4.97	1.23	2.53	0.387	10.3	3.90	0.79	239.	4.98	25.0	10.6	0.74
615	6	8/4	FINE	JAR	144.	9.46	9.2 768.	22.4	33.2	68.0	5.31	1.24	2.75	0.384	11.5	3.69	0.98	246.	5.28	27.2	7.8	1.01
616	8	8/1	FINE	BOWL	53.	9.10	12.4 368.	21.8	31.9	62.3	5.17	1.24	2.52	0.389	11.6	3.89	1.19	236.	5.28	29.2	5.3	0.82
617	7	6/4	FINE	JAR	179.	8.23	3.8 936.	21.6	28.8	59.7	4.69	1.11	2.54	0.365	12.4	3.63	1.40	282.	6.45	26.4	41.3	1.09
618	7	6/4	FINE	JAR	169.	8.25	3.8 639.	22.2	31.4	66.3	4.63	1.08	2.88	0.366	13.2	4.67	1.04	271.	5.46	32.0	23.8	1.09
619	8	8/2	FINE	JAR	134.	6.94	9.1 875.	22.6	32.2	62.6	5.26	1.20	2.88	0.413	11.2	4.50	0.98	242.	5.42	28.2	5.0	0.67
620	5	8/1	FINE	JAR	89.	4.97	8.9 610.	23.8	34.8	67.7	5.45	1.28	2.92	0.380	12.5	3.59	0.94	245.	5.49	29.4	7.6	0.75
621	6	7/4	FINE	SPOON	154.	23.00	9.0 535.	22.4	30.6	55.7	5.05	1.11	2.56	0.384	11.0	3.56	0.84	306.	5.19	30.4	11.0	1.30
FINEST:39 SAMPLES MEAN VALUE				134.	9.45	8.0 908.	22.7	33.9	64.0	5.32	1.26	2.80	0.405	11.7	3.78	0.88	289.	5.69	31.0	6.9	0.97	
STANDARD DEVIATION				37.	5.02	3.5 333.	1.9	2.6	5.7	0.46	0.10	0.25	0.033	0.8	0.48	0.22	90.	0.45	4.2	10.7	0.38	
STD. ERROR OF MEAN				6.	0.80	0.6 53.	0.3	0.4	0.9	0.07	0.02	0.04	0.005	0.1	0.08	0.03	14.	0.07	0.7	1.7	0.06	
MYCENAE:16 SAMPLES MEAN				145.	9.19	9.8	21.1	34.1						0.374	10.7	3.21	0.82	221.	5.16	28.2		
STANDARD DEVIATION				14.	0.76	0.8	0.6	1.2						0.016	0.3	0.31	0.04	14.	0.18	1.4		
STD. ERROR OF MEAN				4.	0.19	0.2	0.3	0.3						0.004	0.1	0.08	0.01	4.	0.05	0.4		

\* ANALYSES REPORTED IN KARAGEORGHIS ET AL. (1972:196)

TABLE V (CONTINUED)

ID	COLOR	FABRIC	FORM	RB	CS	CA(%)	BA	SC	LA	CE	SM	EU	YB	LU	TM	HF	TA	CR	FE(%)	CO	AS	SB
DOO																						
186	7 7/4	COARSE	BOWL	56.	5.70	5.12109.	18.3	33.0	66.0	5.43	0.89	2.53	0.398	11.8	5.04	0.73	185.	4.78	28.5	0.0	0.69	
301	7 7/4	SEMIFINE	JUG	42.	5.85	13.01232.	15.6	38.8	65.0		1.68	3.03	0.422	11.1	4.83	1.41	330.	4.99	26.3	25.2	0.93	
421	7 6/1	FINE	BOWL RIM	116.	8.91	2.2 571.	15.3	40.9	79.7	6.38	1.55	3.19	0.417	11.5	6.29	1.44	330.	4.31	36.0	12.3	1.13	
605	7 7/4	FINE	BOWL	70.	5.07	1.9 878.	13.4	32.8	66.2	5.37	1.22	2.51	0.370	11.6	5.52	1.17	258.	3.93	30.2	13.8	0.72	
607	7 7/3	MEDIUM	FRYINGPAN	94.	7.21	2.2 820.	15.6	30.6	60.4	5.08	1.26	2.85	0.365	9.6	5.13	1.02	335.	4.21	32.0	9.4	0.82	
DOO:	5 SAMPLES MEAN VALUE			76.	6.55	4.91122.	15.6	35.2	67.5	5.56	1.32	2.82	0.394	11.1	5.36	1.15	288.	4.44	30.6	12.1	0.86	
	STANDARD DEVIATION			30.	1.53	4.7 600.	1.7	4.4	7.2	0.56	0.31	0.30	0.026	0.9	0.58	0.29	66.	0.43	3.7	9.1	0.18	
	STD. ERROR OF MEAN			13.	0.69	2.1 268.	0.6	2.0	3.2	0.28	0.14	0.13	0.012	0.4	0.26	0.13	29.	0.19	1.6	4.1	0.08	
ROUGH																						
185	5 6/4	SEMIFINE	BOWL	98.	4.58	1.9 286.	21.9	22.4	47.9	4.97	1.24	4.00	0.429	7.8	5.63	0.58	102.	4.59	19.2	9.1	1.87	
186	7 7/4	COARSE	BOWL	65.	2.30	0.81112.	19.7	18.9	42.2	4.29	1.06	3.09	0.528	5.9	5.01	0.75	238.	4.09	23.4	7.8	1.08	
187	6 6/4	COARSE	BOWL	115.	3.20	2.11065.	22.5	21.5	46.2	5.06	1.28	3.15	0.478	6.8	4.83	0.56	210.	4.66	21.3	17.6	1.62	
188	7 6/3	COARSE	BOWL	55.	2.87	5.11109.	23.6	26.2	51.9	5.72	1.44	3.78	0.547	7.5	5.28	0.70	209.	4.75	24.4	11.0	1.37	
189	6 6/4	COARSE	BOWL	67.	4.09	4.5 479.	20.2	23.6	47.2	5.08	1.23	3.20	0.495	7.0	5.66	0.77	164.	4.44	23.0	8.7	1.53	
411	6 6/2	COARSE	BOWL RIM	82.	3.90	5.2 332.	20.0	17.5	61.5	4.27	1.23	3.64	0.557	7.9	5.18	0.55	95.	4.07	16.5	5.2	1.82	
602	5 7/3	FINE	JAR	68.	3.55	2.01110.	21.8	23.0	52.9	2.84	1.22	2.68	0.371	9.6	5.10	1.18	99.	5.11	22.6	7.4	0.43	
604	7 6/1	MEDIUM	JUG	122.	5.10	2.3 918.	24.2	24.6	54.7	4.63	1.15	3.24	0.461	8.1	4.49	0.94	141.	5.41	34.5	9.0	0.87	
606	6 6/2	MEDIUM	FRYINGPAN	89.	6.26	5.6 662.	20.4	26.9	59.5	5.65	1.49	3.44	0.491	8.7	4.40	0.72	142.	4.40	23.8	13.3	1.07	
611	7 6/2	COARSE	FRYINGPAN	51.	3.74	4.11250.	21.0	17.8	39.0	4.04	1.06	3.02	0.430	6.1	4.16	0.49	104.	4.48	14.0	17.6	1.39	
612	8 6/2	COARSE	FRYINGPAN	74.	5.17	6.1 446.	16.8	24.3	46.8	4.61	1.05	2.59	0.381	7.5	3.76	0.61	94.	3.88	17.8	11.7	0.65	
623	7 7/2	COARSE	PYXIS	96.	4.32	2.4 652.	16.0	27.5	59.1	4.20	1.06	2.35	0.345	11.5	5.34	0.74	83.	4.18	17.3	4.1	0.46	
ROUGH:	12 SAMPLES MEAN VALUE			82.	4.11	3.5 785.	20.7	22.9	50.7	4.61	1.21	3.16	0.465	7.9	4.70	0.72	140.	4.51	21.5	10.2	1.18	
	STANDARD DEVIATION			23.	1.09	1.8 347.	2.4	3.4	7.1	0.78	0.15	0.49	0.070	1.5	0.59	0.19	54.	0.44	5.3	4.3	0.50	
	STD. ERROR OF MEAN			7.	0.31	0.5 100.	0.7	1.0	2.0	0.23	0.04	0.14	0.020	0.4	0.17	0.06	15.	0.13	1.5	1.2	0.14	
UNCLUSTERED SAMPLES																						
019	5 5/8	EXTRAFINECLAY		169.	16.55	0.0 206.	22.5	27.6	51.2	4.24	1.06	2.43	0.374	9.2	3.45	0.66	267.	6.31	37.3	15.5	1.10	
018	7 5/6	EXTRAFINECLAY		153.	12.03	11.3 266.	22.7	27.5	52.0	4.07	0.97	2.44	0.331	10.7	3.46	0.64	268.	6.36	39.0	13.5	1.16	
103	9 8/7	FINE	SAUCEBOAT	20.	5.92	10.3 787.	20.7	26.5	58.1		0.52	2.35	0.328	9.6	4.31	0.44	277.	5.15	26.9	4.8	1.43	
104	5 8/4	SEMIFINE	SAUCEBOAT	14.	4.20	17.51655.	15.0	20.4	39.0		0.92	1.89	0.251	5.6	2.59	0.24	424.	3.97	36.6	6.9	0.64	
111	6 7/4	SEMIFINE	SHERD	22.	6.41	14.4 466.	16.4	21.7	39.1		0.11	1.97	0.286	6.0	2.92	0.36	260.	4.10	29.9	8.1	0.68	
116	8 8/2	SEMIFINE	WASTER	23.	6.29	16.8 171.	18.1	21.4	38.2		0.99	2.02	0.270	7.4	2.99	0.25	380.	4.56	33.9	5.8	0.74	
160	6 7/2	FINE	SAUCEBOAT	68.	0.90	7.61328.	26.8	32.9	69.0	5.32	1.40	3.02	0.388	12.6	3.89	1.12	292.	6.42	36.7	11.8	0.70	
303	6 7/4	SEMIFINE	SAUCEBOAT	14.	1.38	6.51513.	25.1	24.4	53.3	4.81	1.23	2.89	0.373	7.8	3.41	0.72	539.	6.09	45.9	5.6	0.73	
401	6 6/4	COARSE	PLATE	74.	4.72	5.6 299.	19.7	20.0	40.3	3.48	0.96	1.94	0.296	6.2	2.87	0.561112.	5.04	48.9	4.2	0.82		
405	8 7/2	COARSE	PLATE	107.	8.72	6.2 385.	23.4	38.3	69.2	8.71	2.39	5.08	0.710	8.8	5.88	0.60	122.	4.38	19.6	0.0	2.26	
412	6 6/4	COARSE	BOWL RIM	120.	6.42	4.3 373.	23.0	26.2	57.0	7.29	2.01	5.22	0.790	9.0	6.76	0.72	92.	4.36	16.5	20.2	2.82	
601	7 6/2	COARSE	FRYINGPAN	67.	4.56	5.2 839.	19.6	27.8	61.3	6.26	1.56	3.50	0.713	9.0	5.29	2.08	102.	4.02	86.4	19.3	1.92	



The group FINEST has very high values of all the trace elements. Its calcium and cobalt concentrations are slightly lower than those of CLOCAL, however. Group ODD follows the same pattern as FINEST, differing only in much higher hafnium and tantalum values, and lower rubidium, scandium, and iron concentrations. Finally, the group ROUGH has a pattern of trace-element concentrations intermediate to those of the "L" and "F" groups. It is characterized by low cesium, calcium, chromium, and cobalt values, but high ytterbium, lutetium, and hafnium ones.

Certain sets of elements seem to follow the same pattern in the rise and fall of their values within different groups. Iron and scandium are notable in this respect, as are the trio ytterbium, lutetium, and hafnium. The degree of correlation between pairs of elements has been computed by the clustering program used in this study. Elements with correlations around 0.9 are the pair scandium-iron, the trio lanthanum-cerium-thorium, and the pair ytterbium-lutetium. At a coefficient of 0.7-0.8 the elements europium and hafnium are also correlated with ytterbium and lutetium. (A correlation coefficient of 1.0 indicates perfect correlation or strict dependence, and one of 0 indicates independent variation.)

The high correlations among sets of rare earth elements (lanthanum to lutetium in the Periodic Table) has led some workers to use only two or three of those elements for pottery classification by trace-element concentration (Perlman

and Asaro 1969). However, Brooks et al. have shown (1974) that, although correlations between rare-earth elements may be high, slight variations in the ratio of, for instance, scandium to iron or thorium to hafnium are significant criteria for distinguishing between groups. These correlations are taken into account by the multivariate statistical procedures used in the present study, so that no elements were omitted from the grouping procedure because of high correlation coefficients.

The large spreads of some concentration values even within a group can be caused by either of two factors. The first is the low precision of the activity measurements themselves as shown in Table III. Elements difficult to determine accurately included tantalum and rubidium. The second is the large variation in concentrations of certain elements in pottery made from the same clay bed, caused by variations intrinsic to the clay bed itself or by changes in concentration taking place since the pottery was made (see section 1.1). Cesium, calcium, and barium probably suffered from this fault. Nevertheless, clustering programs run without these elements gave approximately the same groups (Table VI). The differences in the placement of a few specific samples are discussed in section 6.4.5.

#### 6.4 Archaeological Implications of the Groups

##### 6.4.1 Locally-Manufactured Material

The decision to assign to the pottery of groups A, B, and C a local origin was made on the basis of the inclusion of five clay samples 010-015 and the six mud-brick samples 201-206 among those groups (see section 4). The subdivision into 3 groups was rather surprising, but can be explained by postulating that the ancient potters used several nearby clay beds for their raw material. Only the clay beneath the rubbish dump could be analysed, but good clay sources also exist both below the central part of the site (as revealed by the modern canal joining lake and sea) and a few hundred metres to the north. It is possible that the groups ALOCAL and BLOCAL differ only in the degree of refinement of the clay, since clay samples 012, 013 and 014 were members of BLOCAL, but 010 and 011 belonged to ALOCAL, with 011 to some degree intermediate between the two groups, as shown in Figure 9 (top, slightly right of centre). Pottery in group CLOCAL seems to have been made from a different clay source. However, examination of Table V reveals that BLOCAL is more similar to CLOCAL in composition than to ALOCAL, the reverse of the expected situation. The relations among these 3 groups can be clarified only by further analysis (see section 7) but their local origin is certain.

The material contained in these local groups is all of EH date. Besides the clay and mud-brick samples, there is a lot of material from the pottery dump. This is a reassuring sign, since by far the greatest amounts of pottery recovered came from those excavation levels, and to import such quantities of ordinary pottery when good clay was available would have been unusual for a settlement of this size. Shapes include shallow plates (402, 403, 404, 406, 407), large bowls (408, 409, 410, 413, 419, 420, 422), a pan (414), a deep saucer (417), and a couple of jar rims (415, 416), in semicoarse and semifine fabrics ranging in colour from reddish-brown to pale yellow. Sample 422, which may be a waster fragment, is also local in origin.

The local nature of much of the material from the small square structure, the middle occupation phase of the EH II period, is of great interest in that some of the most unusual ceramic pieces were found in it. The two saucers 101 and 102 are typical EH II products (as is 302, the one from the "B" excavation area), but the very shallow bowl 105 is less commonly found. The rectangular dish (107) divided into two compartments (here termed a "salt pot" because of its resemblance to modern Greek salt-and-pepper dishes) is apparently unique, though the inclusions in the fabric are common enough, as is the dark red slip. The vase in the form of a ram is also unique. It would be interesting to analyse the sauceboats from Tiryns and Korakou with spouts in the form of ram heads mentioned by Weinberg (1969),

to see if they too were Vouliagméni products or were made where they were found.

Also of local manufacture were four unusual objects from the pottery dump which had been recorded separately during the excavation. The bowl fragment with the impression of a woven mat on its base (112) shows that at the Vouliagméni site potters occasionally placed their pots on such a mat so that they could be easily turned while being formed, a technique common enough in Early Bronze Age Greece (see, e.g., Wiseman 1967: 25 n.19). (The potter's wheel had not yet been introduced to, or invented in Greece at this time.) The clay lump with impressions of a round seal on it (113) indicates that products of some sort were being stored or transferred for eventual use at some other time or place so that a record of their origin had to be marked on them. Renfrew (1972: 386-90) has hypothesized from the large number of seal impressions found in the large "House of the Tiles" at Lerna (Heath 1958) that a complex system of produce redistribution had been organized with the large building acting as the storage centre. This process, possibly on a smaller scale, may have been taking place also at Lake Vouliagméni. The fact that one sealing was found does not prove this, but the local origin of the clay indicates that whatever was sealed, was sealed at Vouliagméni and was not just a stray imported piece. Of course, the seal itself may have been made elsewhere, though in fact its design is not similar to that of any of the Lerna sealings.

Another feature in common between various Argolid sites (including Lerna) and the site at Lake Vouliagméni is the use of ceramic tiles, presumably as roofing material. That some of the Vouliagméni ones were made locally is shown by the analysis of sample 115, a tile decorated with triangular impressions along its rim. Only one tile fragment was sampled, though the type of inclusions present in the others suggest association with the ROUGH group (see below, section 6.4.4).

The creative imagination of the Vouliagméni potters is further shown by sample 115, part of a ceramic figurine in the shape of a fish. This was made of better-refined clay than the ram vase, and more care was taken in its execution and surface finish. It could have been made in a mold, although there is no evidence for this.

Four samples from an occupation level of the final phase of EH II occupation proved to be of local manufacture (151-154). The first three are made in a "green-with-tiny-black-inclusions" fabric, of which are also made the mud-brick samples 201 and 205, and jars 415 and 416, rather more yellowish in colour (and the waster 116, which has been designated as an unclustered sample and so is discussed in section 6.4.5). All of these are local products, so it is probably safe to say that this fabric indicates local provenance for unsampled Vouliagméni pottery as well. Sample 154 is catalogued as "semi-fine buff with a few dark red inclusions". This is an even more

common fabric type at Vouliagméni, occurring in much of the local material from the square structure and the dump. It, too, is a reasonable sign of local manufacture, though pottery with the same type of mineral inclusions can and probably does also occur elsewhere. Buried below the Archaic sanctuary of Hera at the end of the Perakhóra Peninsula was found a small EH deposit (Payne 1940). Among the coarser wares of that deposit were pieces in the same fabric with dark red inclusions, which Payne said were "presumably the chippings from a local limestone" (1940: 51). The ones in Vouliagméni pottery are not limestone, since HCl does not dissolve them, but they may be bits of chert, a flintlike stone often found in the form of nodules within limestone formations, and common at many points around the east end of the Gulf of Corinth. The restricted extent of the sanctuary area indicates an EH settlement consisting of a few houses at most. It is highly unlikely that pottery was made there, and indeed since the site at Lake Vouliagméni was probably the largest EH settlement on the peninsula, it may have served as a regional centre for pottery manufacture.

Early Helladic pottery of the same fabrics has also been found across the Gulf of Corinth at Keramidáki (Cherry 1973). Cherry has classified a sample of over 1,000 sherds from EH levels there into six fabric groups, one of which was further divided into four subgroups. His group 1 (accounting for 20% of the total sample) corresponds exactly with the "green-with-black-inclusions" fabric, and his ~~group~~ 3b (4%) matches the "buff

with dark red inclusions". The former occurred mostly in jars and jugs, while the latter was spread over various shapes. He stated (1973: 79), "The small number of fabric classes at Keramidáki does suggest ... that the overwhelming majority of the ceramics are of local origin and manufacture." In view of the close connection of some of these fabrics with the Vouliagméni site, chemical analysis of sherds from Keramidáki might prove particularly revealing (see section 7.2.1).

Finally, two sherds of EH I date (613, 622), both rather unusual in nature, also fall in the local groups. It is perhaps surprising that only two EH I sherds fall into these groups, given the large number of EH II sherds that do. The nature of the EH I settlement at Lake Vouliagméni is discussed in the next section.

#### 6.4.2 The Group FINEST

This large but uniform group comprises every piece of **sampléd** pottery of Late Helladic and Archaic date, together with about half of the **sampléd** EH I pottery and three EH II sherds. This material was not made at Lake Vouliagméni, for it matches none of the other local material, and more importantly the extents of the Late Helladic and Archaic occupation at the site seem so small that pottery manufacture there is unlikely. Such fine pottery as was found there must have been made at a major production centre. For Archaic "Corinthian" pottery the



major centre was ancient Corinth. From the harbours of Corinth, pottery was exported throughout the Archaic Greek world; Lake Vouliagméni was but a short distance away. There is little doubt that all the Archaic pottery found at Lake Vouliagméni was made at Corinth. Therefore the Late Helladic, or Mycenaean, pottery must also have been made there, as well as the EH I sherds of FINEST and the three EH II sherds.

Another check on the origin of this pottery can be made. Perlman and Asaro have analysed Late Helladic sherds from Mycenae using their own standard pottery as reference material (Karageorghis et al. 1972). The results of their analysis of 16 sherds, given as an average in Table V, are thus directly comparable to the ones of the present work. An average-link cluster analysis using the eleven elements common to both sets of results yielded a dendrogram with the Mycenae "average sample" well within the FINEST group, clustering together with 523, 606, and 615. This means either that pottery produced at Mycenae matches Corinthian ware in composition, or that the Mycenae pottery sampled was actually made at Corinth. At any rate, the Late Helladic FINEST pottery was made in the north-east Peloponnese, across the Corinthian Gulf from Lake Vouliagméni.

What does this imply about the site during the EH I period? Obviously, it had close connections with the Corinthian area. In fact, very little of its pottery seems to have been made at Lake Vouliagméni itself. It is significant that no

pottery from the preceding Neolithic period has been found during surface surveys at the site. It seems that the earliest occupation at Vouliagméni was during the first phase of the Early Bronze Age, and that it was restricted to the lower, central portion of the land between lake and sea. (It certainly did not extend as far west as the area of the 1972 excavations.) The EH I settlement may have been merely an offshoot of settlement in the area of Corinth itself, dependent on that area for its fine pottery, and not using the locally-available clay sources. By EH II times it had grown larger and more self-sufficient.

The three EH II sherds included in FINEST are 304, 418, and 510. Of these, 304, a semifine askos rim from the "B" excavation area, is less closely related to the main group (differing slightly in rubidium, cesium, calcium, barium, and chromium contents) though it very probably shares the same place of origin; the fine jar rim 418 certainly does. The mottled-ware sherd 510 also does, in contrast to the sherd 160 of the same fabric, which has been relegated to the set of unclustered samples. Among the Late Helladic and Archaic pottery the samples 506, 521, 501, and 526 are less closely related to the main group, the first pair because of high chromium concentration and the second because of high barium concentration, but their attachment to the group is still quite strong, and they probably were also made in the Corinth area. At any rate, nothing in their physical appearance suggests otherwise.

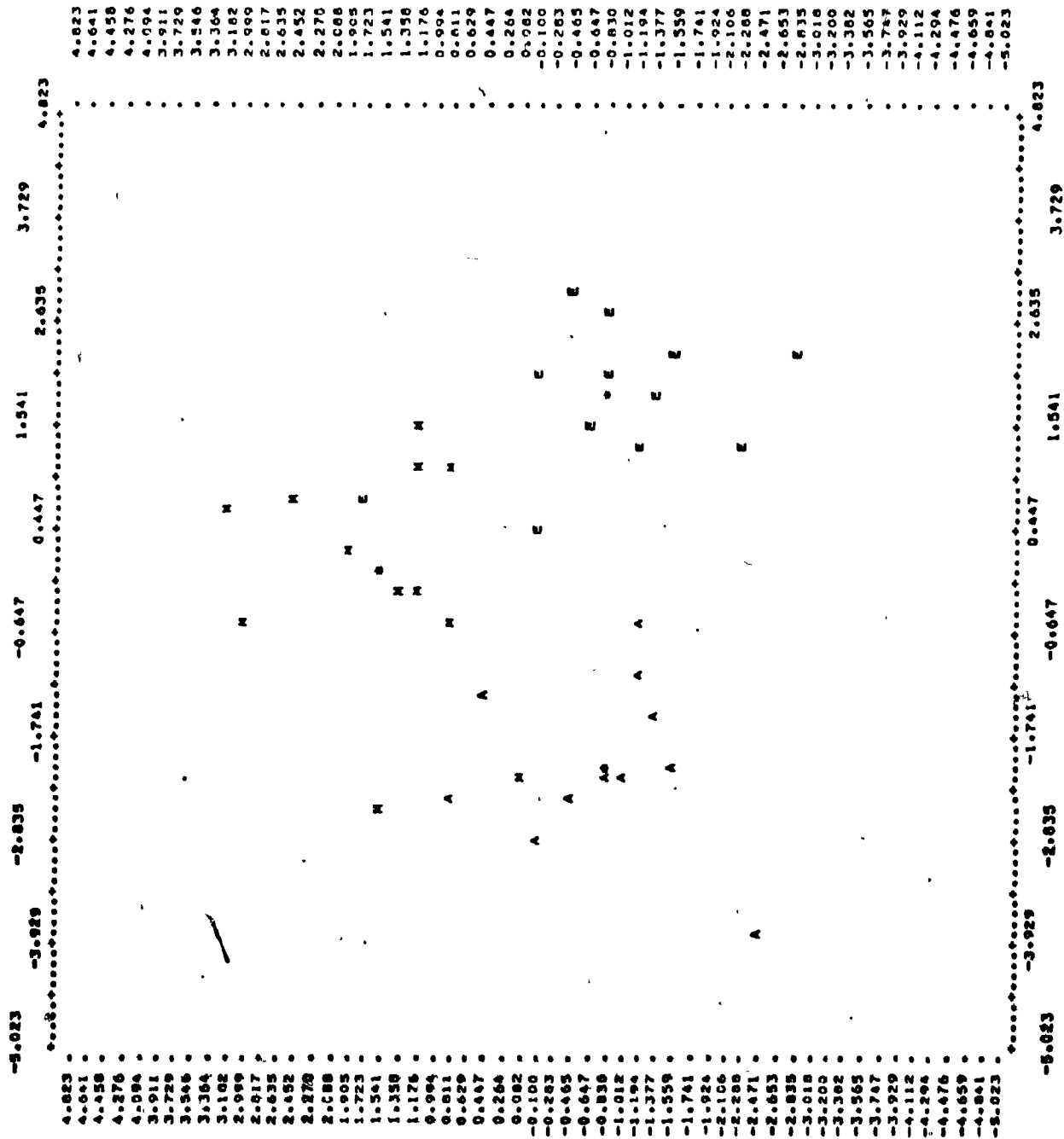
An attempt was made to find chemical differences among the EH ~~or~~, Late Helladic, and Archaic pottery of FINEST, using discriminant analysis. The resulting plot showing the best separation of these samples into chronological groups is given in Figure 10. The separation is quite poor, though some differentiation is visible. The elements causing this are given by the program as cobalt and barium, and to a lesser extent lanthanum, scandium, hafnium, and ytterbium. These slight differences are most probably due either to mining of the same clay bed at slightly different locations, or to varying degrees of clay refinement.

#### 6.4.3 The Group ODD

Little can be stated about the group ODD. The fabrics range from coarse to fine and the surface colours from dark red through orange, buff, brown, grey, and black, though the colour at the core of the sherds stays close to 10YR 7/4. Nevertheless the group is quite homogeneous chemically. Three of the shapes are unusual for Lake Vouliagmeni: the jug 301, the bowl rim with the heavy loop handle 605, and the "frying pan" 607. This may indicate that the group is not local, and indeed may be Cycladic in origin, as the "frying pan" is probably of the Syros type (Renfrew 1972: 528). Its composition certainly does not match that of any of the products so far considered local. The pitted surface and twisted form of the bowl rim 421 suggest that it was damaged during firing, so that it may be a local waster,

FIGURE 10

Discriminant-analysis plot of the first two canonical variables for group FINEST, showing the chronological subdivision into EH I ("E"), Mycenaean ("M"), and Archaic ("A") wares (group centroids are indicated by asterisks).



but on the other hand its variegated surface may have been attractive enough to overcome its deficiencies. Too little of the pot survives to make a definite decision. The nature of the group as a whole is likewise left vague.

#### 6.4.4 The Group ROUGH

This group is composed almost entirely of coarse pottery. The EH I fabrics are mostly grey-brown while the EH II ones tend to be reddish, but almost all have large grey angular inclusions. This large amount of tempering material probably accounts for the uniformity in the trace-element composition of the group (though 155 and 602 are semifine and fine respectively). The differences in colour between the EH I and EH II fabrics may derive from differences in the availability of oxygen during the firing of the pots: an oxidizing atmosphere transforms the iron in the clay body to its reddish ferric state from its darker ferrous form (Shepard 1965). The origin of this group is not entirely clear. Coarse pottery is generally designated local ware by archaeologists on the grounds that it is made less carefully without adhering to high artistic standards, and that its often large size makes it difficult to transport (unless, of course, it is being used as a container for transporting other goods). This group of pots may be locally made, though it does not match any other local products in trace-element composition; the EH I settle-

ment may have been self-sufficient as far as coarse pottery is concerned. On the other hand, though the "frying pans" need not be considered imports from the Cycladic islands, an origin in Attica is implied for them by Renfrew (1972: 535). The problem could be solved by analysing other "frying pans", or by petrological examination of the inclusions. It is interesting (but puzzling) to note that the inclusions of 105 and 613, both members of CLOCAL, seem to be of the same type as those of most of the ROUGH sherds.

#### 6.4.5 Unclustered Samples

This section is necessarily less conclusive than the preceding ones, but nevertheless illustrates that sherds of unusual chemical composition can either be unusual also in appearance or else may seem to belong to quite common types.

The samples 015 and 016, though prepared from the same clay as 010-014, show radically different composition patterns. Compared to those of 010-014, the concentrations in 015 and 016 of rubidium, cesium, scandium, iron, cobalt, arsenic, and antimony almost double, while those of lanthanum, cesium, thorium, and chromium show only slight increases, those of barium, samarium, europium, ytterbium, lutetium, hafnium, and tantalum remain approximately the same, and that of calcium decreases. The effect of centrifuging is to draw out of suspension all particles larger than a certain size. That the concentration

of calcium decreased indicates that in this clay some of those particles have a high calcium content. That the concentration of other elements remained constant or rose to various extents indicates that the particles have generally low concentrations of some trace elements, but that the pattern of trace-element concentrations differs from that of the fine clay. If indeed the degree of refinement of samples 015 and 016 corresponds to that of the liquid "slip" occasionally applied as a surface coating to pottery, analysis of this slip (which flakes off some pots quite easily) could also serve as an indication of place of origin. This analysis could perhaps be accomplished by X-ray fluorescence without the necessity of defacing an intact pot.

Samples 103 and 104 are both from sauceboats found in the square structure. The fabric of 103 is a very fine pale green, not otherwise found at Vouliagmeni except for some EH I pottery which belongs to the FINEST group. 104 is not as fine, but contains small inclusions of various sorts. Though the extremely well-made sauceboat 103 could be considered an import on archaeological grounds, nothing about 104 is exceptional. They have been excluded from clusters because of their very low rubidium contents, though 103 is very low also in europium. The sherd 111 has an even lower europium content; the mass of deep incisions on it is very unusual but gives no hint as to its origin.



One surprising result of the cluster and multivariate analyses was the relegation of the waster fragment 116 to the set of unclustered samples. It was put there probably because of its low barium content, though the rubidium and tantalum values are also below normal. A possible explanation of these discrepancies in the composition of an object whose origin was assumed without a doubt to be local, is that the extremely high temperatures to which it was subjected left it in a chemical state either already depleted in some elements or amenable to their depletion during subsequent burial. In retrospect it is easy to say that the sampling and analysis of several more of these waster fragments might have clarified their status among Vouliagmeni wares.

The mottled-ware sherd 160 was also left unclustered, primarily because of a very low cesium content. Its composition is thus in marked contrast to that of the other mottled-ware sherd 510, which has one of the highest cesium contents. They also differ by a factor of two in rubidium concentration, though the other elements agree quite well. Their fabric is technically the best found in the Early Helladic period, so that the existence of only a small number of specialized production centres for this ware would not be surprising. Its distribution is relatively wide, ranging from Eutresis to Lerna. The sauce-boat 303, although quite different (and rather ordinary) in appearance, also has a low cesium content, but its extremely

low rubidium concentration sets it apart from the other samples.

Two of the sherds from plates or shallow bowls had unusual composition patterns, though neither of them looked unusual. 401 had a chromium concentration of over 0.1%, more than double the normal value. The composition of plate 405 matched that of 412, a bowl rim with "piecrust" decoration. The former is described in the catalogue as "coarse green" and the latter as "coarse red ... with a thick green slip". In fact, these may be the same fabric with the red colour not showing up well in 405. Both are characterized by extremely high concentrations of samarium, europium, ytterbium, lutetium, and to a lesser extent hafnium and antimony.

Finally the "frying pan" 601, similar in fabric to pans 611 and 612 and absolutely typical of the mainland type (Renfrew 1972: 536), is left unclustered mainly because of its high tantalum and cobalt concentrations, though omitting those in the clustering programs did not cause it to join any group very closely. In the case of 601 these high values were caused by contamination from the drill bit, which had broken during sampling. The same problem had occurred with 621, which fortunately could be re-sampled with a new bit. Both contaminated samples showed very large gamma-ray peaks at 134.2, 479.5, and 685.7 keV when the activity was measured one week after irradiation, indicating the presence of tungsten (Wakat 1971). The later activity measurement showed very high tantalum and

cobalt concentrations in the contaminated first analysis of sample 621 compared to those of the uncontaminated second analysis. (The results of only the second analysis of 621 are presented in Tables II and V.) These contaminated samples illustrate the improvements made in analytical technique since the first neutron activation studies of pottery were done. One such early study (Emeleus 1958) found tungsten carbide drill bits totally unsatisfactory for sampling since the radiation from the activated tungsten covered the whole spectrum of the sodium iodide gamma-ray detector, obscuring all the other peaks. The high-resolution detectors used in studies today avoid that problem altogether. The only elements affected (of the ones measured in this study) are tantalum and cobalt, which probably occur in small quantities in the drill bit material.

A comparison of these unclustered samples with the analyses of Late Helladic pottery reported in Bieber et al. (1975) failed to show any matching composition patterns.

Because so many of these unclustered samples have erratic rubidium, cesium, or barium values, and because these elements are easily soluble and can be leached out of or deposited into buried pottery (see section 1.1), a cluster analysis excluding them was attempted. Tantalum was also omitted since it is determined only with very low precision in this study (as are the other three elements too, in fact). The resulting clusters are shown in Table VI. The major groups

TABLE VI

Major groups as indicated by average-link clustering  
using as variables the concentrations of the elements Sc, La,  
Ce, Eu, Yb, Lu, Th, Hf, Cr, Fe, Co.

A	B	C	F	O	R	<u>unclustered samples</u>
010	011	101	(015)	301	155	111
104	012	102	(016)	421	156	405, 412
113	013	103	(106)	605	157	601
114	014	105	(153)	607	158	623
115	151	107	160		159	
202	(154)	108	304		411	
206	201	112	(417)		602	
402	406	116	418		604	
(403)	410	(152)	501-505		608	
404	(416)	203	(506)		611	
409	419	204	507-514			
414	622	205	516-520			
420		302	(521)			
422		(303)	522-526			
		(401)	603			
		407	606			
		(408)	609			
		413	610			
		415	(613)			
			614-621			
			(622)			

are approximately the same, and have been labelled accordingly, but some of the previously unclustered samples have been added to these groups. In particular the sauceboat 104 is in "A", the sauceboat 103, waster 116, sauceboat 303 and plate 401 are in "C" (though the latter two are not too closely associated), and the mottled-ware sherd 160 is in "F" as are the clays 015 and 016. The incised sherd 111, the plate and bowl rims 405 and 412, and the "frying pan" 601 were left unclustered, as was the lentoid pyxis 623.

These assignments are interesting and not totally unexpected, though they should be accepted only with reservations. To say that this classification is "better" because it assigns the waster 116 to a local group as well as lowering the number of unclustered samples is faulty logic, because the desirability of these results is not based on their intrinsic value but on the archaeological interpretation applied to them. In principle, the more variables included in a cluster analysis, the better the analysis will be; certain elements may be excluded only if there is substantial independent evidence for doing so. Table VI is presented here only to show the possibility that some of the unclustered samples actually belong to major groups. Much more research needs to be done into the ease of deposition or leaching of various elements in archaeological ceramics before certain elements can a priori be excluded from consideration in group formation.

## 7. CONCLUSIONS

### 7.1 The Sequence of Phases at Lake Vouliagméni

The results of the pottery analyses have helped to clarify the nature of the Vouliagméni site and its relationship to others in its vicinity at various times during the span of over two thousand years from the earliest to the latest phases of occupation there. During the EH I period, the site seems to have been in close contact with some settlement(s) in the vicinity of Corinth. Its fine pottery was all imported from there, to such an extent that locally-available clay was hardly used. Its coarse, "domestic" pottery seems to have all been made at a single production centre in a distinctive fabric though the origin of this pottery is not known.

• During the succeeding EH II period the settlement at Lake Vouliagméni gained a measure of independence, or perhaps isolation. The flow of fine pottery from the Corinth area stopped, to be replaced by locally-made fine and semifine wares, including some of the most distinctive and unusual vases found there. At least two local clay sources were used, one of which was right at the site. Much of the coarse pottery came from the same source as the corresponding EH I material. (This move to independence in ceramic production was echoed by a similar move in the production of flaked stone blades (Fossey 1974b)). Whereas in EH I the lithic raw material was obsidian, originating

in the Cycladic island of Melos, in EH II the slightly inferior but locally-available chert was largely used instead.)

The other two phases of occupation at Lake Vouliagméni, during the Late Helladic and Archaic periods, seemed from the evidence of the excavations to be very minor indeed. This was confirmed by the ceramic analyses, which showed that all the sampled pottery in both periods originated across the Gulf of Corinth. There has been no evidence for subsequent occupation at the site from the fifth century BC to the present day.

## 7.2 Directions for Future Research

### 7.2.1 Further Investigations of Vouliagméni Ceramics

In retrospect a number of additional facets of ceramic production at Lake Vouliagméni could have been explored. (There may be opportunities for this at some future time.) The confusing result of the single waster fragment analysis could perhaps be clarified by further analyses of half a dozen more of these pieces, to determine if the one sampled was actually characteristic in composition. Loom weights, many of which were found belonging to both the EH I and EH II periods, are simple clay objects almost certainly of local manufacture whose composition could provide yet another check on the chemical "fingerprint" of local material. Many fragments of decorated tile (which may in fact be pieces of "ceremonial hearths"; (cf. Vermeule 1972: 39) were

found in the debris of the final phase of EH II occupation, apparently made in the same fabric as the coarsest EH I and II material. Trace-element analysis could perhaps confirm this suspicion. Finally, a concentrated study of the clay beds available to Early Helladic potters along the entire Perakhóra Peninsula would prove invaluable as a check on the variability in the trace-element composition of clay over a restricted region, and might clarify the relationship of the coarse pottery group to the local wares.

One method of pottery provenance especially relevant to this problem is the separation and mineralogical examination of inclusions in the ceramic fabric (Peacock 1970). In the study of coarse and semicoarse wares such as the ones from Lake Vouliagméni this method may be even more useful than neutron activation analysis. The two methods can also be combined: separate activation analyses of the inclusions and the fine fraction of a pot-sherd could clarify the relationship between tempered and untempered pottery made from the same clay.

Further experiments in the refining and firing of the clay sample already analysed, and of others if possible, would no doubt shed much light on the relationship of colour, fineness, and hardness to clay pretreatments and firing conditions. More study of the changes in the pattern of trace-element concentrations in clay as it undergoes progressive refinement seems to promise interesting results. An estimate of the firing



temperatures of Vouliagméni ceramics can be obtained by microscopic examination of the mineral phases in thin sections of the pottery. Another aspect of pottery manufacture is being explored by Donald Sedgwick, who is preparing a computer study correlating form and fabric types of a large sample of rim sherds from the pottery dump.

#### 7.2.2 Trade Relations in the Early Bronze Age Aegean

A larger project (using the Vouliagméni analyses as a basis) investigating Early Helladic pottery found at other sites would do much to clarify relationships between various regions of Greece during that period. In particular, a concentrated study by neutron activation of Keramidáki pottery and of the nearby clay sources could determine the directions of ceramic trade across the Corinthian Gulf. Other excavated EH sites in the north-east Peloponnese have much to offer for sampling as well. At Lerna the transition from EH II to EH III is especially interesting in view of the wheel-made pottery found there in the latter phase (Caskey 1960). To the north, the pottery of Eutresis stands out as ideal comparative material to that from Lake Vouliagméni, though some pottery from closer sites should be sampled as well. The composition of pottery from Áyios Kosmás in Attica may be relevant to Central Greek trade patterns to some extent, but it nevertheless is probably related more closely to Cycladic patterns, as is Early Bronze Age pottery from the island of Kéa.

It might seem redundant to analyse pottery made in the same place at many different times, since the composition is not likely to vary much unless different clay beds were used. To some extent this attitude is justified, and the many analyses of Late Helladic pottery already done save some work for students of the Early Helladic period. Nevertheless, there are many problems specific to this period which require analyses of Early Bronze Age ceramics. One which concerns the Vouliagméni site in particular is the origin of the different types of "frying pan". Another is the question of whether different forms of sauceboats were made in different areas of Greece, and indeed whether the sauceboat originated in the Cyclades or not. The validity of the regional divisions of the second and third phases of the Early Bronze Age in mainland Greece suggested by Fossey (1974b) can be tested by trace-element analysis of the pottery from each of the various regions. The relative ease of pottery transportation over land and sea can also perhaps be determined by an examination of the principal directions and routes of trade.

As far as the above projects are concerned, the programme of ceramic analysis of Vouliagméni material is only a beginning. Obviously, much more work needs to be done before large-scale results become apparent. However, the value of the analyses to an understanding of the nature of the site at Lake Vouliagméni is already evident. It emphasizes once again the great promise that application of physical science to archaeology holds.

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