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THE PROVENANCE OF BRONZE AGE POTTERY  
FROM CENTRAL AND EASTERN GREECE

The analysis of Bronze Age pottery from Eastern Thessaly, Boeotia and  
Euboea by optical emission and atomic absorption spectroscopy, and  
considerations of its place of manufacture.

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by

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ABSTRACT

The Provenance of Bronze Age Pottery from Central and Eastern Greece.

Samples from nearly 800 Bronze Age pottery sherds from Euboea, Eastern Boeotia and Eastern Thessaly were analysed together with 9 raw clays from the same areas. The analysis was carried out in an attempt to identify areas of pottery manufacture, to discover the origin of specific groups of pottery, to relate pottery to raw clays and to see how far pottery compositions can be associated with, and predicted by, geology. The work was done on the same lines as earlier studies at the Oxford Laboratory and at the British School at Athens. The main analytical technique used was therefore optical emission spectroscopy. Some 25% of the total number of sherds were also analysed by atomic absorption spectrophotometry so that the results obtained by the two techniques could be compared. The interpretation of the results was facilitated by the use of computer program packages for cluster and discriminant analysis.

Both optical emission and atomic absorption analysis resulted in broadly similar groupings although the absolute concentrations were not directly comparable. The groupings obtained after atomic absorption analysis had the narrower concentration ranges. Nine elements were measured by both techniques but in atomic absorption potassium was added and proved useful as an additional discriminant.

Six composition groups were distinguished from the data. One of them was identified as Euboean, 2 as Boeotian and 3 as coming from different regions of Thessaly. The greatest movement of pottery within these areas was from Euboea to Thessaly. No composition group which originated from outside these regions was identified. Six of the 9 raw clays were associated with the prevailing composition group in the area from which they came. It was not possible to predict trends in pottery composition by examination of the local geology.

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PREFACE

This thesis describes the analysis by the author of nearly 800 sherds of Bronze Age pottery and 9 raw clays from Central and Eastern Greece with a view to establishing their place of manufacture according to their chemical composition and to answering specific archaeological questions. The analysis was done using optical emission and atomic absorption spectroscopy. The optical emission analysis was carried out in the Fitch Research Laboratory of the British School at Athens under the supervision of the Director of the laboratory, Dr. R. E. Jones, who also helped to obtain the samples for analysis. The technique used throughout the analysis was that established at the Oxford laboratory in the early 1960s and followed both there and subsequently at the Fitch Laboratory. The Fitch Laboratory's data bank of previous analyses was also used. Nearly a quarter of the samples were also analysed by atomic absorption at the University of Bradford using the method of sample preparation recommended by Dr. M. Hughes of the British Museum Research Laboratory. All of the data was submitted to multivariate analysis using the CLUSTAN and SPSS computer packages at the University of Bradford Computer Centre and with a link to the computer of the University of Manchester.

The sherds from the Euboean sites, from five of the Boeotian sites and from 5 of the Thessalian sites are housed in the sherd collection of the British School at Athens and were selected for analysis by the Director of the School, Dr. H. W. Catling. Dr. Catling also advised on the scope of the project and arranged for the necessary permission to be given for sherds housed in Volos and Larissa Museums to be sampled. The sherds from Thebes in Boeotia are housed in the Swedish Institute in Athens and they were sampled by courtesy of the Director, Dr. R. Hägg.

The remainder of the Thessalian material is housed in the museums of Volos and Larissa. Permission to sample these sherds was given by the Greek Archaeological Service and by the Ephors, Mr. Hourmouziades and Mr. Gallis. Mr. and Mrs. Kakavoyannis of Volos Museum selected the sherds from Velestino which were analysed and provided information about them. The sherds from Argissa and Pevkakia were made available by Dr. K. Kiliános of the German Institute in Athens. The material from Iolkos was sampled for the author by Mr. Robert Avila. The rest of the sherds were sampled by the author. The discussion and the opinions expressed in the text are the responsibility of the author.

Abbreviations used in the text (other than those in common usage).

OES	Optical emission spectroscopy
AAS	Atomic Absorption Spectrophotometry
NAA	Neutron Activation analysis
XRF	X-Ray Fluorescence analysis
BSA	Annual of the British School at Athens
EBA	Early Bronze Age
MBA/MH	Middle Bronze Age/Middle Helladic
LBA/LH	Late Bronze Age/Late Helladic
USGS	United States Geological Survey
GAMS	Gazetteer and Atlas of Mycenaean Sites. R. Hope Simpson, 1965
GAC	Gazetteer of Aegean Civilisation in the Bronze Age. R. Hope Simpson and O.T.P.K. Dickinson, 1979
EUB	Prehistoric Euboea: Contributions towards a survey. L. H. Sackett <u>et al.</u> , 1966
DF	Dr. D. H. French's unpublished survey of Thessaly
Hunter	The Bronze Age in Thessaly and its environs with Special Reference to Mycenaean Culture. B.Litt. Thesis, Oxford, 1954
Oxford	Research Laboratory for Archaeology and the History of Art. University of Oxford
Athens/Fitch Laboratory.	Fitch Research Laboratory of the British School at Athens
$\lambda$	Wavelength
$\nu$	Frequency
$\gamma$	The maximum slope of the graph for Seidel density over $\log_{10}$ exposure, or the contrast factor for the emulsion of the photographic plate



ml	Millilitre
μl	Microlitre
mg	Milligramme
ppm	Parts per million
nm	Nanometre = $10^{-9}$ metre
s.d.	Standard deviation
$\bar{x}$	Mean
I	Intensity
D	Density
S	Seidel density
Exp	Exposure
d.c.	Direct Current
P	Percentage absorption
A	Absorbance

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CHAPTER 1

INTRODUCTION



CHAPTER I

INTRODUCTION

1.1 Introduction to Composition and Provenance Studies of Aegean Pottery by Spectrochemical Analysis.

Composition and provenance studies of pottery are founded on the basic assumption that all clays contain over 50% silica, although the actual amount will vary from clay to clay, yet there will be more significant variations in the concentrations of other elements (major, minor and trace) according to the rocks from which the clay particles originate. These variations are assumed to be greater between clay beds than within any one bed. In this way analysis can hopefully be used to identify centres of pottery manufacture. All the techniques mentioned below involve the removal of a small sample of pottery:- between 10 mg - 2 gms depending on the technique used, and they provide an analysis of the body of the sherd. A sample of this size can be drilled out of a pot so that it hardly shows or broken off the corner of a pot sherd. The choice of elements used is restricted by the choice of analytical technique. Optical emission spectroscopy, for example, uses major, minor and trace elements whereas neutron activation analysis concentrates primarily on minor and trace elements. The usefulness of particular elements will also vary between geographical areas.

In 1960 following a suggestion from Mr. S. Hood, then Director of the British School at Athens, Dr. H. Catling of the Ashmolean Museum, Oxford, and A. E. Blin-Stoyle and E. E. Richards of the Art History and Archaeology Research Laboratory of the University of Oxford began a pilot study involving optical emission spectrographic analysis of Late Bronze

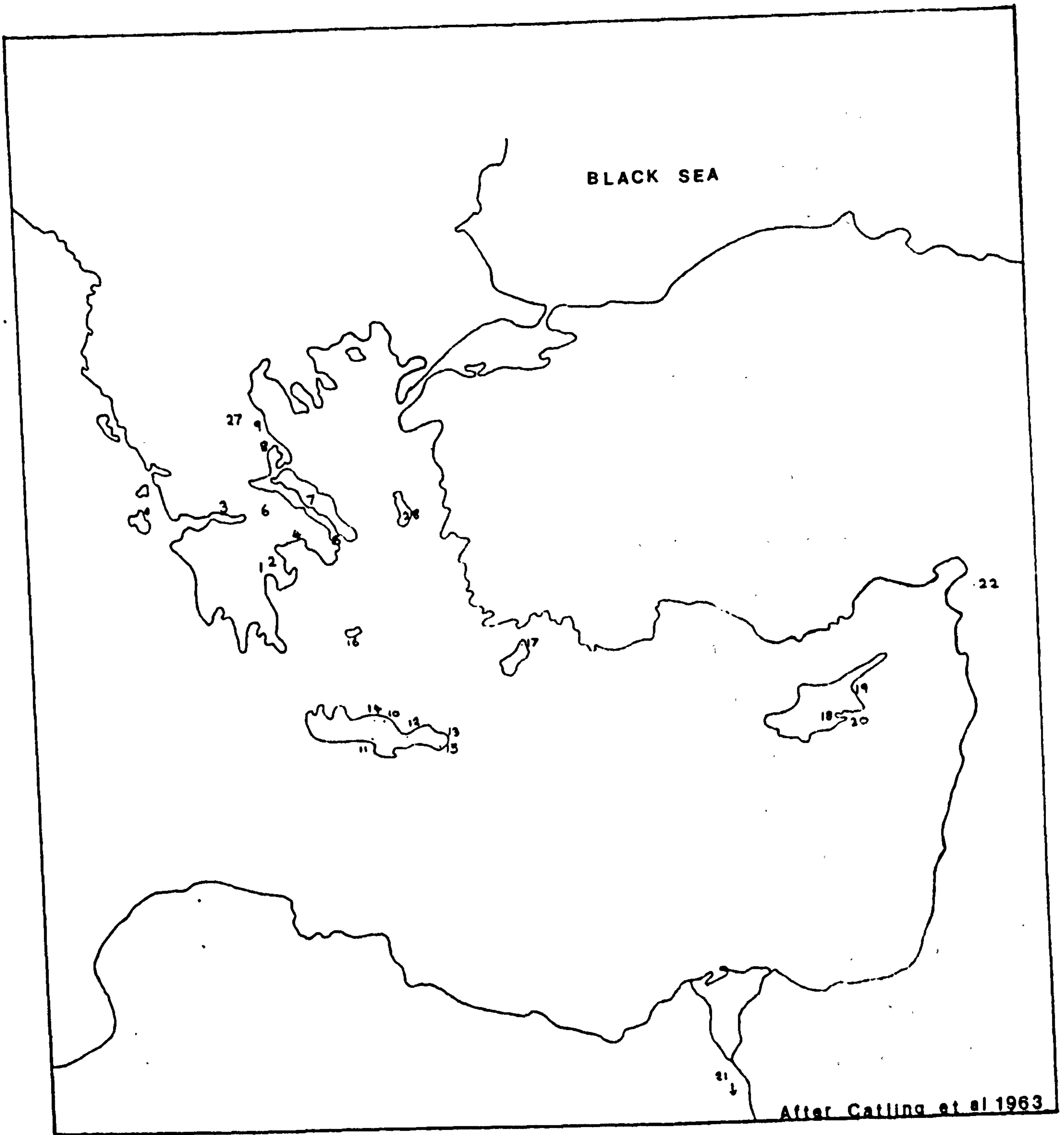
Age Greek pottery sherds to see if they could indeed distinguish between the inferred places of pottery manufacture by the chemical composition of the sherds. They chose the Late Bronze Age for various reasons, including the abundance of well-dated material and the problems associated with identifying the place of manufacture of pottery which was visually very similar throughout the large area under the influence of Mycenaean culture (Catling, 1963, Catling et al., 1963:94-5). Not only were the same decorative motifs and vessel types popular throughout this area but it also appears that wherever they worked the potters tried to use clays which resembled those of the Argolid both in their light colour and in their firing properties. It is probable that important sites like Mycenae and Knossos would probably have manufactured the bulk of their own pottery, but, due to finds of 'closed vessels' of imported types which were obviously used as containers, it is also clear that there will have been trade which involved pottery, not only for its own sake but also as a container for wine, oil, nuts, dried fruit and other substances within the Aegean area. It would also be interesting to discover from where Mycenaean pottery was brought to the Mycenaean settlements and trading stations abroad and how much imitation Mycenaean pottery was made at these sites from local clays.

The original programme of analysis was aimed particularly at trying to differentiate between pottery from Mycenae in the Peloponnese and from Knossos on Crete. These two sites were of especial interest due to the close ties which developed between them in the Late Bronze Age. Not least amongst these was the increasing similarity of their painted pottery. Forty sherds from each of these sites were analysed and material was also included from five other Cretan sites. This period was



also marked by expansion eastwards to the Dodecanese and to the West Coast of Asia Minor. However, since there was such homogeneity in the pottery it remains unclear just how much of this expansion had its origins in Crete and how much on the Greek mainland. To examine this aspect of the problem a total of 137 sherds from 9 other sites as far apart as Rhodes, Cyprus and Thessaly were analysed. The optical emission technique used was that evolved by Richards at Oxford for use on small archaeological samples of pottery rather than metal (Richards, 1959). The results of this project were encouraging, allowing sherds from Knossos and Mycenae to be distinguished from each other and from the Thessalian samples, and from some of those from Phylakopi on Melos. Others from Melos had clearly been imported from the Peloponnese as they closely resembled the Mycenaean sherds in composition (Catling et al., 1961).

An extended project was then inaugurated at Oxford which brought the total number of sherds analysed to over 500 from 28 sites (see map, Figure 1). In this project sherds were examined not only from likely manufacturing sites but also from sites beyond the main area of Mycenaean influence where a considerable amount of Mycenaean pottery has been found. These sites included Tell-el-Amarna in Egypt, 3 towns in Cyprus and Tell Atchana in Northern Syria. The results of this survey were published in *Archaeometry* (Catling, 1963) and more fully in *BSA* (Catling et al., 1963). From the results of these analyses 13 distinct groups, described as Group A to Group M, were identified. They also revealed difficulties in differentiating between the different sites in the Peloponnese. Another problem has been that composition Group B from Crete which is the second most common group and the composition of



1 Mycenae

2 Berbati

3 Korakou

4 Megara Minoa

5 Perati

6 Thebes

7 Amarynthos

8 Volos

9 Marmariani

10 Knossos

11 Ayla Triadha

12 Gournia

13 Palaikastro

14 Tylissos

15 Zakro

16 Phylakopi

17 Ialysos

18 Arpera

19 Enkomi

20 Hala Sultan Tekke

21 Tell - el - Amarna

22 Tell - Atchana

25 Ayios Stephanos

27 Argyropoullis

28 Emporio

Fig 1 Location of sites sampled by Oxford up to 1963

pottery from Thebes in Central Greece appear to be indistinguishable. This has caused considerable controversy over the years because of the effect it has on the provenancing of the Linear B inscribed stirrup jars from Thebes (Catling and Millett, 1965; Catling and Jones, 1977; Catling et al., 1980; Wilson, 1976; McArthur, 1974, 1978). Attempts to solve this problem by examining the germanium contents of the sherds have also failed and one is left to conclude that these two geographically distinct areas have extremely similar clay compositions.

Since 1963 the original scope of the work has been extended to cover a wider geographical area and a greater chronological range whilst maintaining the aim of establishing as complete a composition map as possible for the Greek Late Bronze Age (Millett and Catling, 1967: p.70). By 1967 over 1000 sherds had been analysed but despite good intentions (Millett and Catling, 1967: 70), not all the results have been published. Specific problems have received careful attention. These include the Theban stirrup jars mentioned above which have been the subject of a major study (Catling et al., 1980); the composition of Mycenaean pictorial pottery from Cyprus (Catling and Millett, 1965b); Hellenistic pottery from Athens and South Italy (Prag et al., 1974) and a study of Archaic Greek pottery (Boardman and Schweizer 1973). As the work expanded it was decided to establish the Fitch Research Laboratory at the British School at Athens. It was opened in 1974, run by Dr. R. E. Jones, and after a period of collaboration all optical emission work was transferred to Athens. The results of this work have been published in *Archaeometry* and in the *Annual of the British School at Athens* (Catling and Jones, 1977; Mountjoy, Jones and Cherry, 1978; Jones and Johnston, 1978, etc.).



In aiming to establish a composition map for Late Bronze Age Greek pottery scientists and archaeologists had to establish 'control groups' for each site. This involved the analysis of 10-30 sherds believed on archaeological grounds to have been made at the site in question (Catling and Millett, 1961: 36). A 'control group' should thus give the composition pattern which is present at such a site, or, as is sometimes said, its 'fingerprint'. However, as Catling commented in 1961 (Ibid.: 33) and Perlman and Asaro in 1969 (Perlman and Asaro, 1969), the situation is generally more complex and two or more composition patterns may come from one site and represent not imports but an area in which two clay beds with a different geochemical history have been exploited. In the same article (p.30) Perlman and Asaro stressed that the first aim in such work must be "to establish pottery groups from sherds found at a site, whatever might be the archaeological story behind the groupings". Catling (Millett and Catling, 1967: 70) and Harbottle (1970) both declared that this, and then the application of the results to specific archaeological problems, should be the aims behind composition and provenance work.

In 1974 F. Schweizer working on analysis of Hellenistic pottery at the Oxford Laboratory found it necessary to conduct a recalibration of the analytical method used. One of his reasons for doing this was the fact that the original calibration was based on the analysis of BCRS primary standards and secondary "Greek pottery standards". The composition of the latter had been determined by wet chemical methods. When using this calibration Schweizer found discrepancies between the composition values he obtained for USGS and French pottery standards and the published figures. He wanted USGS standards to be used as the

basis for the calibration. This would make it easier to compare Oxford's results with those obtained in other laboratories. At the same time there had been a change in the spectrographic plates used which had in turn necessitated a change in the internal standard mix (see below, Section 5.2.2.) in order to obtain lines of the right density. (Jones, personal communication, July, 1981). In *Archaeometry* (Prag et al., 1974, 168) he presented a list of conversion factors to be applied to earlier results so that they could be compared with those obtained using the new calibration. Unfortunately, beyond saying that (Ibid.: 169) "Extensive tests were carried out and special care was taken to assess the long-term reproducibility" no details have ever been published of how the recalibration was achieved.

During the late 1950s scientists began to experiment with the application of another analytical technique to the problems of pottery composition and provenance work (Sayre and Dodson, 1956). This technique is known as neutron activation analysis and it has been well described by Perlman and Asaro (Perlman and Asaro, 1969). It is a technique which offers relatively high precision analysis for a large range of elements but which requires elaborate equipment and a fairly large sample size as a pellet has to be made by compressing a powdered sample. The earliest work was not done on Mediterranean material but on Roman (Emeleus and Simpson, 1960) and Medieval Pottery (Aspinall et al., 1968). Two laboratories, those at Berkeley and Brookhaven in the United States have been largely responsible for neutron activation analysis of Mediterranean pottery (Artzy, 1976; Perlman and Asaro, 1969; Harbottle, 1970).

A project by Harbottle (1970) is of especial interest. He decided to do Neutron activation analysis on some of the samples which had



previously been analysed by optical emission spectroscopy. Since these techniques complement rather than duplicate each other in the range of elements looked at, it was particularly useful. He analysed 20 sherds from each of Catling and Millett's Groups A and B (from Mycenae and Knossos). Using an almost completely different range of elements, 38 out of the 40 sherds were grouped in the same way as by optical emission. These results and those of a similar project by Asaro and Perlman (1972) harmonised with the optical emission results in a way that Dr. Catling said (Discussion following Asaro and Perlman, 1972: 386) he 'hardly dreamed possible'. They thus not only encouraged people involved in the work but also helped to allay the fears of some archaeologists who had voiced doubts about the validity of optical emission in this field.

Three guidelines for composition and provenance work were laid down by Asaro and Perlman in 1972 (Asaro and Perlman, 1972: 13) which should be borne in mind by other pottery analysts. They were that "1. Vast numbers of specimens would have to be analysed. 2. All analyses over a long period of time must be inter-comparable. 3. Since we do not know which elements will permit one to distinguish one place from another, the more elements which can be determined the better." However, in practice the last of these must be limited to some extent by the time and facilities available.

For about 10 years the technique of atomic absorption spectrophotometrical analysis has been applied to metal artifacts and has been a standard technique in geochemistry for some time. It has also been applied to archaeological specimens of obsidian (Wheeler and Clark, 1977) but it is only recently that, as in this project, it has been

applied to archaeological pottery finds. In a comprehensive paper Hughes, Cowell and Craddock (1976) outlined clearly the background to atomic absorption, its application to various materials and the techniques involved in sample preparation and analysis. They too, however, were mostly concerned with metal analysis. Recently there has been a renewal of interest in the application of atomic absorption to pottery analysis because of the wide range of elements which can be determined from a small sample with good accuracy and precision. In 1980 two papers on this subject were published in the same volume of *Archaeometry* (22.2.1980). The first paper, by Hatcher, Hedges, Pollard and Kenrick from Oxford deals with the analysis of Hellenistic and Roman fine pottery and they decided to compare their results with the earlier optical emission analyses of Hellenistic material by re-analysing 24 sherds from the earlier project (Prag et al., 1974). They concluded that there were some differences in the values of certain oxides which could not simply be explained away by the effects of the recalibration in 1973 (Boardman and Schweizer) and that more work needed to be done on this problem. The second paper, by Tubb, Parker and Nickless in Bristol, was concerned with the analysis of Romano-British pottery and they give a succinct summary of their reasons for choosing atomic absorption, their sample preparation and their treatment of their results.

Once sample preparation techniques have become well established and some problems of inter-element interference have been overcome, atomic absorption seems likely to increase rapidly in popularity as a technique since it can detect concentration levels of from under 1 ppm in the sample to major constituent levels.



A fourth technique of spectrographic analysis, X-ray fluorescence analysis, was applied to archaeological ceramics as long ago as 1957 when Young and Whitmore (Young and Whitmore, 1957) analysed oriental ceramics by non-destructive X-ray methods. However, to be non-destructive this technique can only provide an analysis of the surface of a sample and so it has mostly been applied to the study of metals, paints and glazes. To give a body analysis a relatively large sample, up to 750 mg, must be made into a compressed powder pellet. However this sample is not destroyed and can be retained for future analysis. More recently, Stern and Descoğudres (1977) analysed 67 Archaic Greek pottery sherds by X-ray fluorescence and a research project involving X-ray fluorescence analysis of Romano-British pottery is currently under way at Bradford University.

From attempting to identify composition groups among pottery samples it is an obvious step to trying to relate pottery composition to the composition of extant clay beds at or near a site (Boardman and Schweizer, 1975; Prag et al., 1974). However, obvious as this approach may be, it meets with various difficulties. Firstly, a potter may wish to enhance or reduce some of the properties of his clay by adding temper or grog (ground down pottery), or by levigating out the coarsest particles. The addition of temper or grog will reduce the plasticity of an over plastic clay, making it easier and less sticky to use and reducing the likelihood of damage due to shrinkage on cooling. A primary clay (one that has formed in situ), which is very rich in kaolinite may need the addition of a clay which contains more impurities to make it more plastic. A brick maker needs a coarser, less plastic clay than a potter. The temper is likely to come from a different source from the clay and in a



spectrographic analysis the composition of the temper and the clay will appear combined. This is less of a problem with some fine wares than with coarse, since they are more likely to contain grog than temper and this may have originated from the same clay bed as the clay which is being used to make the pot. On the other hand, coarse wares may consist of unrefined local clay without additions. However, only fine wares are really suitable for spectrographic analysis. Secondly, there is no way of telling if the clay bed sampled is the same one that was used in antiquity and no way of knowing which bed, if any, is typical of the area. Most of the clays used in pottery manufacture have gradually been formed by the weathering of rocks and by the redeposition of the eroded particles. The deposits may have formed in marine, lacustrine or river-side environments (Hedges, 1974, unpublished). The clays which contain the smallest amounts of impurities like iron oxides, lime or soluble salts are the white china clays which have formed in situ. Some of them contain as much as 95% kaolinite ( $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ ). It can thus be seen that the composition of a clay may be affected not only by the geology of the immediate area in which it is found but also by the geology of the areas from which the particles originate (Perlman and Asaro, 1969:35). The ideal situation would clearly be that which would occur if a kiln with wasters in situ were excavated in an area where there were good clay beds to hand.

This approach was suggested by several people in the early days of composition and provenance work and the Oxford team was criticised for their slowness in attempting it. However, in 1965 they did analyse clay from the modern brickworks adjacent to the site of Lefkandi on Euboea. Its composition fell within the limits of group D which was

characteristic of Lefkandi on Euboea and Volos and Argyroupolis in Thessaly. In 1966 various clay samples were taken from throughout Greece but their compositions have not been published.

Perlman remarked (Discussion, following Asaro and Perlman, 1972: 389) that although they had found clay near the site of Enkomi on Cyprus which corresponded well with the composition of pottery from Enkomi they discovered that a clay from near the site of Berbati in the Peloponnese which bore a very close visual resemblance to Berbati pottery was very different in composition due to its high Calcium Carbonate content (over 50%). Levigation of the clay failed to remove the calcium. At Tell Ashod they had a similar experience.

In 1977 Farnsworth, Perlman and Asaro (Farnsworth, Perlman and Asaro, 1977) reported attempts made in 1971 to identify the clay source used by Corinthian potters. Their task was complicated by the fact that the modern landsurface is c 3 metres higher than it was in Classical times. Out of 17 samples that they were able to take 15 were too full of lime to be of use. The other 2 were very similar to each other. They were also similar in composition to Corinthian pots but not similar enough to be identified as the clays used by the potters.

The most thorough assessment to date of the feasibility of relating clay beds to pots has been published by S. J. Freeth (Freeth, 1967). He analysed 28 Bronze-Age coarseware sherds from a pit on a site in Lincolnshire and 18 clay samples from 10 localities in the neighbourhood for 9 elements each. This project sidestepped one of the problems touched on by earlier workers for, since coarseware was sampled the problems associated with the addition of temper will not arise. On the other hand, he also analysed the different fractions of a levigated



sample which showed very little alteration during refining. He suggested that, because of the possibility of post-depositional changes, calcium should not be relied on as a discriminant.

Although this approach clearly has an important role to play in composition and provenance studies it is complex and in the long run it would be better if some projects could be devoted solely to this. Generally, as in this project, workers do the best they can by including some clay analyses in a programme of pottery analysis.

There have inevitably been criticisms of this kind of work and of the way in which it has been carried out over the last 20 years. Some archaeologists, including Stubbings (1972) have had doubts as to whether the removal and in some cases destruction of a small sample from an artifact was justified by the knowledge gained from the subsequent analysis. Others have seemed to forget that provenance is not being assigned with 100% certainty. Generally an 80% level of confidence is chosen. This means, as Catling et al. said (1961: 97), "that in the long run 80% i.e. 4 out of 5 sherds belonging to the same population should have concentrations within the calculated range". It is generally agreed, moreover, that although analysis can differentiate between groups of pottery it is a different matter altogether to try to provenance individual sherds in this way. It must also be remembered that no one technique can do everything. Perhaps the most satisfactory approach will be shown to be the use of a combination of techniques or a combination of spectrochemical and petrological analysis. Various authors (Wilson, 1978; Musty and Thomas, 1962; Boardman and Schweizer, 1973; Ives, 1975) have stressed that it is much easier to say that a pot did not originate from a site than to pinpoint its place of origin by composition alone.

During the controversy mentioned above, which was engendered by the work on the inscribed stirrup jars from Thebes, criticisms were not only levelled at the interpretation of the results in this specific case but also at the techniques of analysis and at the statistical treatment of the results. Some of these criticisms were indeed valid but were perhaps attributable to the kind of teething problems associated with any new fields. Some, like the insufficient size of some sample groups (Wilson, 1978: 227) have been recognised and are now avoided. Others, like criticism of the choice of elements used (McArthur, 1974: 79; Peacock, 1970; Wilson, 1978: 223) are still controversial.

A. L. Wilson published an informative and constructive review of elemental pottery analysis (Wilson, 1978) where he emphasised that "much valuable experience and information has been gathered by the pioneering laboratories" but he went on to say that he thought a critical review of the subject was due. Although he felt that several of the initial problems had been ironed out by the passing of time he, like McArthur (1976) was concerned that the statistical procedures applied to the analytical results were inadequate, especially in optical emission work.

In his conclusion Wilson made a very valid point in asking authors to give fuller details of their experimental procedures and their results in their articles. It should also be stressed that some problems could have been avoided and others reduced if there were adequate contact between archaeologists and scientists at all stages of the work. This would help to convince archaeologists as to the value of this kind of analysis and would help to make sure that each set of analyses was backed by sound archaeological data and a set of questions which the analyses would hopefully elucidate.

1.2. Aims.

The aims of this thesis are:-

1. To examine the composition of samples of Bronze Age pottery from Euboea, eastern Boeotia and eastern Thessaly in central and eastern Greece.
2. To fill in some of the blanks in our existing knowledge of the pottery compositions in these areas and to test inter- and intra-area distinctions.
3. To test for variation in composition with time during the Bronze Age of the pottery from one well-stratified site in Thessaly.
4. To investigate which areas of Greece had the closest contacts with eastern Thessaly in the Late Bronze Age by examination of the pottery composition.
5. To examine the contact between Euboea, eastern Boeotia and eastern Thessaly in the Late Bronze Age by means of the pottery composition.
6. By using both optical emission and atomic absorption analysis on the same samples to investigate the relative merits of these two techniques with regard to element range, sensitivity, precision, accuracy and the comparison of the resultant groupings.
7. To test the groupings obtained through the analysis with cluster analysis and discriminant analysis.
8. To see how far geology can be related to pottery composition within these areas and how far pottery can be related to clay sources.



CHAPTER 2.

ARCHAEOLOGY

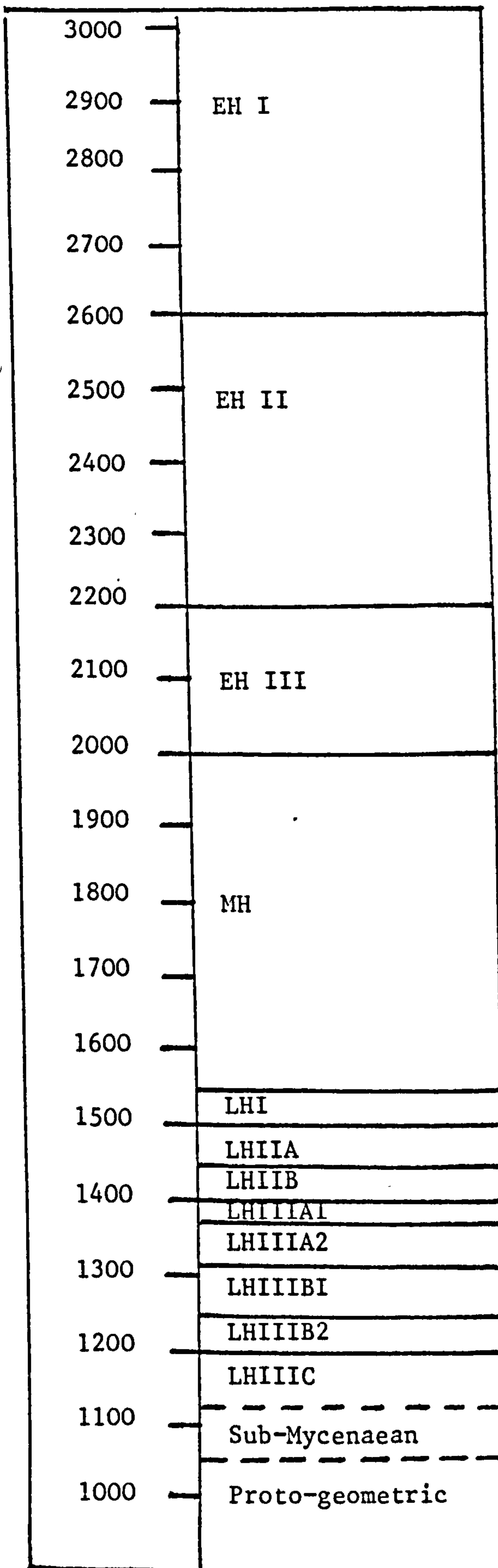
CHAPTER 2.

ARCHAEOLOGY

2.1. General Comments (see Time Chart, Figure 2)

There are several reasons why this project concentrated on the Late Bronze Age. Firstly, because of the relative abundance of excavated pottery from this period, the sequence and development of pottery styles and decoration has been firmly established. This is particularly evident when compared with what is known about the sequence of development for a similar period in Britain. This relative abundance of material also meant that there was not too much difficulty in obtaining adequately large sample groups (see Chapter 4 on sample choice). In addition to and partly because of this the bulk of the analyses done in Oxford and Athens have concentrated on this period and these analyses are therefore available for comparison where necessary. The present examination of the Late Bronze Age pottery from Euboea, eastern Boeotia and eastern Thessaly can be expected to throw some light on several archaeological points. These points include which areas of Mycenaean Greece were in contact with Thessaly in the Late Bronze Age, the pattern of the spread of Mycenaean pottery within Thessaly and the extent of contacts between Euboea and Boeotia. Out of nearly 800 sherds which were analysed in this project 90% were Late Bronze Age in date.

The Late Bronze Age should not be considered in isolation since it was in large measure a development of the periods which preceded it. In Euboea, for example, 48.1% of the Early Bronze Age sites were still occupied in the Middle Helladic and 82.4% of the Middle Helladic sites were still occupied in the Late Helladic (Renfrew, 1972:245). Therefore, although it was not possible to include a comprehensive study of



After Hope Simpson and Dickinson (1979)

Figure 2. Chronological Chart for mainland Greece in the Bronze Age.

the Early and Middle Bronze Ages, Pevkakia (site 16) in Thessaly was selected for a chronological study to see if some insight could be gained into whether the same clay sources were exploited throughout the Bronze Age and into the proportion of material that was imported in the different periods. Twenty-nine Early Bronze Age and thirty-six Middle Bronze Age sherds were analysed along with the Late Bronze Age material.

The Early Bronze Age on the Greek mainland began in the third millennium B.C. and its first phase can be recognised by the red-slipped pottery which has been found in the north-east Peloponnese, Attica and Boeotia. Related wares have been found in Thessaly. It is difficult to relate the beginning of the Early Bronze Age to the Late Neolithic culture, since few excavated Early Bronze Age sites have also produced Late Neolithic levels. The early fortifications at Pevkakia are Early Bronze Age in date. The second phase of the Early Bronze Age (Early Helladic on the Greek mainland south of Thessaly), was a period of general expansion and an increase in the number of settlements can be seen including about 24 on Euboea. This phase of the Early Bronze Age can be traced all over the mainland south of Thessaly although by this time the southern mainland appears to lead culturally. Hope Simpson and Dickinson (1979:373) noted that cultivation of olives and vines and the domestication of the donkey "must have contributed to the increasing prosperity". The end of this phase was marked by widespread burning of settlements in the Argolid. Lerna, in the Argolid, was among the largest and better-known Early Bronze Age sites and had large buildings and fortifications. The famous "House of Tiles" at Lerna was a well-planned, two-storey building which was one of those which was burnt. The last phase of the Early Bronze Age shows a contraction in settlements and the introduction of new styles



of pottery. From the known sites it appears that the disruption was worse in southern than in central Greece. The potter's wheel appears at Lerna at this time but otherwise there was a drop in the standard of the material culture.

The origins of the Middle Bronze Age or Middle Helladic culture remain controversial and unclear. Minyan pottery (see below) may have been made before the start of the Middle Bronze Age (Evans 1973:25), but whether its introduction can be taken to indicate the arrival of a new group of people, the Indo-European Greek speakers, as is sometimes suggested, is not certain. Evans also suggested (Ibid) that Minyan ware was an Aegean development whatever its background and that because the sequence of cultural development is not uniform throughout the Aegean there is no need to infer from this an invasion by a new people. This is a viewpoint shared by D. H. French (1972:51). Although archaeologists have given considerable attention to this problem, as Howell said (1973:94): "much more excavation will have to take place before the origins of the Middle Helladic or "Minyan" culture can be defined conclusively".

To some extent early Middle Helladic pottery and architecture can be related to that of the Late Early Bronze Age. Many more Middle Helladic than Early Bronze Age sites have been excavated and most of this material comes from the north-east Peloponnese, Attica and Boeotia. The two best-known pottery types of this period are Matt-painted and Minyan. The former of these had dark, geometric patterns painted directly on to the clay and the latter was a fine, grey, monochrome ware with a 'soapy' feel. It was a wheel-made ware of high quality and was first identified by Schliemann at Orchomenos. Outside central and eastern Greece poor quality imitations of Minyan pots are often found. Middle Helladic settle-



ments were generally on hills and consisted of small buildings with a simple megaron plan. A megaron was a large rectangular room with a porch at one end and sometimes another room at the opposite end to the porch. The Middle Helladic period is also characterised by cist graves, initially with only a few grave-goods included in the burial and by intramural burials. The latter were most often of children. The Middle Helladic was not a period of great prosperity although by its end an improvement can be noticed and Cretan influence in pottery became increasingly strong. Overseas trade in the Middle Helladic is marked, among other things, by the discovery of Minyan pottery at Troy.

The Shaft Graves of Grave Circle A at Mycenae date from ~~about 1550-1500 B.C.~~ about 1550-1500 B.C. Grave Circle B is more primitive and probably dates from about 1600-1525 B.C. No buildings contemporary with the graves have been found at Mycenae. Grave Circle B contained the larger number of burials. Some of the objects they contained, like the rhytons, have definite Cretan parallels.

The Late Bronze Age, or Late Helladic period on the Greek mainland began in the mid C 16th B.C. and its culture began as a mixture of the Middle Helladic culture and Minoan influence. It is not clear what finally brought about the fall of Knossos c.1380 B.C. but when it happened Mycenaean dominance in the Aegean was assured. At Miletus large quantities of Mycenaean pottery dates to LHIIIA and was found in the levels immediately above the remains of a fire which had destroyed the Minoan settlement.

One important development in the early Late Bronze Age was the emergence of a wealthy ruling class which established centres of administrative and political power. The wealth of this class is reflected in the quality and number of their grave-goods. This ruling class lived

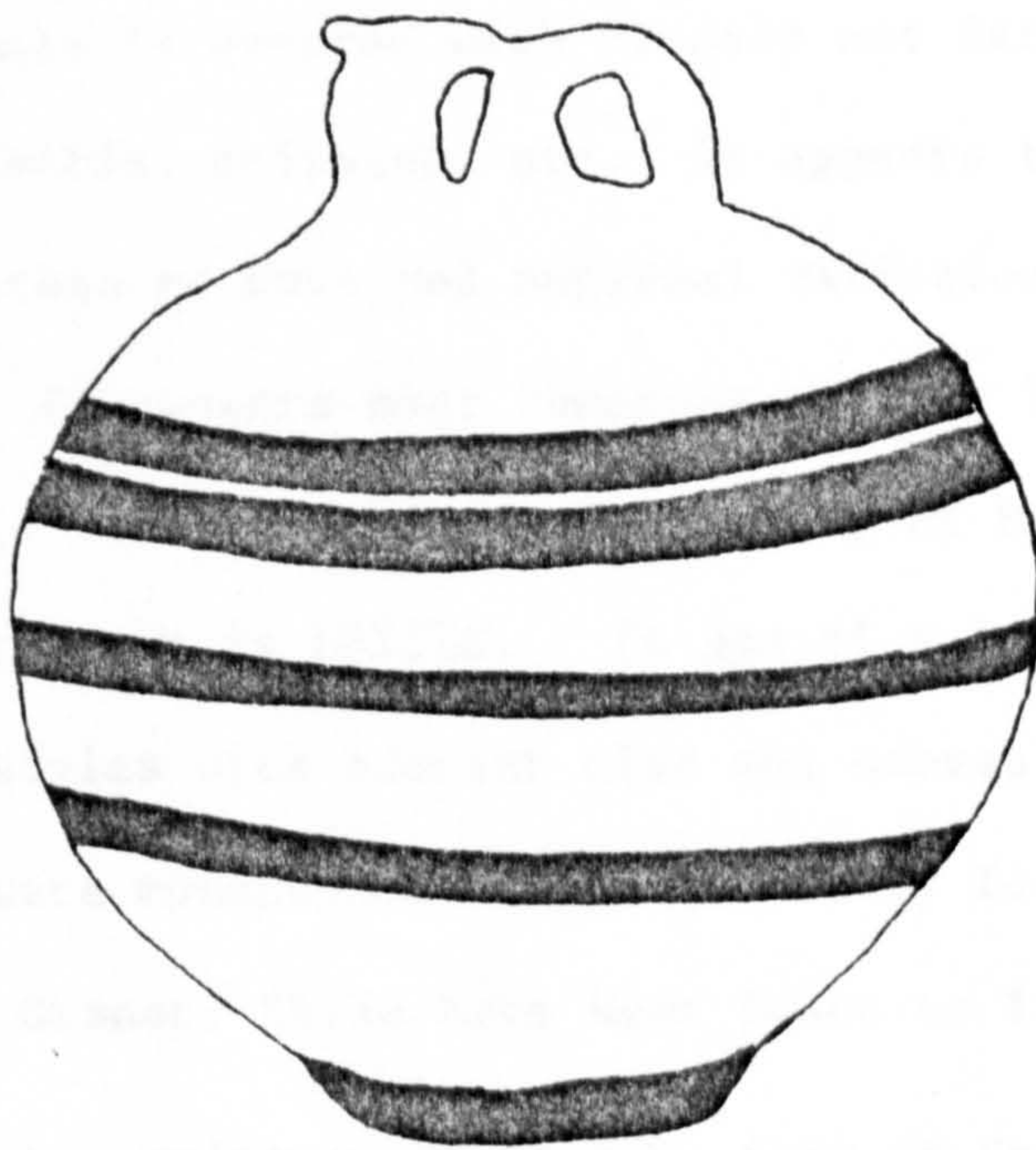
in palaces like those at Mycenae, Tiryns, Pylos and Thebes. The plan of the palaces was based on that of the Middle Helladic megaron with a large room, antechamber and porch rather than on the Minoan style. The best-preserved palace is "Nestor's Palace" in the western Peloponnese. Minoan influence can, however, be seen in the decorative columns and frescoes which adorned the palaces. The buildings had a timber frame and stone or unbaked brick walls. The most northerly suggested palace was at Iolkos in Thessaly (see below, site 14).

In LHIII signs of Minoan influence in mainland Greece diminished and finally active Minoan influence came to an end. This is true in pottery as in other fields. At the same time an increase in stylisation and industrialisation can be seen. Many vases were painted on the inside with a brown/black paint. It was also common to cover vessels in a slip and then to decorate them with lustrous paint. Some decorative elements, like the octopus and plant motifs which had been popular in LHII, continued to be used but decoration became more restrained and tended to be restricted to separate zones on the pots. Pictorial scenes began to be used for the first time. Two of the vessels which were especially popular in LHIIIA were the kylix and the stirrup jar (see Figure 3). By LHIIIB although the kylix was still popular its stem had become taller and more slender and the most common vessel type was the deep bowl (see Figure 3). Stirrup jars were still popular although they became more globular in shape. Decoration was increasingly precise and it can be seen that a faster wheel and a hotter kiln were being used. Pictorial scenes showed more stylisation and many of the animals were drawn in outline with decorative motifs on their bodies. In LHIIIB there was great homogeneity of style throughout the Mycenaean world. Different types

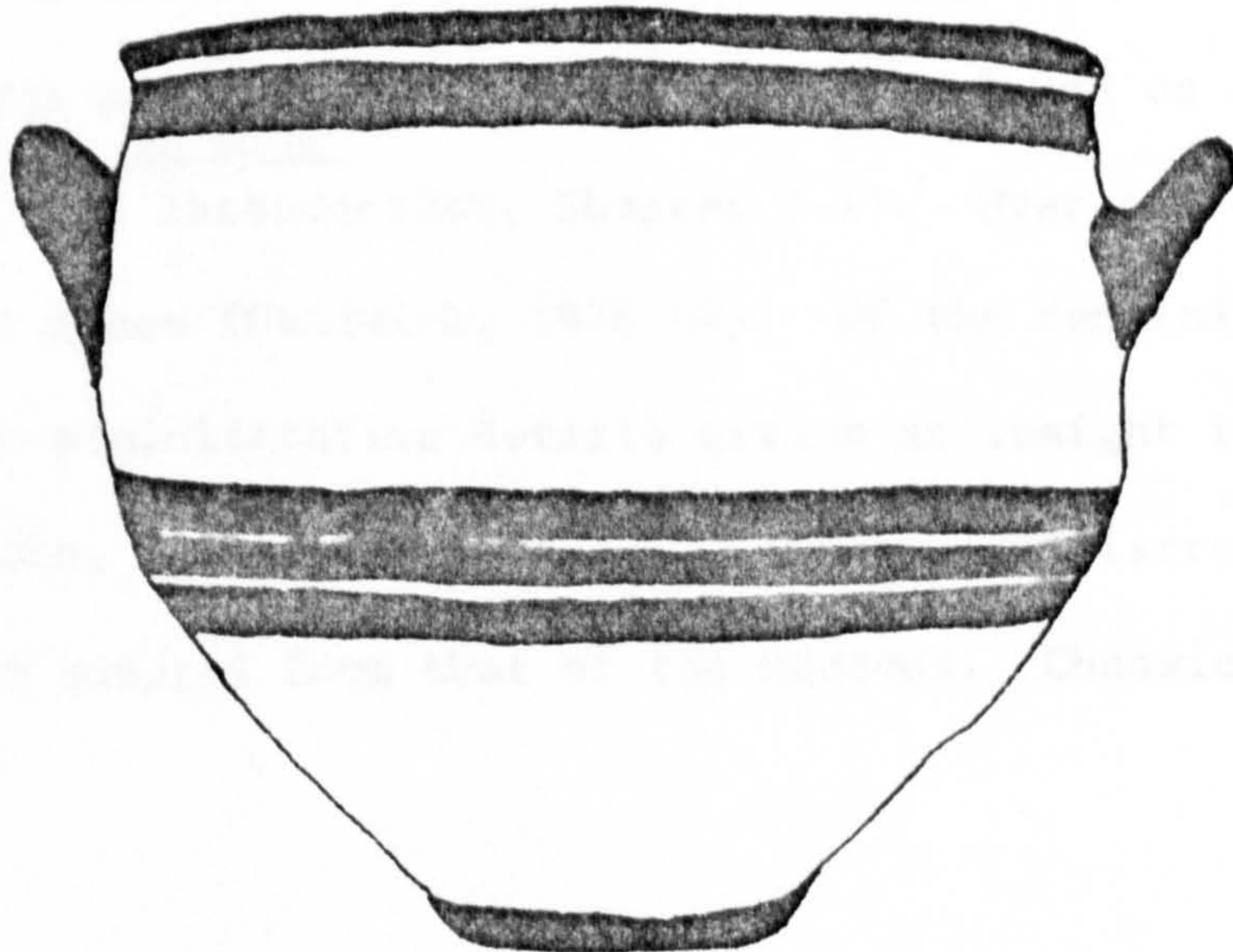




Kylix



Stirrup jar



Deep bowl

of vessels are found in tombs and in settlements, but more tombs than settlements have been excavated so far. Bowls and kraters are particularly associated with settlements and other vessel types, notably stirrup jars, kylikes and three-handled piriform jars are associated with tombs. By LHIIIIC local styles had begun to appear, reflecting the break-up of the Mycenaean world, but some features like the overall black painting of deep bowls were common to all areas. The two best-known styles from LHIIIIC are the Close Style and the Granary Style. The Close Style ~~is~~ began in ~~early~~ LHIIIIC. In this the whole surface of the vessels is covered with closely set detailed decoration and with friezes of birds, dolphins, etc. It appears to have developed in the Argolid and then to have had regional variations like the Aegean Octopus Style. It appears most commonly on deep bowls and stirrup jars. The Granary Style was named after the "granary" at Mycenae where it was first found. It began in LHIIIIC. It was of a lower technical standard than preceding styles with coarser clay and uneven manufacture. Most of the vessels were monochrome and it is mostly found on deep bowls. Examples of the Granary Style have been found as far afield as Troy.

Linear B, the script in an archaic form of Greek which was deciphered in 1952 by Michael Ventris has not been found in contexts which are dated to after LHIIIIB. It has been found on tablets from Mycenae, Pylos, Knossos and Thebes. It has also been found on some stirrup jars from Thebes/<sup>and elsewhere</sup> (see Introduction, Chapter 1.1). Over 60% of the known words are personal names (Chadwick, 1976:64). Of the remainder many refer to goods and to administrative details giving an insight into the economy and the running of Mycenaean Greece. Their administrative system seems to have been adapted from that of the Minoans. Chadwick wrote (1976: 6)



that "the Greeks borrowed from them the system of writing, both adapting it to their own language and improving the book-keeping". The Minoans used the Linear A script.

The first citadel remains date from early LHIIIA which is the C 14th B.C. These citadels include Mycenae and Tiryns, built with Cyclopean masonry, ~~and~~ Gla and Eutresis. The last two of these had walls which were built of smaller, regularly coursed stones, quite unlike the Cyclopean masonry of the others. When the wall was ~~extended~~ around Mycenae in c 1300 B.C. it enclosed grave circle A which was preserved and clearly respected within it. At both Mycenae and Tiryns a water supply was assured within the citadel. Settlement sites tend to cluster around these citadels. The peak in settlement numbers was in LHIIIB (see maps, Figures 4-6). However, by the end of LHIIIB the fortifications at Mycenae and Tiryns had been strengthened and a wall had been built across the Isthmus near Corinth as if to protect the region from attack from the north. Many sites were damaged or destroyed late in LHIIIB. Houses were damaged at Mycenae and ~~Pylos and Gla~~ *Pylos and Gla were destroyed.* Many of the sites were burnt.

~~~~~~~~~ A large number of the mainland centres were then deserted.

The two methods of burial favoured by the Mycenaeans were tholos and chamber tombs. The earliest dated tholoi may date from the late Middle Helladic and include one at Karditsa in Thessaly and Moira and Koryphasion in Messenia. Tholos tombs are generally thought to have spread from Messenia in the Peloponnese during LHI. Apart from the famous tholoi at Mycenae - the Treasury of Atreus and the Tomb of Clytemnestra - perhaps the best known tholos is the so-called Treasury of



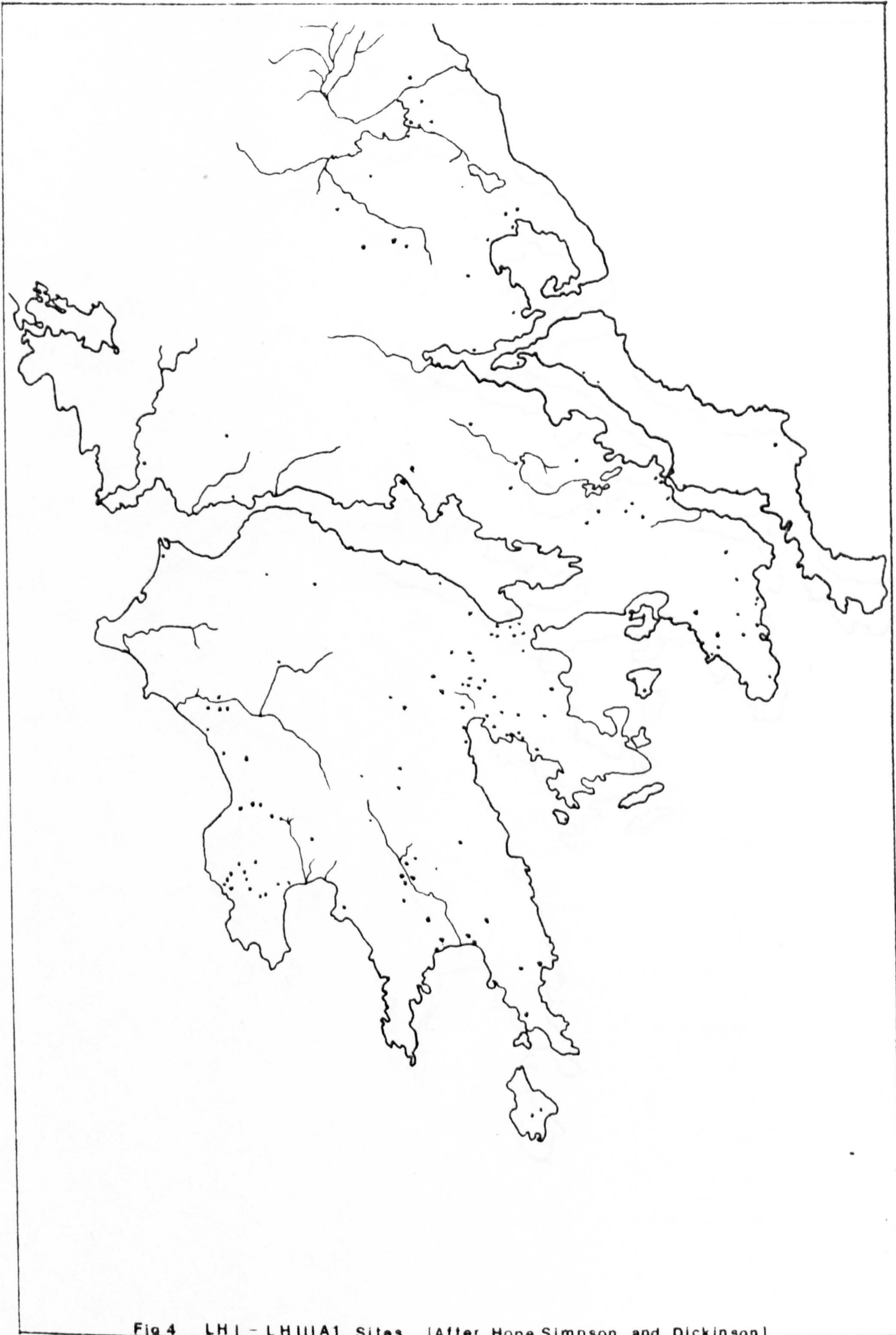


Fig 4 LHI - LHIIIA1 Sites (After Hope Simpson and Dickinson)

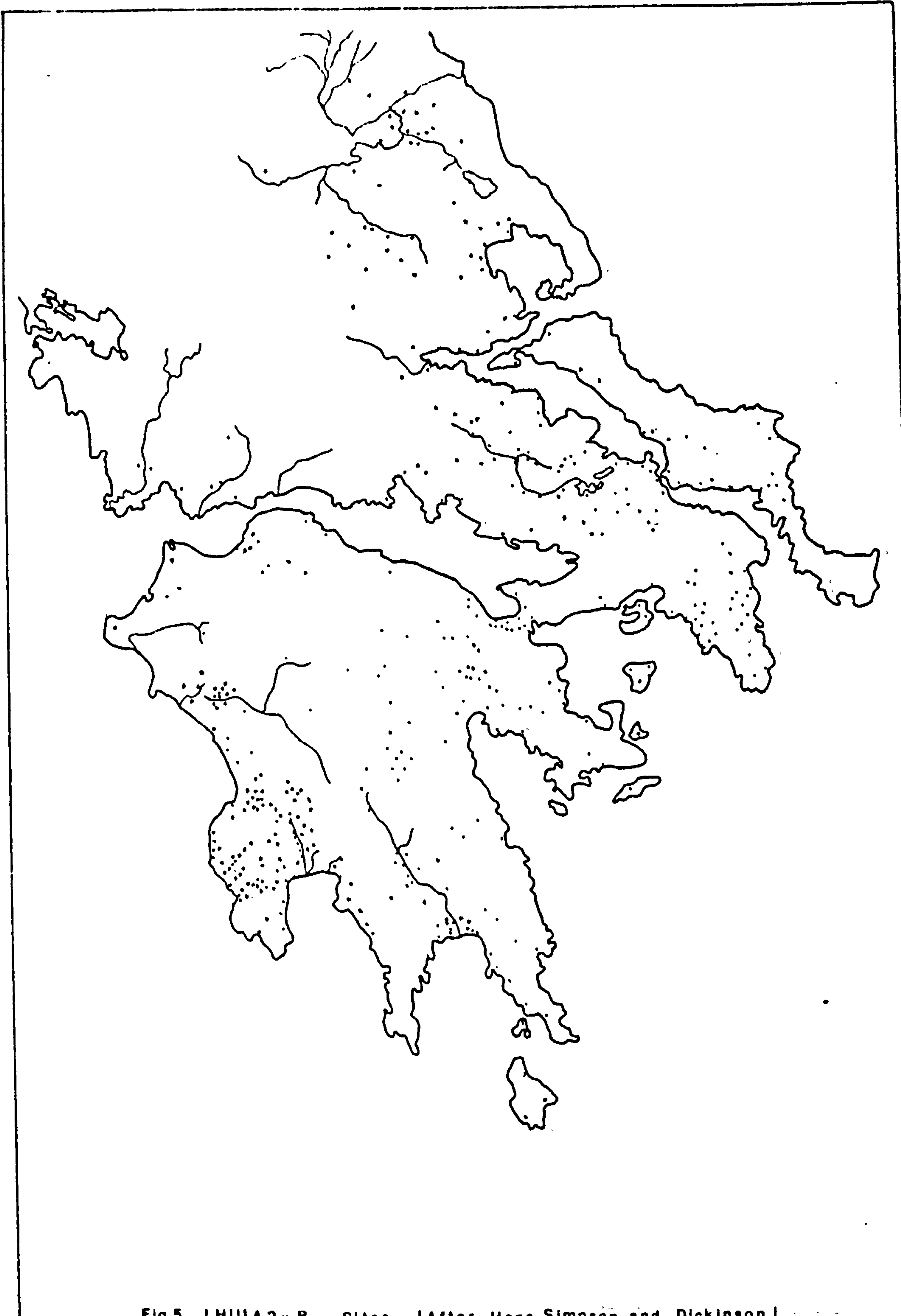


Fig 5 LH11A2 - B Sites [After Hope Simpson and Dickinson]



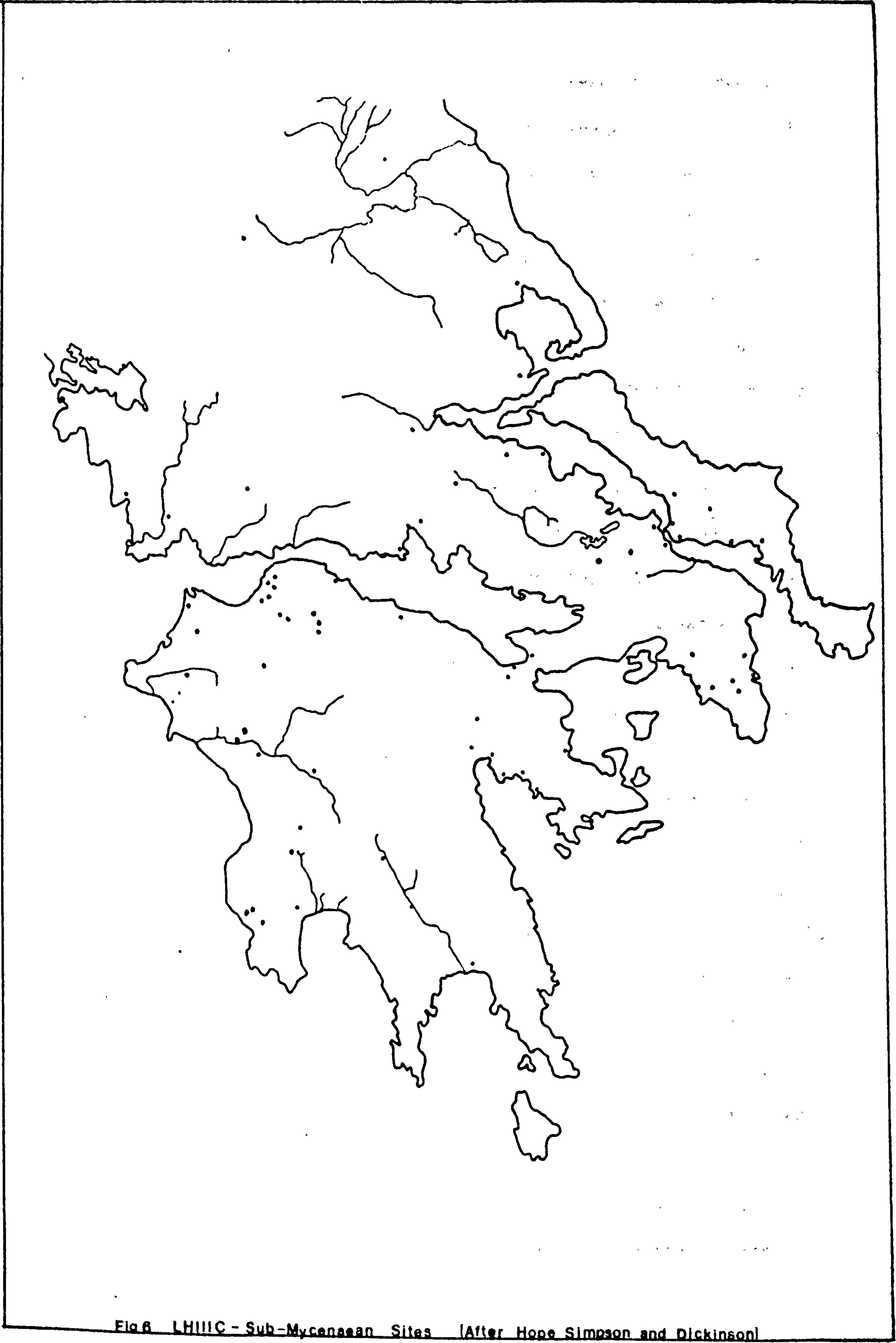


Fig. 6 LHIIC - Sub-Mycenaean Sites [After Hope Simpson and Dickinson]



Minyas at Orchomenos in Boeotia. It may date from LHII $\frac{1}{2}$ . Tholos tombs went out of use in LHIII. It is sometimes suggested that tholoi were used by the 'nobler' families, the more popular version being the chamber tomb. Even if this is in some measure true it takes no account of whether it was feasible to build certain types of tomb in all terrains and neither does it take account of the poor quality of some tholoi. In both tholos and chamber tombs the corpse was accompanied by grave goods, even though in some cases this was only a pot. From LHII onwards chamber tombs began to replace cist burials in popularity.

The events of LHIII $\frac{1}{2}$ C are not fully understood. Many areas became depopulated as settlement numbers decreased. In Boeotia, for example, 7 C 13th settlements are known but only three from the C 12th (Desborough 1972). On the other hand the population in western Euboea, eastern Attica, Achaea in the northern Peloponnese and the island of Cephallonia in the west of Greece increased. In Attica the culture hardly seems to have been disrupted by the events in other areas. A little LHIII $\frac{1}{2}$ C occupation continued at Mycenae but Pylos ~~was~~ deserted. LHIII $\frac{1}{2}$ C was on the whole a period of decline. Hope Simpson and Dickinson (1979: 380) say that in the area covered by their survey, including south-west Anatolia, Sub-Mycenaean pottery has been found at "barely two dozen sites". There are quite probably some more sites which have not yet been discovered, but it is unlikely that such sites would effectively alter the picture of the period that we have at the moment. Despite the general decline, some new types of object appeared during LHIII $\frac{1}{2}$ C. They included new types of sword, already in use in Central Europe, hand-made pottery, fibulae and pins, but it cannot be said with certainty who was responsible for their introduction. The "Dorian" invasion suggested by some



writers is unlikely, as is invasion by people from somewhere to the north. The various facets of the problem have been thoroughly studied and written about by Snodgrass (Snodgrass, 1971) and Desborough (Desborough 1964:1972).

Within the areas under consideration in this thesis the suggested increase in LHIIIC population in western Euboea but not in Boeotia or inland Thessaly, is reflected in the samples which were available for analysis. Among the Boeotian sherds only a minority are dated to after LHIIIB (and all of the sherds from Thebes are dated to LHIIIB). The majority of these later sherds come from Kynos (site II). In Euboea some of the sherds from Amarynthos (site 2) and almost all of those from Gialtra (site 3) are dated to LHIIIB-C and the majority of the Lefkandi sherds (site 4) are dated to LHIIIC. In Thessaly a few of the sherds from Marmariani were dated by Hunter (1954) to LHIIIC but otherwise the Octopus Style sherd from Revmatia (see below, Chapter 4.4) is the only LHIIIC sherd that has been found in inland Thessaly. None of the material from Pevkakia that was analysed postdates LHIIIB but all of the 'local' group of sherds and the small group of 'Iolkos' sherds from Velestino date to LHIIIC, reflecting the continuation of a Mycenaean lifestyle around the Gulf of Volos, if not inland. However there is no evidence for expansion in this period. Very little in the way of sub-Mycenaean material has been found in Thessaly and none at all around the Gulf of Volos. Only a small amount has been found in Eastern Boeotia either and even sites like Lefkandi in Euboea which flourished in the Iron Age have a gap after the LHIIIC occupation. Therefore none of the material analysed in this project postdates LHIIIC.



## 2.2. Late Bronze Age Euboea.

In 1966 when publishing the results of their Euboea Survey (Sackett et al., 1966) Sackett et al. wrote that "the gaps in our knowledge of Bronze Age Euboea are so serious as to amount in some areas to a total blank". It was because of these gaps that they undertook their survey. Prior to their work, Dr. Theochares in 1959 published the only other archaeological survey of Euboea (Theochares, 1959). He listed 35 pre-historic sites which he dated on the basis of sherd collection and examination and he described his limited excavations at Chalkis. Some topographical and geographical survey work had been done in 1903 by F. Geyer and summarised by Philippson (1950). Sackett et al. made it clear (Ibid: 35) that they did not regard their survey as the definitive work on Euboea but in increasing our knowledge of Bronze Age Euboea they have considerably improved the situation. Following the survey they excavated at Lefkandi (see below, Chapter 4.2) and this, although not yet fully published, has in turn led to the publication of interesting articles by Popham and Sackett (see references under Lefkandi, Chapter 4.2) and Popham and Milburn (1971).

Euboea is a fertile island in a strategically important position close to the eastern coast of the Greek mainland and it is strange that, as Sackett et al. noted "there remains a marked disparity between the state of our information and both the importance suggested by literary tradition and the archaeological potential of so well-placed and fertile an island" (Ibid:34). Homer (Iliad ii 536-545) in the "Catalogue of Ships" recorded 7 cities in Euboea.

Over 50 sites are now known to have been occupied in the Bronze Age and in the Late Bronze Age all the major arable areas contained Mycenaean



settlements. Most of these sites had also been occupied in the Middle Helladic. There is no evidence to suggest that there was any one main town in Euboea but rather that each of these fertile areas supported one fairly large town. These towns included Psakhna, Chalkis, Lefkandi, Amarynthos and Aliveri, all of which were occupied into LHIIIIC. Unlike other areas there are indications that the peak of Late Helladic population in Euboea was in LHIIIIC.

The three main areas of LH settlement were around Chalkis and Aliveri in the west and around Kimi in the east. The south of the island is notably lacking in settlements. The centre of Euboea, and especially around the Lelantine Plain, is the most fertile area of the island and the centre of the west coast where Euboea is closest to the mainland maintained the densest Mycenaean settlement. The area to the south of Amarynthos was notable for its lack of LHIIIIC prosperity compared with the rest of the island. Due to the lack of excavation we still have relatively little knowledge about the relative prosperity of the different phases of occupation at Euboean sites.

The pottery of LHI-II is described by Sackett et al. (1966) as "unexceptional" and its origin cannot be placed. It has been suggested that in inspiration, if no more, Euboea may have looked to Thebes rather than to Crete, for there is an unusual lack of Minoan penetration in the early phases of the LH in Euboea.



### 2.3. Late Bronze Age Boeotia and Locris.

Although a considerable number of Late Bronze Age sites are known in Boeotia and Locris, no proper archaeological survey has ever been carried out there. It is therefore probable that we receive a distorted picture of the relative population size and importance of the different areas. The Universities of Cambridge and Bradford are currently involved in a long-term survey of Boeotia (CABBAGE) but since they have only completed 2 seasons' field work so far their work has not been used in this thesis. Ancient Boeotia included the areas occupied by modern Boeotia and by Eastern Locris.

Because of the geography of Boeotia, with ranges of mountains stretching down its centre and western edge settlements tend to cluster in the valleys and to have been medium-sized local centres rather than large towns. The majority of sites are in the valley of the River Asopos and around Lake Kopais. Boeotia was dominated by the two towns of Thebes and Orchomenos in the Late Bronze Age and they were rivals for power. Another fairly large site was Eutresis, which dominated the Leuctra Plain and was built in LHIII.

Lake Kopais was at least partly drained in the C15th B.C. and remains of the drainage works, the dykes and ditches, can still be seen. Strabo ascribed the drainage works to the Minyans

who are believed to have come from Orchomenos. Schliemann excavated at Orchomenos in the late C 19th

and he named the soapy grey Middle Helladic pottery he found Minyan. It is not clear whether the drainage works were neglected and fell into disrepair or whether



they were destroyed. Platon (in Christopoulos ed. 1974) suggested that the Thebans destroyed the drainage works and let the land revert to marsh. If this is so, it can be seen as a considerable blow to the power of the people from Orchomenos.

The "Catalogue of Ships" mentions 31 towns in Boeotia, 18 of which have so far been identified by archaeologists (Demakopoulou and Konsola 1981:12).

As in most areas of Greece, LHIIIA-B saw an increase in the number of settlements in Boeotia and Locris and an increase in prosperity. Several of the sites were fortified against a threat either from outsiders or from other large sites in the area during LHIIIB.

The largest citadel in Boeotia and in fact in the whole of Greece is Gla. The site is on a rocky outcrop at the eastern end of Lake Kopais, rising to a height of 70 metres above the surrounding land. The citadel has a circuit wall of three kilometres enclosing an area of 200,000 square metres. The area enclosed is seven times that of the citadel at Mycenae and ten times that of the citadel at Tiryns. One unique feature at Gla is that there are four gates in the outer wall whereas other Mycenaean citadels have only a main gate and a smaller postern. It is not known who was responsible for building Gla or for what purpose it was built. There is no evidence to suggest that it was ever fully inhabited although parts of it were in use at the end of LHIIIB. There is no large settlement nearby and it has been suggested that it was built as a refuge for people from all the small settlements around the edge of the lake. If this was its purpose it is the only known structure of its kind in Mycenaean Greece.



In LHIIIIC there was a drop in the number of settlements in Boeotia and Locris following a wave of destructions at the end of LHIIIB. At this time there were fires at Thebes, Orchomenos, Eutresis and Gla. These destructions appear to be more or less contemporary with those that happened in other parts of mainland Greece.

#### 2.4. Bronze Age Thessaly.

Settlement patterns in Thessaly have always been determined to a large extent by its geography. From the Neolithic onwards most sites have been on the two large, fertile plains and around the Gulf of Pagasae. Sites lie not only on the plains themselves but also on the lower slopes of the enclosing mountains. Since the Neolithic the western plain has been less populated and less important than the eastern plain.

Thessaly has been less neglected archaeologically than Boeotia and Euboea with studies by Wace and Thompson (1911), Hansen (1933) and Hunter (1954) having been published and with excavations by Theochares and Milojcic. However, as Hope Simpson and Dickinson commented (1979:272), any conclusions we draw about Bronze Age settlement in Thessaly must be "more than usually tentative" until Dr. D. H. French publishes his survey work.

The well-established importance of Neolithic Thessaly with sites like Dhimini and Sesklo has contributed to a neglect of the Bronze Age. A bias is also introduced by the damage done to Bronze Age levels by erosion. Whereas Thessaly had been in the vanguard of Neolithic development, it fell behind in the Bronze Age and it is not always easy to relate the sequence of developments in Thessaly to that in southern Greece. The transition from the Neolithic to the Early Bronze Age remains



obscure (Evans, 1973:20). It is however clear that Thessaly was slower than the rest of the mainland to the south to adopt Mycenaean culture. In part this may be due to the fact that access to Thessaly from the north is relatively easy but Thessaly is almost cut off from southern and western Greece by mountains, the only easy route of access being from the sea via the Gulf of Pagasae and the Bay of Volos.

It is in Early Bronze Age I that developments in Thessaly can be directly compared with those in southern Greece, but in Early Bronze Age II the only connection is the pottery at Pevkakia (Dickinson 1977:99). At the end of the Early Bronze Age fires destroyed both the settlements at Pevkakia and Argissa (sites 16 and 13).

There was an increase in settlement numbers in the Middle Helladic period in Thessaly, and here the Middle Helladic culture appears to be a local development growing directly from the Early Bronze Age culture. In the area around the Gulf of Pagasae there are similarities to the Middle Helladic of areas further south. Mylonas (1974: 170) has described the Middle Helladic pottery from Argissa as similar to that from Eutresis in Boeotia. Around the Gulf of Pagasae, Grey Minyan pottery appears to have been produced but in the inland areas it appears only as the occasional import. Local hand-made wares predominate in inland areas.

Although the Mycenaean culture was intrusive to Thessaly, 75% of the known Middle Helladic sites were also occupied in the Late Helladic period (Halstead, 1976). Because of its relative geographical isolation it is not obvious from which area of southern Greece Mycenaean culture was introduced. Hunter (1954) and others have claimed that the influence came from the Argolid and Euboea and not from Boeotia and while there



is no evidence that the land route from Boeotia was used in the Late Helladic period neither is there incontrovertible evidence for contact with the Argolid. As an extension of this theory they suggest that up to late LHIII B the only Mycenaean-style pottery in Thessaly was imported from the Argolid. If this is indeed the case it is strange that stirrup jars which were so popular in the Argolid are absent from Thessaly. The first Mycenaean pottery reached the areas around the Gulf of Pagasae in LHII but none which can be said to predate LHIII A has yet been found in inland areas. As Dickinson emphasised (1977:100) and despite Hunter's beliefs (1954) the introduction of Mycenaean features into the culture should not be taken to indicate Mycenaean immigration. Perhaps more realistically Hunter (1954) suggested that there was a LHIII B-C pottery industry at Marmariani (site 15) which produced a limited range of vessel types among which bowls and stemmed cups predominated. Many of these vessels were hand-made. He also commented that the pottery at Volos showed a greater variety than elsewhere in Thessaly.

It is unlikely that the adoption of Mycenaean culture took more time in Thessaly than further south and the degree to which it became a part of the Mycenaean world is still unclear. Halstead (1976:27) remarked that in the east of Thessaly there were too many large sites in close contact for any one of them to have easily become dominant. He suggested that there was a low level of social organisation in Thessaly. There is no evidence to show that Late Helladic Thessaly had a social elite like those in the south and the only suggested palace is at Iolkos. The social organisation in Thessaly seems to have been at best therefore a watered-down version of that in the main Mycenaean area and perhaps Thessaly retained a greater degree of independence than regions like



Boeotia. There is little evidence for external trade.

In the Homeric Catalogue of Ships which is sometimes thought to refer to LHIIIC 8 small kingdoms with about 25 towns between them are ascribed to Thessaly (Cambridge Ancient History, 1975).

Hope Simpson and Dickinson suggested (197 :272) that tholos tombs in Thessaly may be the local equivalent of chamber tombs, of which there are very few in Thessaly. On the other hand, the use of cist tombs continued into the Late Helladic in Thessaly.

There is no evidence to suggest that LHIII in Thessaly saw a large expansion. Neither is there evidence for widespread catastrophes in LHIIIB but very few sites have produced finds which can be firmly dated to LHIIIC. The fragment of a stirrup jar with Aegean Octopus Style decoration from near Pharsala (see below, site 17) is one of the few firm pieces of LHIIIC evidence from inland Thessaly. The course of events in late LHIIIC and the early Dark Ages remains very unclear.



CHAPTER 3.

GEOLOGY AND GEOGRAPHY

3.1. Euboea: Geology and Geography (see map, Figure 1.)

Euboea is the second largest Greek island and lies along the east coast of the central Greek mainland. At Chalkis, where there are only a few metres between the island and the mainland flow the Euripos Straits with very strong currents. The straits have been bridged since the 5th Century A.D. Euboea lies approximately north-west to south-east and is a continuation of the Peloponnesian Strait from eastern Ionia. The island is composed of dense crystalline Palaeozoic rocks. It was due to subsidence in the Pliocene Euboea became an island, separated from the mainland by the Gulfs of Euboea and Petalioi to the west and the Straits of Gressi and Trikeri to the north.

CHAPTER 3.

GEOLOGY AND GEOGRAPHY

Euboea consists of a number of mountain ranges and lower hills with intervening basins. Some of the mountain ranges run parallel to the general trend of the island and were formed due to folding during the Mesozoic period. Other ranges are made of Mesozoic limestones, they are older and run across the island. In between these ranges the basins are covered with a variety of tertiary and Quaternary sediments.

In Euboea, as in the rest of Greece, there are three sets of mountains: higher, middle and lower. The highest peninsula is 747 metres at its highest point. The middle range is made of limestones. The next range is the lower range. The next peaks are those of the lower range which are made of crystalline schists and gneisses. The lowest range is made of tertiary and Quaternary sediments. Last comes Mount Aegion in north-east Euboea which is covered with limestones. The hills and mountains of Euboea are composed of Palaeozoic sediments.



CHAPTER 3.

GEOLOGY AND GEOGRAPHY

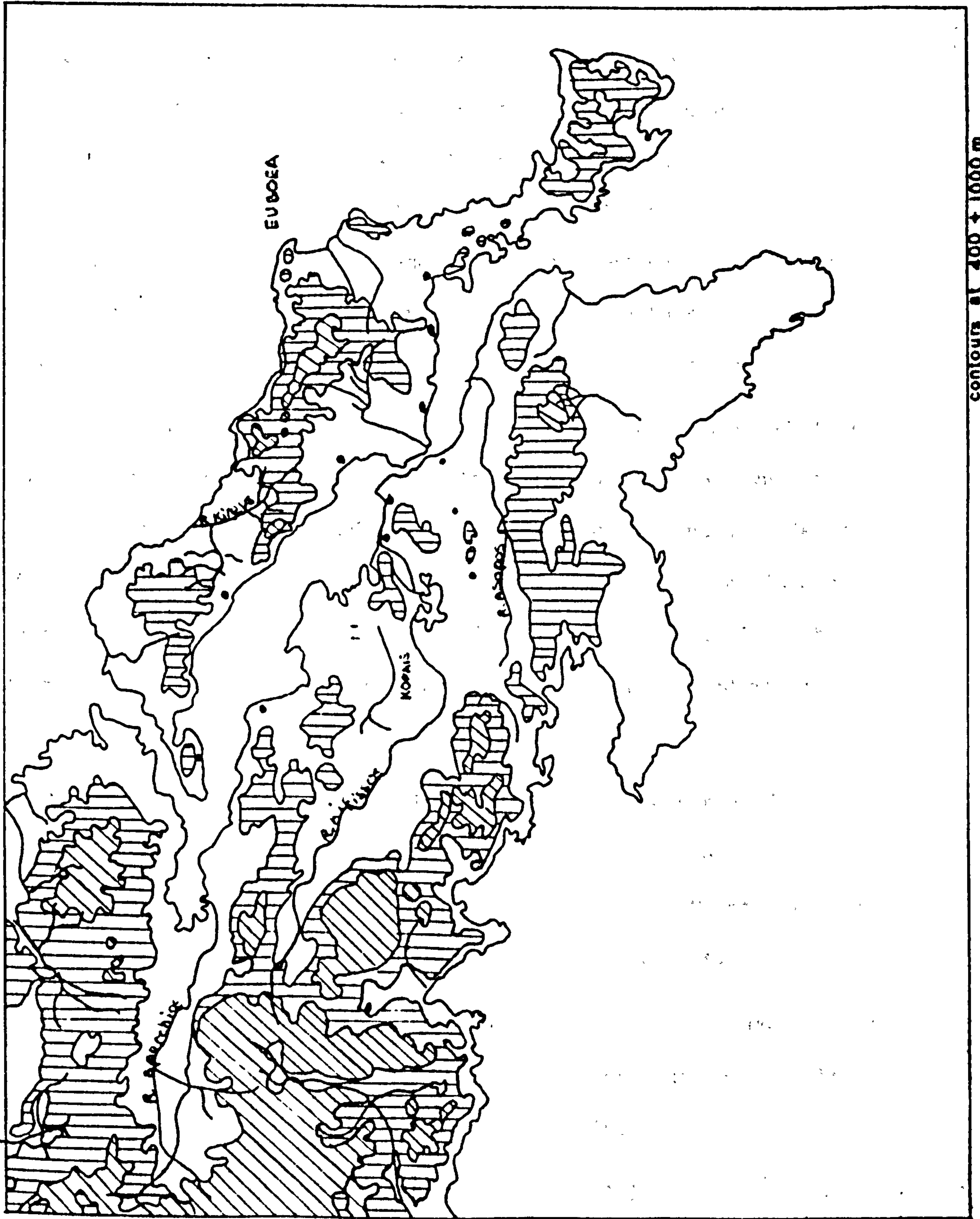
3.1. Euboea: Geology and Geography (see map, Figure 7.)

Euboea is the second largest Greek island and lies along the east coast of the central Greek mainland. At Chalkis, where there are only a few metres between the island and the mainland flow the Euripos Straits with very strong currents. The straits have been bridged since the 5th Century A.D. Euboea lies approximately north-west to south-east and is a continuation of the Pelagonian Massif from eastern Thessaly. The massif is composed of dense crystalline Palaeozoic rocks. It was due to subsidence in the Pelagonian zone that Euboea became an island, separated from the mainland by the Gulfs of Euboea and Petalioi to the west and the Straits of Oreoi and Trikkeri to the north.

Euboea consists of a number of mountain ranges and lower hills with interlying basins. Some of the mountain ranges run parallel to the general trend of the island and were formed due to folding during the Alpine orogeny. Other ranges are made of Mesozoic limestones, they are older and run across the island. In between these ranges the basins are covered with a variety of Tertiary and Quaternary sediments.

In Euboea, to the north of Limni, there are three sets of mountains: Likhas, Telethrion and Xiron. The Likhas peninsula is 747 metres at its highest and is made of limestone. On the marl which runs around its edge lies Gialtra (site 3). Moving eastwards the next peaks are those of the Telethrion Mountains which are made of crystalline schists and rise to 986 metres with steep scarps. Last comes Mount Xiron in north east Euboea, formed of gabbro covered with limestone. The hills surrounding Mount Xiron are composed of Pleistocene sediments.





contours at 400 + 1000 m

Fig.7: Euboea. and Boeotia: Geography.

In an area running south from Limni to Aliveri Bay one finds Euboea's largest plains and highest mountains. The highest mountain is Dhirfis (1766 m) but others are not much lower, these include Pixaria (1134 m) and Skotini (1431 m). These all lie along the east coast. Mount Kandhilion (1237 m) faces the west coast. The basin of Psakhna (site 5) and Yidhes lies to the south of Mount Kandhilion and to the west of the other three mountains. On its south are Mount Olimbos (1149 m) and Mount Oktonia (673 m). All these mountains are made of limestone. The plain of Psakhna and Yidhes has a gravel floor except at its lowest where the plain is alluvial. Underneath these sediments lies Upper Cretaceous limestone with iron nickel ores and bauxite.

The most fertile area of Euboea is the Lelantine Plain which lies between Mount Olimbos and the coast. It is flanked by the towns of Chalkis and Eretria which fought over it in the Archaic period (Jeffery, 1976). Lefkandi (site 4) lies in the Lelantine Plain. The plain has always been renowned for its deep deposits of clayey red soil which is not only very fertile but which is also used for pottery and modern brickmaking (Sackett and Popham, 1972).

Chalkis, the largest town in Euboea, lies near the narrow Euripos Straits and on the fertile land of the Yidhes delta. The small triangular plain of Amarynthos (site 2) has tall limestone Mount Servouni to its east. The plain is mostly composed of river fans.

Between these plains and Kimi in eastern Euboea are a range of serpentine hills and a Karst plateau. The lowland area around Kimi has good agricultural land although it is rather marly.

Southern Euboea is composed of folded crystalline rocks and is a



high area, much around 600 metres and rising to Mount Okhi (1404 m) which is made of schist. Very little of this area is cultivatable but there are pockets of alluvium and red earth and 2 fertile plains covered in Tertiary deposits at Styra and Karistos. The dearth of arable land in this area is reflected in the paucity of sites which have been found here.

The climate of Euboea is like that of the neighbouring parts of the mainland, with dry summers and considerable precipitation in winter.

It can be seen that among the mountains in Euboea a majority are composed of limestone and Euboean clays might well be expected to have a fairly high calcium content. The presence of serpentine around Psakhna and again in the south of the island could affect the magnesium and nickel content of the local clays. Nickel and magnesite are in fact mined not far from Psakhna. There are not large differences in the geology of the different areas of the island and it is not therefore very likely that analysis would allow pottery from different areas within Euboea to be distinguished from each other.

3.2. Boeotia and Locris: Geology and Geography (see map, Figure 7).

Western Boeotia is very mountainous. These mountains include Mount Parnassos (2480 m), Mount Giona (2000 m) and Mount Elikon (1765 m). Mount Parnassos and Mount Giona are made of limestone. Between Parnassos and Elikon is a valley leading from Itea on the coast through the mountains into Central Boeotia. The valley is floored with red shale and is very fertile. Mount Elikon is also made of limestone but is flanked by outcrops of sandstone and red shale. It is also rich in bauxite. The river Askris divides Elikon from the Kithairon and Pastra mountains which lead, in the east, to the Mount Parnes range. These mountains extend eastwards for a total of 60 km. They too are made of limestone.

The mountains of Oiti and Kallidromon in northern Boeotia and Locris form a barrier between these areas and the Spercheios valley to the north. Mount Oiti has a plateau at 1908 m and then rises to crags at 2172 m. It is made of limestone and cut by several gorges on its eastern face including that of the Kifissos river. Its southern edge is formed of less resistant rocks and slopes more gently.

Mount Kallidhromon itself rises to 1385 m and several of the mountains around it reach 1230 m. The range is composed of folded limestone with slate and red chert. There are steep fault scarps on both the north and the south.

To the east of these mountains a region of Pliocene marl and conglomerate only c 750 m high deeply cut by rivers stretches from the Maliaic Gulf south to the triangular coastal plain of Atalandi where site II is situated. Along the southern edge of the plain of Atalandi



is some dark serpentine and slightly further to the south iron and nickel are mined. This area is overlooked by Mount Khlomon (1090 m) composed of hard dolomitic limestone.

Central Boeotia consists of a depression cut by the rivers Kifissos and Asopos and flanked by the mountains described above. This depression is c 120 km long and reaches from near Mount Oiti in the north, south east to reach the Gulf of Euboea near Chalkis. It consists of a series of faulted basins running parallel to the trend of the folded rocks. These basins are floored with alluvial soils and are quite fertile.. The Elatia basin contains the very large fan of coarse particles deposited by the waters draining off Mount Parnassos.

The largest of these basins is Lake Kopais which covers c 350 square kilometres. It was formed by crustal disturbance followed by erosion of the limestone. It was drained artificially in the Bronze Age and again in modern times. Its natural drainage is underground. To the south east of Lake Kopais a series of bare Karstic ridges divides the lake from lakes Iliki and Paralimni which lead to the Gulf of Euboea near to sites 7 and 8. Here too is Mount Ktipas which is only c 1000m high. Ktipas is formed of limestone resting upon serpentine. Magnesite is quarried from vans in the serpentine.

The river Asopos runs almost west to east in a shallow valley across southern Boeotia. It runs across easily eroded Pliocene sands, marls and conglomerates covered with red or brown soil. Thebes (site 12) is situated on a spur of the northern escarpment of the river. Between Thebes and Lake Iliki, and extending up beside Lake Kopais is the Theban Plain. Between Thebes and the east coast are 2 limestone ridges, Soros and Termessos and beside the former is site 10. To the east of these

ridges the plain of Tanagra leads to the coast. The plain is floored with red soil and easily eroded sediments.

In Boeotia and Locris, even more than in Euboea, the mountains are predominantly made of limestone. In some areas this is dolomitic which could thus affect the magnesium as well as the calcium content of clays. The serpentine which occurs around the Plain of Atalandi near Kynos (site 11), and the local nickel and iron ores which are mined today could have affected the clays which formed in this area. As mentioned above, the mountains which overlook sites 7 and 8 by the Gulf of Euboea and composed of limestone on serpentine. It might be expected from this geology that clays in Boeotia and Euboea would be fairly similar in chemical composition and not always easy to tell apart.



### 3.3. Eastern Thessaly: Geology and Geography (see map, Figure 8).

The southern edge of Thessaly consists of a mountain barrier which all but cuts Thessaly off from Central and Southern Greece. These mountains are the Othrys range, the highest of which are over 1500 m high. They are made of rounded limestone and are surrounded by extensive hills. The rivers running off the Othrys range mostly drain into the Khiliadhiotikos river which, as the Enipevs, is the largest tributary of the Pinios river. On the northern edge of Othrys are the hills of Kassidhiari and Narthakion. Pharsala lies at the foot of these hills and at times the surrounding land becomes marshy due to the volume of water draining off Othrys.

Thessaly is dominated by its two large plains. They are enclosed by mountains: Othrys to the south, Pindos to the west, Kamvouni to the north, in the north east Olympos and along the east coast mount Ossa and mount Pilion. The plains are separated by the Mavrovouni hills. The Pindos mountains are mostly limestone with outcrops of sandstone and chert. On either side of the limestone is a lower belt of sandstone and shale outcrops containing numerous springs. The Pindos mountains are drained by the headwaters of 5 rivers including the Pinios which flow down into the western plain.

In the north the Kamvouni mountains are made of crystalline rocks and mica-schists and have several peaks up to 1500 m high. The peaks are not sharp but rounded and dip to the north-east.

In the north-east Mount Olympos (2917 m) dominates the horizon, its dome-shaped summit remaining snow-covered for most of the year. It is made of limestone over gneiss and green schists. Some of the lime-

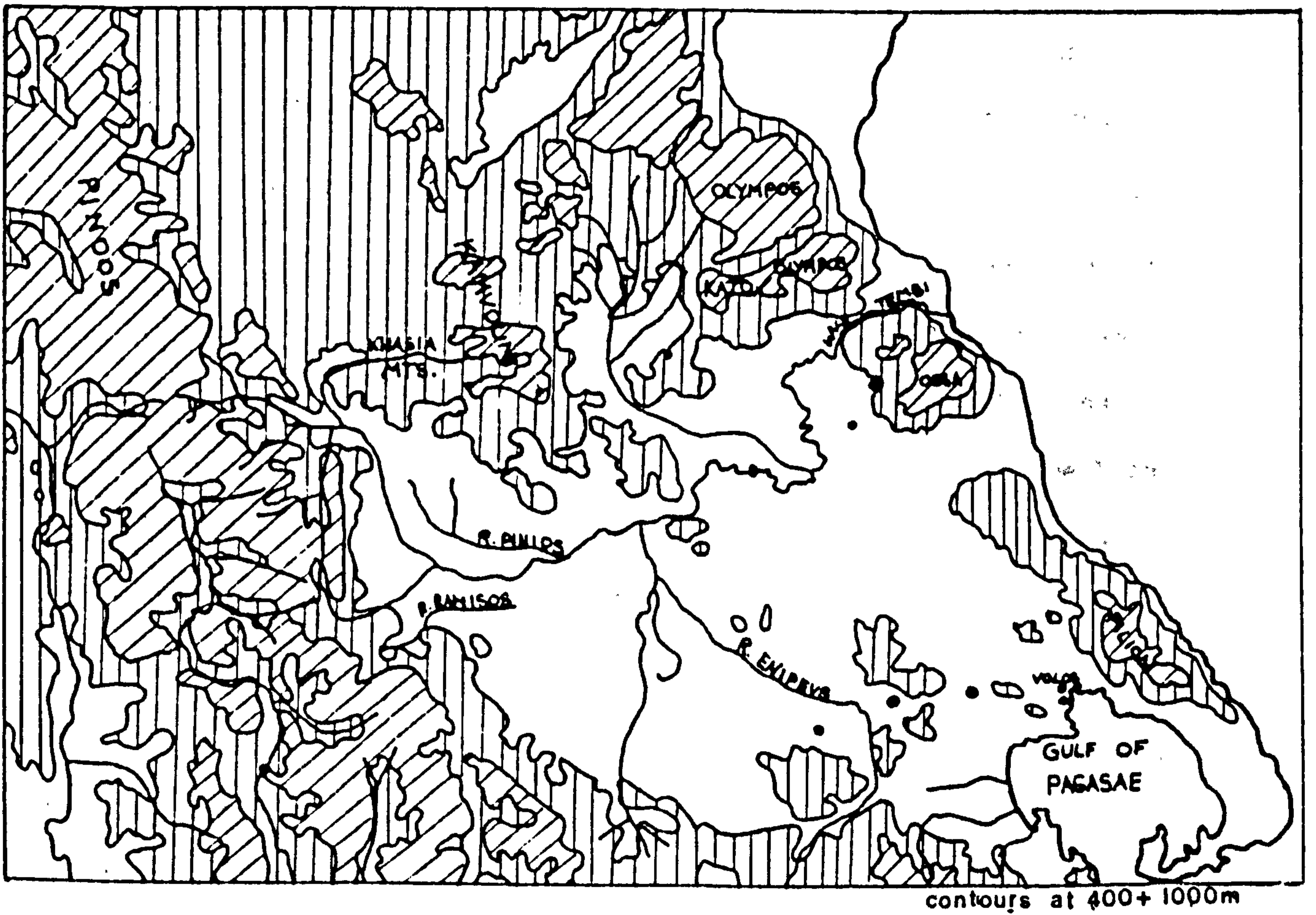


Fig 8 Thessaly: Geography



stone is dolomitic and some semi-crystalline. Kato Olympos is similar in composition only lower. The River Titarisios flows down from Olympus to join the Pinios near Larissa. Since dolomitic limestone generally contains over 15%  $MgCO_3$  (Whitton & Brooks, 1972) and the rivers flowing down to join the Pinios come from Olympus it is possible that the high magnesium content of the limestone might be reflected in the local clay compositions. The River Titarisios also passes along the edge of the Kamvouni mountains before reaching the Pinios and may carry mica down to the Larissa area. This could account for the higher than usual mica content of the pottery from this area (sites 13 and 20).

Between Kato Olympos and Ossa lie the deep ravines of the Vale of Tembi where the Pinios flows through the mountains to the sea. Mount Ossa is composed of gneiss and mica schist covered with dolomitic and crystalline limestones and has a pyramidal peak c 2100 m high. Ossa is drained by the Gavroneri stream flowing to the north east and the Megalo stream flowing to the south west. The composition of Ossa may again be reflected in the local clay compositions (site 15).

Between Ossa and Mavrovouni is a coastal plain of considerable fertility and a little further inland is a plain c 150 m above sea level. Mavrovouni itself consists of rounded summits adjoining Mount Pilion and forming the Magnesia Peninsula. The high ridge of the peninsula falls sharply to the Gulf of Pagasae. Pilion consists mainly of marble. Ossa and Pilion are part of the Pelagonian Massif formed of dense crystalline rocks, marble, granite and schist which continues into Euboea and the Cyclades.

Behind Volos the Pilaftete Pass between the Volos plateau and Pilion allows access between Velestino and the Gulf. It runs between

peaks up to 600 m high and was probably a river valley in origin. The Mavrovouni hills form a low barrier between the two plains and are ultimately an extension of Othrys. They consist of crystalline and calcareous rocks.

The two large plains (the western and the eastern plains) are both large and unusually fertile and well-watered by Greek standards. The western plain is centred on Pharsala and the eastern on Larissa. The western plain is the larger, being approximately 80 x 35 km while the eastern plain is approximately 60 x 20 km. Both have a remarkable even surface and are for the most part around 90 m above sea level.

Commenting on the formation of the western plain Schneider (1975) wrote that by the Tertiary, if not the Miocene period, subsidence of a part of the Thessalian massif had led to the formation of a basin of sedimentation. The basin is covered at least in part by the products of erosion carried down from the mountains. At the centre of the basin these deposits are clayey but the closer one gets to the mountains and to the heads of the rivers, the coarser the deposited particles. The bedrock lies at an unknown depth beneath these easily eroded sediments.

The western plain lies in the Sub-Pelagonian zone and is drained by the River Pinios and its tributaries, the Enipevs, the Sofaditikos and the Zarkos Gorge where the Pinios enters the eastern plain from the west. The rivers flow down from the surrounding mountains and, due to the snow-melt and rainwater, carry a considerable volume of deposit with them to the plain, with clay being deposited between the fans.

The eastern plain has a double drainage system. The north west is drained via the Pinios and the south east via ancient Lake Karla which



has now been artificially drained by an underground gulley running towards the Gulf of Volos. Due to its position the eastern plain receives the larger share of the finer sediments carried by the Pinios. The only river in the eastern plain which is powerful enough to build a large fan is the Xirias. In both plains there is considerable flooding, contrasted with summer aridity.

Sivignon (1975, 86) wrote that c 60% of the soils in Thessaly are recent alluvial deposits, 25% are rendzinas developed from older materials on the hill slopes and 15% are varied soils situated around the plains. He added (p.89) that alluvial soils with a fine colloidal subsoil and poor drainage cover almost all of the eastern plain and the southern part of the western plain. Considerable areas of this soil type are clayey.

Thessaly has more geological variety than Euboea or Boeotia which may make it less difficult to identify different areas of pottery manufacture within Thessaly. Near Pharsala and sites 17 and 19, around the River Enipevs the clays may perhaps be expected to show evidence of their origin in the Othrys range of limestone mountains. Around Larissa, as mentioned above, a variety of mountains will have contributed particles which were carried down by the River Pinios and formed the clay beds. The mica in the pottery from this area and in Mount Olympos could be reflected in higher than usual potassium content and where the limestone is dolomitic, a high magnesium content might be seen. The other sites which were sampled lie around the Gulf of Volos on alluvial deposits which are likely to have formed from particles from both marble mount Pilion and the calcareous and crystalline Mavrovouni hills which flank modern Volos.

CHAPTER 4.

SAMPLE CHOICE



CHAPTER 4.

SAMPLE CHOICE

4.1. General Comments.

Throughout the extensive programmes of analysis of Late Bronze Age Greek pottery which have been carried out over the last twenty years, the areas dealt with in this thesis have been largely neglected. By 1963, out of the 500 sherds analysed by Optical Emission spectroscopy only a total of 95, from 5 sites, came from this large area. The sites in question were Thebes in Boeotia, Amarynthos in Euboea and Volos, Marmariani and Argyropoulis in Thessaly. Although the linear B inscribed stirrup jars from Thebes have been the focus of considerable attention, the situation with respect to Boeotia, Euboea and Thessaly is little better today than it was in 1960. In the intervening years analyses have been done on sherds from Lefkandi in Euboea (soon to be published), Gla, Orchomenos, Pyrgos, Eutresis, Kalami and Arva in Boeotia and Velestino in Thessaly, but although these analyses are mentioned in Archaeometry (Millett and Catling, 1967: 73) they have never been published. Dr. Jones, however, intends to publish them in his forthcoming monograph on the analysis of ancient Greek and Cypriot pottery.

This gap in our knowledge is partly due to the relative lack of excavation in these areas. Late Bronze Age Boeotia has been described (Popham and Milburn 1971: 358) as "practically an archaeological blank". Until the Euboea Survey (Sackett et al., 1966) the situation in Euboea was even worse. Thanks to the work of the late Drs. Theochares and Milojcic there have been more excavations in Thessaly but there remain large and perplexing gaps in our knowledge of the Mycenaean period in this region.

In Euboea the 6 largest sites which are known to have had Late Bronze Age occupation were chosen for sampling. These sites include Amarynthos and Lefkandi which had already been sampled. However, different sherds were selected for analysis in this project and without these two sites an unbalanced picture of the situation in Euboea would have been obtained.

Six Boeotian sites were also sampled and it was decided that the sites to be examined should be Thebes and sites which lie between it and the Gulf of Euboea since this part of Boeotia is closest to Euboea and most likely to have had contacts with it. Indeed Hankey (Hankey, 1952) commented on the apparent Theban influence which can be seen on some Euboean pottery. Of these sites only Thebes had been sampled before but here different sherds of the same period were analysed and Thebes was too important a site not to be included.

Volos, Marmariani and Velestino in Thessaly had all been sampled before but were resampled for this project. Volos controls access to the interior of Thessaly via the Gulf of Pagasae. A palace was built there and it was, as far as we can tell, the most important site in Late Bronze Age Thessaly. It was important, therefore, that both Volos (Iolkos) and the nearby site of Pevkakia were included. Moving west from Volos the site of Velestino (Pherae) occupied an important position on the route to the western plain. Beyond its intrinsic importance as a site Velestino also offered the chance to test the theory held by some archaeologists (see above, Chapter 2.4) that it was people from the Argolid who introduced Mycenaean ways to Thessaly and that some of the pottery from Velestino was imported from the Argolid. From the other South Thessalian sites Revmatia-Paliambela and Yephyria were chosen



to add to the picture. Revmatia has the additional significance in that it was there that a sherd of a stirrup jar with Aegean Octopus style decoration was found and this sherd is one of the few indicators of LHIIIC occupation in this area. Revmatia lies on the eastern edge of the western plain. Yephyria lies in the plain itself and is one of the most westerly sites in Thessaly which shows occupation in the late Bronze Age. The other area of considerable Late Bronze Age occupation in Thessaly was further north around modern Larissa in the eastern plain and around the foothills of Mount Ossa. As mentioned above Marmariani was resampled. Argissa (Gremnos) on the north bank of the River Pinios was selected because excavations by the German School have shown that it was a large and important site in the Late Bronze Age. The last site included is Yephyra-Asmakiou which lies between Argissa and Marmariani in the eastern plain.

These sites were all selected because of their importance in relation to each other. The Boeotian and Euboean sites might well be expected to have had contact and possibly trade with each other and they may also be thought likely sites to have had contact with Volos and hence with inland Thessaly. Since it remains uncertain from where Mycenaean ideas were introduced to Thessaly it was logical to examine the 2 closest areas where a Mycenaean way of life flourished.

It should be noted that the area between Thessaly and central Greece, the Sperchios Valley, has not been included in this project because there are very few Late Bronze Age sites there. Even in LHIIIA-B, generally the period within the Late Bronze Age from which we know of the largest number of sites there are only 4 (GAC G75, 76, 77/78 and 79). The Oxford laboratory analysed some samples from Platania (G79), the results

of which were summarised in Archaeometry (Millett and Catling, 1967). Suitable material was not available from the other sites.

In hoping to establish 'control' groups, typical of the pottery composition for a site, there are 4 criteria which it should be aimed to fulfil when selecting samples. They were clearly stated by Jones in his section of the article on Marine Style pottery (Mountjoy et al., 1978: 158-9). They are that: the samples should come from vessels which are readily identifiable and preferably decorated which could confidently be described as local on archaeological grounds; that they should be at least 15 in number; that they should be firmly dated to one period, and that they have a fine fabric. Elsewhere (Jones and Mee, 1978) 20 sherds have been taken as the minimum when testing for a 'control' group. Since 20 sherds will not always form one composition group and indeed may in extreme cases like Chania in Crete (Catling and Jones, 1977) form 3 separate groups, the resultant groups are rather small for statistical testing. Hedges (1974: 4) suggested that 40 sherds was the number needed to show normality of distribution for the establishment of 'control' groups. For testing groups against these controls smaller numbers are acceptable. Following the work mentioned by Jones above, it was decided that 20 sherds should be the preferred minimum size of the groups which were analysed in this project. Exceptions were made in the case of Anthedon in Boeotia (site 7) from where only 18 sherds were available, in the case of a few of the sub-groups from Pevkakia (site 16), and in the case of one sub-group of material from Velestino (site 18) in Thessaly. It was originally hoped to augment this last group but this proved to be impossible.



In the majority of the OES analyses which have been carried out, 'control' groups were established for an area and were then compared and contrasted with those of other areas. As reference to Figure 1, of the sites which had been sampled up to 1963 shows, it was inter-site variation which was studied on the assumption that the composition of pottery from one site would be typical for the region in which it lies. In this project on the other hand extensive analyses have been carried out of material from sites within three linked yet separate geographical areas and it should perhaps be anticipated that there will be less variation in the composition of material from these sites than there would be if sherds had been sampled from, for example, Thessaly and Crete.

To satisfy the third of the criteria mentioned above it is preferable that the sherds come from well stratified archaeological contexts so that the pottery can be dated not only by comparison with other pottery but also possibly by outside means. At Thebes, for example, datable Mesopotamian cylinder-seals were found with Mycenaean pottery of LHIIIB style. The samples which were analysed from Velestino, Iolkos, Pevkakia and Argissa in Thessaly, Lefkandi in Euboea and Thebes in Boeotia all come from excavations. The remainder of the material, all of which is in the sherd collection of the British School at Athens, has been accumulated during survey work. The Euboean material was collected during the Euboea Survey and the Thessalian material was collected by Dr. D. H. French. At Lefkandi it was possible to select sherds which came from only two types of vessels, deep bowls and kylikes. This was not possible with any of the other sites and for the majority of the sherds the type of vessel from which they come has not been determined. The vessel type is included in the sample lists (Appendix I) where it is known.

Since Catling and Millett began their work on pottery analysis a huge volume of data has been amassed. During this time, too, multi-variate techniques for grouping samples and of testing the statistical validity of the resultant groups have been evolved. A computer can look at the relative positions of samples in multi-dimensional space and group them accordingly. It can also handle large volumes of data with far greater ease than can a person. Analysts now apply these techniques to their data as a matter of course and when applied to some of the older data have resulted in re-groupings. Recent re-evaluation of the Amarynthos data (Catling et al., 1963), for example, suggests that the 16 compositions can be accommodated within a single group, not 2, as was originally contended (Jones, personal communication).

Most of the sites listed below are described as being 'high' or 'low' mounds or magoulas. These types of site have been defined by Wace and Thompson (1912: 45). Low mounds, they say, are the most common and generally the earlier in date. They rise gently to a height of only c 3 metres above their surroundings. High mounds are up to 8 m high, oval in shape with steep sides and a flat top. They continued in use later than low mounds. Magoulas differ from both these types for their height is due, as in a tell, to superseding occupation and rubbish levels rather than to the adoption of a natural feature for a site. The kinds of material found on these three types of site might be expected to be similar.

For ease of cross-reference the name of each site is followed by the numbers given to it where relevant, in Hope Simpson's Gazetteer and Atlas of Mycenaean Sites (GAMS), Hope Simpson and Dickinson's Gazetteer of Aegean Civilisation (GAC), the Euboea Survey by Sackett et al. (EUB)

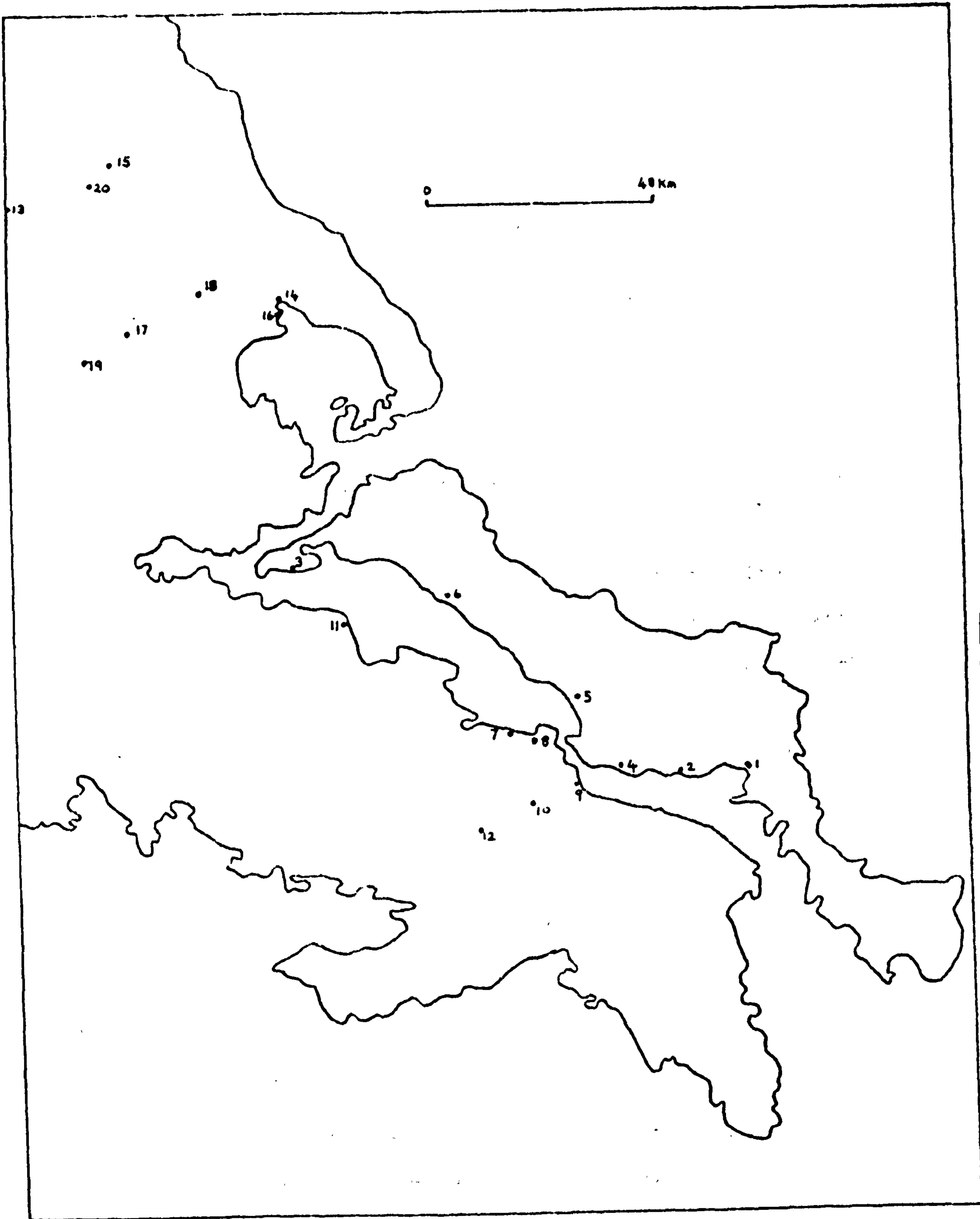


and in Dr. D. H. French's unpublished notes on Thessalian sites and pottery (DF).

A map reference is also included for each site. Following Hope Simpson and Dickinson (1979) they refer to the British War Office Series G.S.G.S. 1:100000 for Greece. Since these maps were prepared during World War II their accuracy, as Hope Simpson and Dickinson remarked (Ibid.: 7), is not always as good as would be hoped.

A brief list of relevant references follows each site description. The full details of the references can be found in the bibliography at the end of this volume. A map (Figure 9) is provided to show the location of the sites.

A list of all the sherds and raw clays which were sampled is given in Appendix I. Plates 2-5 show examples of the sherds analysed.



- 1 Aliveri
- 2 Amarynthos
- 3 Gialtra
- 4 Lefkandi
- 5 Psakhna
- 6 Rovies
- 7 Anthedon
- 8 Chalkia
- 9 Dramesi
- 10 Eleon

- 11 Kynos
- 12 Thebes
- 13 Argissa
- 14 Iolkos
- 15 Marmariani
- 16 Pevkakia
- 17 Revmatia
- 18 Velestino
- 19 Yephyria
- 20 Yephyra-Asmakliou

Fig 9 Sites which were sampled



#### 4.2. EUBOEA

Material was sampled from 6 Euboean sites. Because of site and sample availability the sites which were sampled are all situated on or near to the west coast, facing the Greek mainland, and in the northern two thirds of the island.

##### (1) Aliveri Magoula

GAMS 565. GAC F86. EUB 63.

1.10. Nea Psara 680E/893N.

This is the most southerly of the sites sampled and lies near the coast. It is a 'low mound' site 150 x 100 m which has been eroded by deep ploughing. The pottery from Aliveri Magoula ranges in date from the Neolithic to the Classical periods. Some building materials have also been found on the site. It is the largest known LH site in southern Euboea and according to Sackett et al. (69) it must have been the most important MH and LH settlement in the area. Near to the mound is a chamber tomb which contained LH pottery.

Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Sackett et al. (1966)

##### (2) Amarynthos Palaiochora

GAMS 564. GAC F85. EUB 63. + P117a.

1.10. Nea Psara 561E/889 N.

This site is on a prominent low hill at the eastern end of the Eretrian plain c 2 km east of Amarynthos village. It has steep cliffs on the seaward side and a small sheltered bay to the east, and on the plateau, which is 250 x 150 m there are 2 Byzantine churches and the ruins of a third. The site appears to have been occupied more or less

continuously from Neolithic to Hellenistic times. There are traces of a possible EH destruction level associated with wall foundations and EHII sherds. There is a good range of MH and LH pottery on the top and on the east and west slopes. LH sherds from the upper NW (inland) slopes include 2 LHIIIC pictorial sherds. Although a small excavation here in 1898 (PAE 1898) was unsuccessful the abundant surface material and especially the LHII-LHIIIC sherds, described by Hope Simpson as of 'impeccable quality', indicate that this must have been an important prehistoric site. Sackett et al.(46) conclude that this was 'very probably the principal Mycenaean site of the Eretrian plain'.

Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Sackett et al. (1966)

### (3) Gialtra Kastelli

GAMS 559. GAC G85. EUB 3 + pl 9c.

T.8. Atalandi 772E/449N.

This is the most northern of the Euboean sites sampled in this project and it lies in north-west Euboea on the coast of the Likhas peninsula at the southern end of the Kenaion mountain range 1.5 km west of Gialtra Loutra. It is a fine natural acropolis with a plateau 70 x 50m. It rises sharply from a narrow valley on one side and on the opposite side slopes gradually to the coast. A large number of fine quality sherds have been found here indicating that the site was occupied from Neolithic to Roman times. The LH pottery is of particularly high quality. Traces of buildings and wells have also been found. Gialtra can be seen from the site of Rovies (no. 6).

Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Sackett et al. (1966)



(4) Lefkandi Xeropolis

GAMS 554. GAC F81. EUB 48-50.

1.9. Chalkis 356E/930N.

The site of Xeropolis is sited precisely half way between Eretria and Chalkis on the western coast of Euboea and is strategically placed on the edge of the Lelantine Plain. It is a 'high mound' site 500 x 120 m with steep sides. It is not very high and projects into the sea with a sheltered anchorage to one side. Xeropolis means dry or deserted city. The area of the plateau is comparable with that of the Citadel of Mycenae and over twice that of the Acropolis of Athens (Popham and Sackett, 1972: 11).

The Euboea Survey, carried out by Sackett et al. (BSA 1966, 61) indicated that Xeropolis was likely to have been an important BA town site and between 1964-1966 Popham and Sackett excavated there on behalf of the BSA. Apart from the main area of 300 sq.yds. which was excavated there were wide-spread test trenches dug on the hill and one sounding to bedrock which showed continuity of occupation from the EBA to the LBA or possibly the Geometric period. The sounding cut through over 8 m of occupation levels. The southern side of the site has been eroded by the sea.

The densest occupation was in LHIIIC although it is clear that LHIIIC levels cut into and partly destroyed the LHIIIB levels. Within the LHIIIC 3 major phases can be distinguished. They spread over the whole hill. The first phase was completely destroyed by fire and the second partly so. The settlement then appears to have declined and there may have been a gap in occupation before the Proto-Geometric. Each phase was built in the ruins of the previous phase and each phase

had its own architectural and cultural style. It is remarkable that in the LHIIIIC when much of Greece was depopulated Xeropolis was an active centre (Sackett and Popham, 1972, 13).

The buildings of the first phase were irregular in shape and the pottery appears to have been locally made and simple. This phase was succeeded by one with regular, well-built, rectangular buildings and a lively pictorial style of pottery decoration. At the end of this phase some of the dead were buried indoors in pits beside the walls with no more than a pithos to accompany them. Since some of the dead died violently this is taken to indicate an unsettled period in the history of Xeropolis. After a partial destruction and rebuilding with a slightly altered plan the final LHIIIIC phase shows a decline in living standards with inferior quality pottery and rather poorer buildings.

Not far from Xeropolis are three important Iron Age cemeteries which have been partly excavated and which have produced a mass of PG pottery, weapons and jewellery.

A study of the LHIIIIC pottery from Xeropolis was carried out by Popham and Milburn and published in BSA (vol. 66, 1971). In this study (p.348) they commented that the pottery from Xeropolis resembles that from Athens, Volos and Kea and that the greatest similarities are possibly between Xeropolis and Volos. They added that "in fabric they can rarely be distinguished, both moreover have a similar pictorial style".

Hope Simpson (1965).

Hope Simpson and Dickinson (1979)

Sackett et al. (1966).

Desborough (1972, p.188 ff).

Leekley and Efstratiou (1980).

BSA 1971 p.133 ff Popham and Milburn.

Popham and Sackett Excavations at Lefkandi (1968).



Popham and Sackett (1972).

Popham and Sackett Lefkandi Vol. I plates (1979).

Archaeological reports 1964-5 (p.16), 1965-6 (p.10), 1966-7 (p.12),  
1967-8(p.12), 1969-70 (p.18), 1970-71 (p.7).

(5) Psakhna, Ayios Ilias

GAC F70. EUB 30 + p.112d.

T.9.Psakhna 342E/098N.

This is a prominent hill which dominates the low lying, well watered, fertile plain around the modern village of Psakhna and it has extensive views to the west, south and east. MH, LH and later sherds were found on the western and southern slopes and were concentrated on the south west slopes opposite a medieval tower. There are the remains of MH and LH terraces on the lower south west slopes. The church of Ayios Ilias on the top of the hill is partly built of stones which were taken from the older remains and reused.

Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Sackett et al. (1966)

Leekley and Efstratiou (1980).

(6) Rovies Palaiochori

GAC G96. EUB 19.

T.9.Psakhna 008E/398N

One and a half km east-north-east of the village of Rovies on a track to Palaiochori both sides of the track are strewn with sherds. Hope Simpson identified it as the site of ancient Orobiai. The northern part of the site was abandoned in the EH but the southern part was a

substantial BA settlement. The sherds have been brought to the surface by deep ploughing and by their quality and variety Sackett et al. (p.48) inferred that there must have been a fairly large EH-LH settlement here. To the south-east were some shallow chamber tombs.

Hope Simpson and Dickinson (1979).

Sackett et al. (1966)

Leekley and Efstratiou (1980).

#### 4.3. BOEOTIA AND LOCRI

Material from 5 sites in Boeotia and from one in Locris (site 11) was sampled. Four of the sites lie along the east coast opposite Euboea. Thebes lies c 25 km inland and Eleon between Thebes and the coast. This area was chosen because of its proximity to 6, and relatively to Thessaly.

##### (7) Anthedon

GAMS 437. GAC G43

1.9.Chalkis 163E/037N.

In 1889 J. C. Rolfe and C. D. Buck from the American School of Classical Studies in Athens conducted a three week trial excavation on the shore of the Euripos Straits c 3 km north of the little village of Loukousi where remains of an acropolis, 180 x 160 m, fortification walls and of 2 breakwaters by a small sheltered harbour could be seen. The slopes of the acropolis are terraced. There is a report of this work in AJA VI (1890, p.96-107) which unfortunately has very little discussion of the date of the remains beyond the statement that they are 'Greek' and 'of good period'. During the excavations they traced the whole length of the city wall and found traces of a tower. In 4 trial



trenches cut across the platform of the site they found remains of walls and part of a Roman mosaic pavement. On a hill outside the city wall were some tombs which had been robbed at some time. The robbers had left a trail of pot-sherds. In 3 trenches dug here a hoard of tools and sheet bronze and what may be a part of a decorated tripod rim were found. They are now in the National Museum in Athens. In 1959 Hope Simpson found LHIII B-C sherds and some obsidian on the site. Leekley and Efstratiou suggested that the breakwaters and an irregular building on the quay were Roman and that the hoard was possibly LHIII C in date. Desborough agrees with this date for the hoard.

Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Desborough (1964)

Rolfe (1890)

(8) Chalia (now Drosia)

GAMS 436. GAC G44

1.9. Chalkis 221E/013N

The site is on the south side of a small bay 3½ km west of the village of Drosia. It is a 'high mound' site 95 x 50 metres on the top of a low hill and because of its shape was mentioned by Pausanias as the 'Tomb of Salganeus' who also noted that it was on the way to Anthedon. In 1912 N. Papadakis did a trial excavation here which has never been properly published. He found pottery ranging from the Neolithic to Late Helladic in date. Trenches cut during World War II on this site cut across house foundations. In 1959 Hope Simpson identified traces of chamber tombs on the slopes to the east. In 1969 Th. Spyropoulos conducted a trial excavation here (A.D. 1970, vol. 25) which

confirmed that the site was occupied throughout the Bronze Age although occupation was most concentrated in the EBA. He claimed that the site was abandoned at the end of the LHIII B phase or immediately after.

Hope Simpson and Dickinson add (p.25) that the BSA collection of surface sherds from the site includes material from late LHIII B but 'nothing certainly later'.

Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Leekley and Efstratiou (1980)

(9) Dramesi

GAMS 432. GAC F64

1.9. Chalkis 309E/904N

This is a large 'high mound' site 300 x 100 m and c 15 m high on the northern edge of the village of Dramesi. There is a great deal of EH-LH pottery on the site, of which the Mycenaean was especially fine. In 1911 N. Papadakis dug here and found Neolithic to LHIII B pottery. Stone and clay have been robbed from the site for use as building materials. In 1945 local people taking stone away found a 'doorway' c 1.8m wide associated with human bones and Mycenaean pottery (French, 1972). This appears to have been the remains of a tomb and complete pots and fragments of bronze weapons were removed before the Ephor Mr. Threpsiades could step in and prosecute the plunderers. The site has since been protected although in 1965 (Vermeule) a water reservoir was dug to below the rich EH levels and the tholos was almost completely destroyed. Among the objects retrieved from the plunderers in 1945 was a piece of stone with pictures of ships incised on it.



Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

French (1972)

Vermeule (1966, p.142 note)

Leekley and Efstratiou (1980)

(10) Eleon

GAMS 427. GAC G25

1.9.Chalkis 173E/877N.

North-west of the village of Harma is a steep-sided hill overlooking the East Theban plain. On the flat top of this hill (200 x 120 m) is the prehistoric site of Eleon. There have not been any excavations here and although there are abundant MH and LH sherds of good quality on the site the only structural remains visible are those of an Archaic wall of Lesbian masonry. The pottery lying on the surface of the site led Dickinson and Hope Simpson to say that it 'was undoubtedly a large and important LH settlement, probably second only to Thebes in the Theban plain' (p.247).

Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

(11) Kynos

GAMS 466. GAC G72.

T.8.Atalandi 843E/311N

This is a 'high mound' site 130 x 90 m on a low hill 30 m from the shore 2 km north east of the village of Livanates. Both the hill and the fields on the landward side of it are strewn with sherds from MH to Classical in date although fine LHIIIB-C material predominates. On the north west and west upper slopes are the remains of what may have been

a circuit wall of classical date. To the south east lies a small cist grave.

Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Leekley and Efstratiou (1980)

(12) Thebes

GAMS 416. GAC G23

1.9. Chalkis O35E/847N

The position of the town of Thebes made it inevitable that it would be important. It is placed on an extensive hill with an almost oval plateau, 800 x 600 m on the southern edge of the fertile Theban plain and at the junction of 5 roads. The modern town is built over the Kadmeia which was the centre of the prehistoric town. Dickinson suggests (1977: 235) that in the LH period there was rivalry between the Boeotian towns of Thebes and Orchomenos and that 'on the basis of the finds Thebes and Orchomenos may be considered rivals to Mycenae and Pylos'. Because the prehistoric levels lie under Roman, Medieval and modern buildings excavation must take place as and when a site becomes available. Consequently our knowledge is rather patchy and much of the work has never been fully published.

The earliest structures which have been found in Thebes date from the Early Helladic period and in EHIII a very large apsidal megaron was built in the centre of the Kadmeia. Thebes retained its importance in the MH period and in the deep MH strata a large megaron together with some well-provided graves has been revealed. This megaron may have continued in use into the early LH phase. The large palatial buildings on



the Kadmeia date to LHIII. There is some controversy over whether there are 2 complexes of buildings with different alignments or only one with local rebuildings. Workshops have been excavated but the main administrative buildings have not been found yet. There is some uncertainty over the relative dates of the buildings. The palace was in existence by LHIIIA, was destroyed at the end of the phase and then again in LHIIIB†. The only evidence for LHIIIC occupation comes from a group of nearby chamber tombs.

Thebes was not mentioned in the Homeric Catalogue of Ships. The Catalogue is often thought to refer to events which occurred in LHIIIC and if this is the case it would be after Thebes had been burnt and would serve to illustrate its subsequent desertion.

Thebes was one of the sites included in the first Oxford OES project. Twenty two sherds from Thebes were analysed. The analyses resulted in the identification of 2 composition groups. They were called groups A and B. It was suggested (Catling et al., 1961:104) that the 5 sherds of group A may have been imported from the Peloponnese where this composition appears to be typical. Group B has proved problematical since it is the composition group which is typical of Crete as well as of the majority of the Theban sherds. After supplementary analyses by OES and NAA it has been concluded that the clay beds around Thebes and in Central Crete must be very similar in chemical composition. As mentioned above (Chapter 1.1) the provenance of the stirrup jars from Thebes with Linear B inscriptions has been the subject of several papers because of this confusion over the origin of composition group B (see references above, Chapter 1.1).

Hankey, writing about the LBA pottery from Chalkis on the coast of Euboea (1952) noted (p.54) that "one might say that there is little difference, if any, in the clay" of the pots from Thebes and from Chalkis and that "There is no reason to suppose that the pottery of Chalkis in LH times came from Thebes, but the potters of Chalkis often followed Theban fashions in shape and pattern."

Chadwick noted (1976: 99) that out of 5 Linear B inscriptions found at Thebes one referred to a consignment of wool being sent to Amarynthos (site 2) and this is as clear an indication as one could hope for that there was trade between these two areas.

R. Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Leekley and Efstratiou (1980)

Catling et al. (1961, 1963, 1967)

Catling et al. (1963(b))

Catling et al. (1980)

Cambridge Ancient History

Chadwick (1976)

Hankey (1952)

#### 4.4. THESSALY

The Thessalian sites sampled fall into 3 geographical groups which correspond to the three main areas of LBA settlement in Thessaly. One of these groups is centred around the head of the Gulf of Pagasae where the modern town of Volos lies; the Gulf provided by far the best access to Thessaly from the sea. The second lies in the fertile western plain around modern Pharsala and the third is further north in the eastern



plain between modern Larissa and the foothills of Mount Ossa. The sites of Iolkos, the Pevkakia and Velestino (Pherae) were sampled from the first area, Revmatia and Yephyria from the second and Marmariani, Argissa and Yephyrâ-Asmakiou from the third.

(13) Argissa, Gremnos

GAMS 515 GAC H41

Z7 Larissa 295E/388N

The site of Gremnos (ancient Argissa), lies 7 km west of Larissa on the north bank of the river Pinios. It is one of the largest high mound sites in Thessaly being 350 x 120 m. Between 1955-58 Milošević led excavations here. Partly because of his death the studies of the finds have not yet been completed although some volumes (Argissa I-III) have been published. There were 11m of occupation deposit in some places. On the highest part of the mound Milošević excavated an area 30 x 7 m. The earliest occupation of the site was Palaeolithic and there was an early aceramic neolithic phase of a developed agricultural society and then continuous occupation from EBA to LHIIIB, although there was a fire at the end of the EBA. There were 7 successive building phases, and in each one the houses were constructed more solidly. The excavators found abundant pottery especially of MH and LH date together with MH houses c 5 x 8 m set against each other with narrow alleyways. The site has 2 concentric circuit walls of Archaic and Hellenistic date.

Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Cambridge Ancient History (1973)

Vermeule (1972)

Hanschmann & Milošević (1976)

(14) Volos Iolkos

GAMS 480. GAC hI

H.8. Volos 773E/029N.

Volos has the best harbour in the whole of Thessaly and it is said that it was from here that Jason and the Argonauts set sail. Volos is at the head of the Gulf of Pagasae in south-east Thessaly where not only is there a good harbour but where there is also a break in the mountains allowing access to the Thessalian hinterland.

The Mycenaean settlement of Iolkos is on a hill 400 x 270 m, called Kastro, which is now buried under modern Volos with marshy land to the west and north. It was in a position to dominate both the harbour and the narrow coastal plain. Several excavations have taken place there. In 1901 Kh. Tsountas found Mycenaean remains during an excavation on the hill top and in 1920-21 Arvanitopoulos, when digging near the centre of the mound, uncovered part of a Mycenaean palace with plaster floors and painted wall plaster directly above Neolithic levels. The Early Bronze Age and Middle Helladic layers had possibly been removed by the people who built the palace. He also found Geometric, Archaic, Classical and Byzantine material.

In 1956-7 and in 1960-61 Dr. D. Theochares excavated on the slopes of Kastro where there are fewer medieval and modern buildings to have damaged or obscured the prehistoric levels. He found EBA, MH and LH remains including LHII-III pottery and fragments of red and blue wall plaster. Dr. Theochares thought that some of the pottery was of local manufacture and some of it imported from the Argolid. When digging on the south-west edge he uncovered more of the LHIIIB 'palace' built over LHI-II ruins. In LHIIICi (c 1200 BC) there was a fire which destroyed



the palace. In the main area of his latest soundings Dr. Theochares found 5 building levels of LHIIIA-C date in three metres of deposit with no evidence of an LHIIIC destruction. However, there does appear to have been a brief gap of perhaps a generation between the end of the Mycenaean settlement and the first Protogeometric levels. It appears that although the palace was destroyed the occupation of the surrounding settlement continued. The most recent excavations have been conducted by Dr. Hourmouziades of Volos Museum.

The remains at Iolkos are of undoubted importance. Desborough said (1965) that the ruins at Iolkos have the most substantial masonry in the whole of Thessaly and extremely fine local and imported LHIII pottery. He also said (1964) that the first contact with the south of Greece and the Mycenaeans came in LHI, by LHII it had a palace and that it reached its zenith in LHIII. Hope Simpson and Dickinson (1979:272) wrote that Volos was probably the most important site in all Thessaly and "probably supported a palace comparable with those further south if not as sophisticated".

Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Leekley and Efstratiou (1980)

Desborough (1964, 1965, 1972)

Theochares (1958, 1968, 1970)

(15) Marmariani

GAMS 508. GAC H27.

Z.7.Larissa 510E/428N.

Marmariani is a roughly rectangular, flat-topped mound 100 x 80 m and 10-15m high at the head of a secluded valley at the foot of Mount

Ossa in Eastern Thessaly. The mound lies c 2 km south west of the village of Marmariani. On the edge of the mound are 7 small tholoi 2 of which were examined by V. Leonardos and 5 by Kh. Tsountas. The finds from these tholoi were re-examined by Heurtley and Skeat (1930-31). One tholos contained LHIIIA-B pottery and the others Late Protogeometric and Geometric pottery (GAC). They illustrate that the tholos was in use as a place of burial at a later date in Thessaly than in the rest of Greece apart from Crete and Messenia.

The mound shows traces of Neolithic occupation followed by very deep Bronze-Age settlement layers (shown by Tsountas). There is a great deal of LBA pottery on and around the mound both locally made and imported wares. Some of the pottery probably dates from LHIIIC. Hunter (p. 64f) and Desborough (1972, 213) comment on the local hand-made pottery and Desborough suggests that the wheel was not introduced to this part of Thessaly until the Late Protogeometric period (Ibid). Hunter suggests a local LHIIIC pottery industry making hand-made pottery with a rather limited range of shapes. Heurtley and Skeat (Ibid.) describe the BA levels and pottery as being "remarkable in Thessaly in depth and extent". It is unfortunate that the site has never been properly excavated.

Marmariani was one of the three Thessalian sites included in the early programmes of OES analysis carried out at the Oxford laboratory. Twenty sherds were included in the first major project (Catling et al., 1961) Catling, 1963; Catling, 1963, 1967), and the analyses allowed the formation of a compositional group 'E'. This differed from the composition of 65% of the sherds analysed from Volos and from all of the sherds analysed from Argyropoulis.



Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Leekley and Efstratiou (1980)

Heurtley and Skeat (1931)

Catling et al. (1961, 1963 and 1967)

Hunter (1954)

Desborough (1964, p.133)

Desborough (1972)

(16) Volos Pevkakia

GAMS 482 GAC H2

H.8. Volos 782E/007N

Slightly to the south west of modern Volos, on the edge of the Bay of Volos, lies the Hellenistic site of Demetrias. On a promontory at the north west end of this site is the older site of Pevkakia. The depth and the quality of the prehistoric levels and its proximity to Iolkos have led to the identification of this site with Neleia, the port of ancient Iolkos. There are over 8 metres of Bronze Age deposits and over 2 of these date to the Late Bronze Age. Occupation appears to have been continuous from the Neolithic with 3 phases of building within the EBA. The later prehistoric levels are best preserved to the south of the site. Here there is a cist cemetery superimposed on MH houses. Milojcic described this cemetery as 'the remains of a great necropolis' ( 1960 ). Above the cemetery are LHIII buildings including one very large house. It has walls over one metre thick and this has led to its being called a Mycenaean palace (Hope Simpson, 1965). The important nature of the site was first realised when Dr. Theochares took soundings on the tip of the promontory in 1957 and came upon the

deep Mycenaean levels. In 1967-73 and 1976-77 Dr. Milošević of the German School excavated here. Unfortunately both Dr. Theochares and Dr. Milošević are now dead but members of the German School are working on all the excavated material. There is evidence that bronze smelting was carried out on the site even though the closest exploited source of copper was Othrys (Hope Simpson and Dickinson, 1979). Although LHIIIB pottery of very high quality is abundant there is very little which can be dated to after the very early LHIIIC. There is no clear evidence of a catastrophe here in the late LHIIIB and indeed some occupation of the site up to the Proto-geometric is evidenced by the few sherds which have been found but there does appear to have been a decline in the occupation of Pevkakia even while nearby Iolkos was still flourishing.

Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Leekley and Efstratiou (1980)

BCH 1958 Chronique de Fouilles.

Milošević (1960)

Desborough (1964)

Archaeological Reports 1968

(17) Revmatia-Paliambela

DF 503

H.7. Pharsala 306E/909N

Although the BSA sherd collection contains over 20 Mycenaean sherds from this site including the fragment of an Octopus Style stirrup jar (No. 6) reported by Desborough:(1964: 132; 1972: 99) and Hope Simpson and Dickinson (1979). Little is known about the site. D.F. gives no note of its size and recorded Middle and Late Bronze Age pottery.



Hanschman (Hanschman & Milojcic, 1976) noted EB2/3 pottery from Revmatia.

Hope Simpson and Dickinson (1979)

Desborough (1964, 1972)

Hanschmann and Milojcic (1976)

(18) Velestino Pherae

GAMS 498 GAC H15

H.8. Volos 612E/052N.

Ancient Pherae was the legendary home of King Admetus and Alcestis and reached its peak of importance in the C 4 B.C. Early this century A.Arvanitopoulos discovered prehistoric pottery west of the town on the acropolis. In 1977 E. Kakavoyannis (Arkaiologica Cronica) conducted excavations between the Classical acropolis and the spring of Hypereia, the area under modern Velestino, and found EB to Hellenistic remains. There were over 3 metres of deposit in places and the MH and Mycenaean finds were especially noteworthy and included some complete vases of LHIIIA-B date (Hunter). There are periodic excavations on a small scale around Velestino which continue to produce LH pottery. It is thought that the Mycenaean settlement is somewhere in this area between the acropolis and the modern town.

In Archaeometry 10 (1967, p.73, map 7) Millett and Catling reported that some sherds from Velestino had been analysed but the results have never been published.

Hope Simpson (1965)

Hope Simpson and Dickinson (1979)

Leekley and Efstratiou (1980)

Kakavoyannis (1977)

R. Avila (1980)

Béquignon (1937)

(19) Yephyria

DF 97.

H.7. Pharsala. 106E/002N.

DF mentions the Myc and local MB/LB pottery from this site but adds no further information or comment on its size. No other references to Yephyria have been found.

(20) Yephyra-Asmakiou

DF 272.

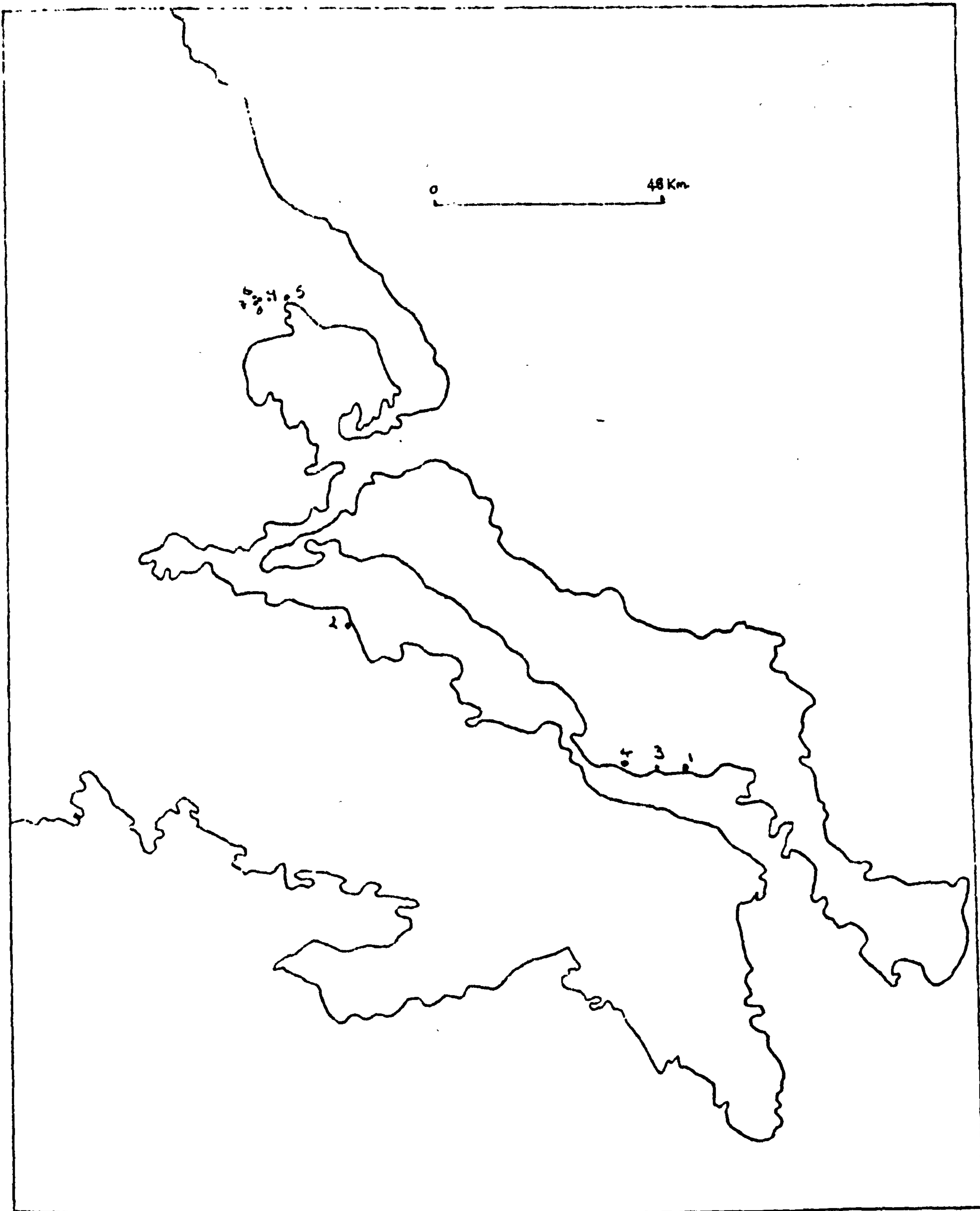
Z.7. Larissa. 407E/308N.

The only information given about this site is a note of its area. cl.2 h.a. by DF. Paul Halstead (Personal Communication) says that this is about standard for an ordinary BA site - somewhere between a small farm and a centre.

5. CLAYS (see Map, Figure 10).

In an attempt to assess how far pots could be identified with clay sources in the areas studied in this project, 8 raw clays and 1 modern brick were analysed. The modern brick came from the brickworks which are adjacent to Lefkandi (site 4). Two raw clays from Euboea were analysed. They came from Amarynthos (site 2) and from Eretria which is on the coast between Lefkandi and Amarynthos. No Boeotian clays were available but one clay from Pirghos, near Kynos (site 11) in Locris was analysed. These samples and one from Volos in Thessaly were available in the British School at Athens. Four other Thessalian clays were also analysed. They were made available by the Volos Museum. One of the Museum's workers had collected 4 separate clays from within walking





- 1 Amarynthos
- 2 Pyrgos
- 3 Eretria
- 4 Lefkandi
- 5 Volos
- 6 Seskio
- 7 Seskio
- 8 Seskio
- 9 Dhimini

Fig 10 Sources of clay that were sampled

distance of the important Neolithic sites of Dhimini and Sesklo. He uses the clays to make pots in imitation of the locally made Neolithic wares. Sesklo and Dhimini are in a useful ~~position~~ for the purposes of this project since they lie between Volos and Velestino but closer to the latter.



**CHAPTER 5.**

**ANALYTICAL TECHNIQUES**

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1. Choice of Techniques

When spectrographic analysis of pottery was first undertaken in Oxford, optical emission was the most readily available spectrographic technique. It also had several inherent advantages. It was relatively cheap and easy to run, it could provide a quantitative analysis of the body of a sherd and it could cover a wide range in concentration from a few parts per million to major elements from a small sized sample. Optical emission, therefore, was the technique adopted and adapted by the Oxford laboratory for analysis of archaeological pottery samples. Hitherto the Fitch Laboratory has been restricted to optical emission for pottery analysis and it was therefore logical for optical emission to be the main technique of analysis used in this project, following the procedures laid down in Oxford and Athens.

As mentioned in the Introduction (Chapter 1.1) however, several other spectrographic techniques are now available and it was decided that some of the sherds analysed in this project (finally c 25% of the total) should also be analysed by a second technique which could provide data for comparison with the optical emission results.

The second technique chosen was atomic absorption spectrophotometry. It was selected because it has greater precision than optical emission and because of the broader range of elements which could be measured beyond those readily available in optical emission (see below, Chapter 5.2.4). Atomic absorption requires a similar sample size to optical emission and also provides a quantitative analysis of the body



of the sherds. It was hoped that the greater precision offered by atomic absorption could tighten the groupings obtained by optical emission while providing a cross-check on them. It was also hoped that additional elements could be measured which would also serve as discriminants and improve the separation of the groups.

When this project was started it was the first specifically designed to compare optical emission analyses with atomic absorption analyses of the same sherds. In the meantime analysts at the Oxford Laboratory have published a study of Hellenistic and Roman Fine Pottery from Benghazi (Hatcher et al., 1980) which used atomic absorption as the analytical technique. They included in their samples 24 of the sherds which had been analysed earlier in Oxford by optical emission (Prag et al., 1974) and offered a consideration of the results obtained by both techniques. It is still the case, however, that no project of the size and scope of this one has been carried out before.

## 5.2. Quantitative Optical Emission Spectroscopy.

### (1) Theory

According to the quantum theory formulated by Niels Bohr in 1913 and later modified by Sommerfeld, electrons rotate in specific concentric shells around the nucleus of the atom. When they are in this, their 'ground state', which is the state of lowest energy, they do not emit any radiation. When an atom is excited out of its ground state and an electron jumps from one shell to another emission and absorption of energy occur. If the first of these stages is  $E_1$  and the second is  $E_2$ , the difference in these two energies,  $\Delta E$  can be expressed as:

$$\Delta E = h\nu = E_1 - E_2$$

where  $\nu$  = the frequency of the emitted light

$h$  = Planck's constant =  $6.623 \times 10^{27}$  erg.sec.

If  $E_1$  is smaller than  $E_2$  radiation is absorbed and if  $E_1$  is larger than  $E_2$  radiation is emitted in the form of ultra-violet and visible light. Such changes in energy only occur in quantized steps. The wavelength of the radiation emitted when an electron returns to its original position from another shell is equivalent to the amount of energy involved in the transition. All the electrons in one shell have the same principal quantum number 'n' which defines the energy level of the shell. The shells are designated K, L, M, N, O and P, which correspond to quantum numbers  $n = 1$  to  $n = 6$ . The higher the value of 'n' the further the shell is from the nucleus of the atom. The number of electrons in any shell is limited. The shells are further divided into sub-shells or orbitals according to their azimuthal quantum number 'l'. The sub-shells are designated sharp, principal, diffuse and fundamental (s, p, d and f) for which the 'l' values are 0, 1, 2 and 3 respectively. S is the simplest of these and p, d and f are progressively more complicated. The number of orbitals per shell increases with shell number as shown in the diagram (Figure 11).

The actual configuration of electrons around the nucleus is unique for atoms of each element. Lithium, for example, has an atomic number (Z) of 3 and therefore has 3 electrons, 2 in the K shell and 1 in the L shell. Nickel on the other hand has an atomic number of 28 with 2 electrons in the K shell, 8 in the L shell, 16 in the M and 2 in the N shells.

Although this theory has now been superseded by wave mechanics, it provides an adequate approximation of the situation for practical purposes.



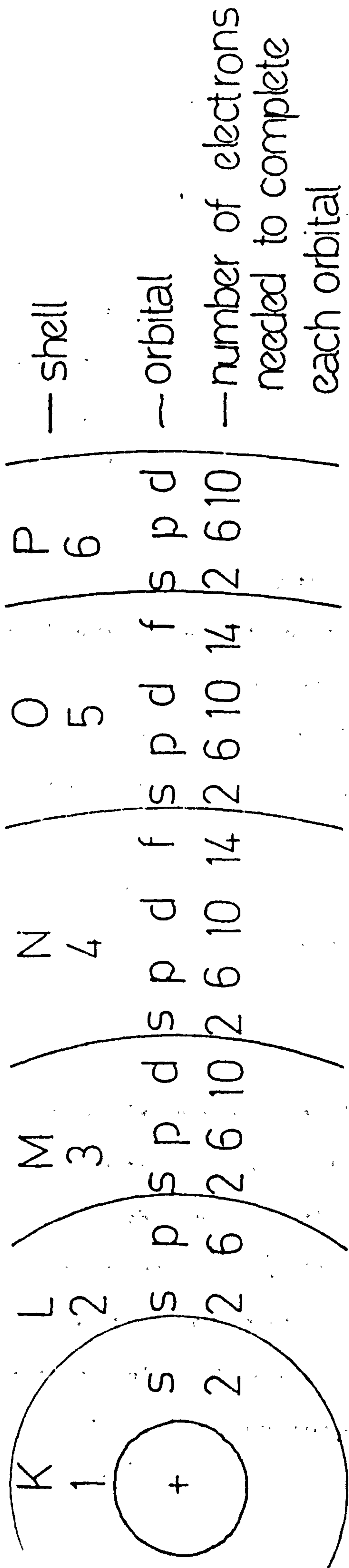


Fig 11 Configuration of electron shells in an atom

Each element will emit many spectral lines. Iron as a slightly extreme example has several thousand lines in its complete spectrum. Towards the short-wavelength (violet) end of the spectrum the lines are closer together and less intense than at the long-wavelength end (Candler, 1937:5). The intensity of each line depends on the number of excited atoms of that element in the sample and that in turn depends on the concentration of element in the sample. Level diagrams for Lithium and Sodium are shown below (Figures 12 and 13) which illustrate the transitions which produce specific spectral lines and the energies that are involved.

In Optical Emission analysis of pottery the sample is excited by means of a d.c. arc which involves the continuous discharge of direct current at a relatively low voltage over the gap between two carbon electrodes. The powdered sample mix (see below, Chapter 5.2.6) is placed in a cavity in the lower electrode, which in this work is the cathode. The arc is ignited when the electrodes are briefly brought together and then parted. The sample is volatilised into the arc column. The excitation breaks the interatomic bonding and excites the electrons in the evaporated atoms in the discharge column between the electrodes.

During arcing the sample mix in the lower electrode is volatilized into the arc column due to the high temperature of the source. The rate of upward diffusion of the sample in the arc column is approximately 1 metre/second, (Ahrens and Tylour, 1950: 18) but is dependent on the source temperature and on the mass of the atoms involved. For the elements used in this project the order of volatilization is: Li, Na, Cr, Mn, Fe, Ni, Mg, Al, Ca, Ti. The source temperature is between 4000 and 7000 degrees K.



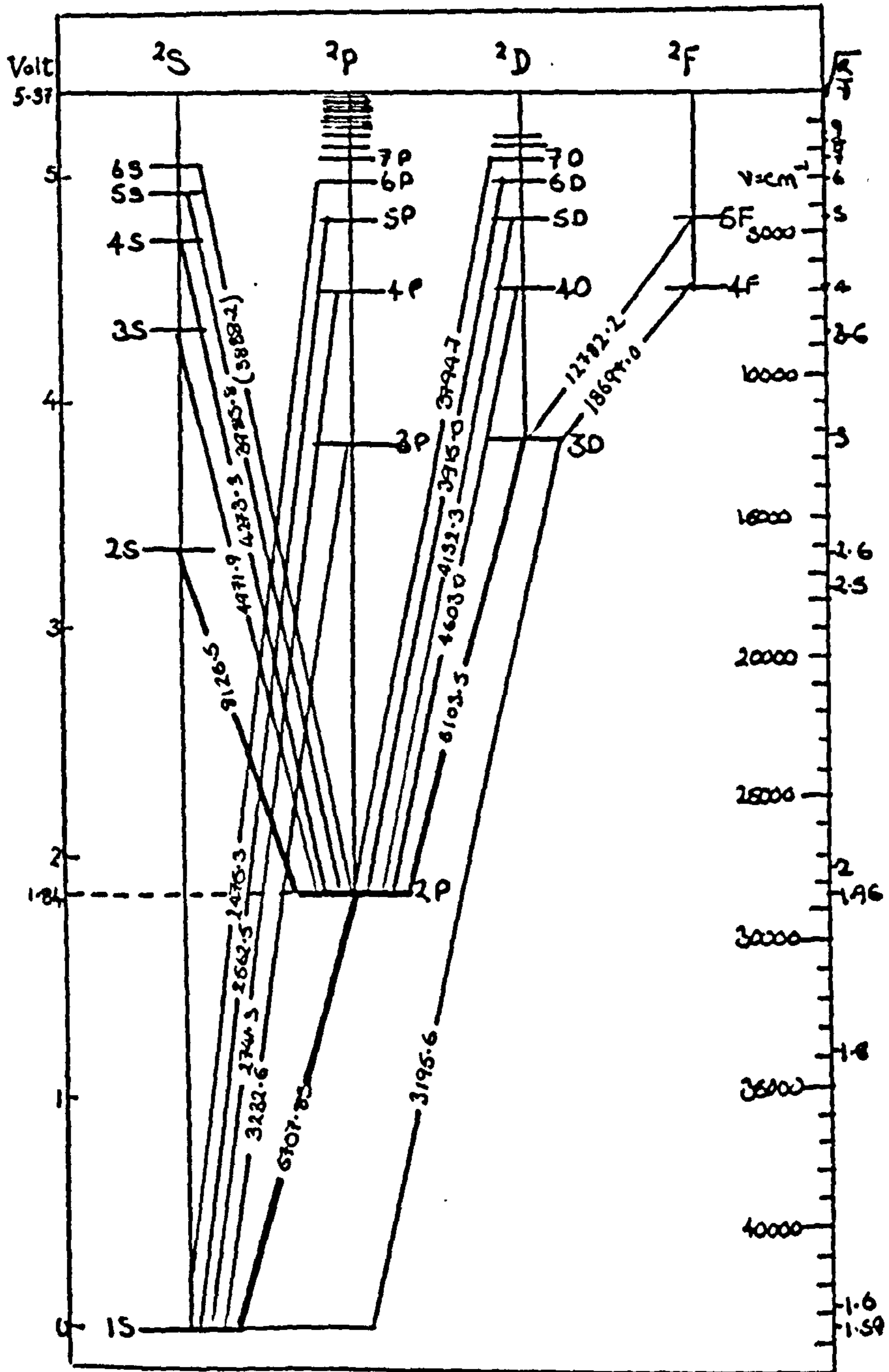


Fig 12 Level diagram for lithium

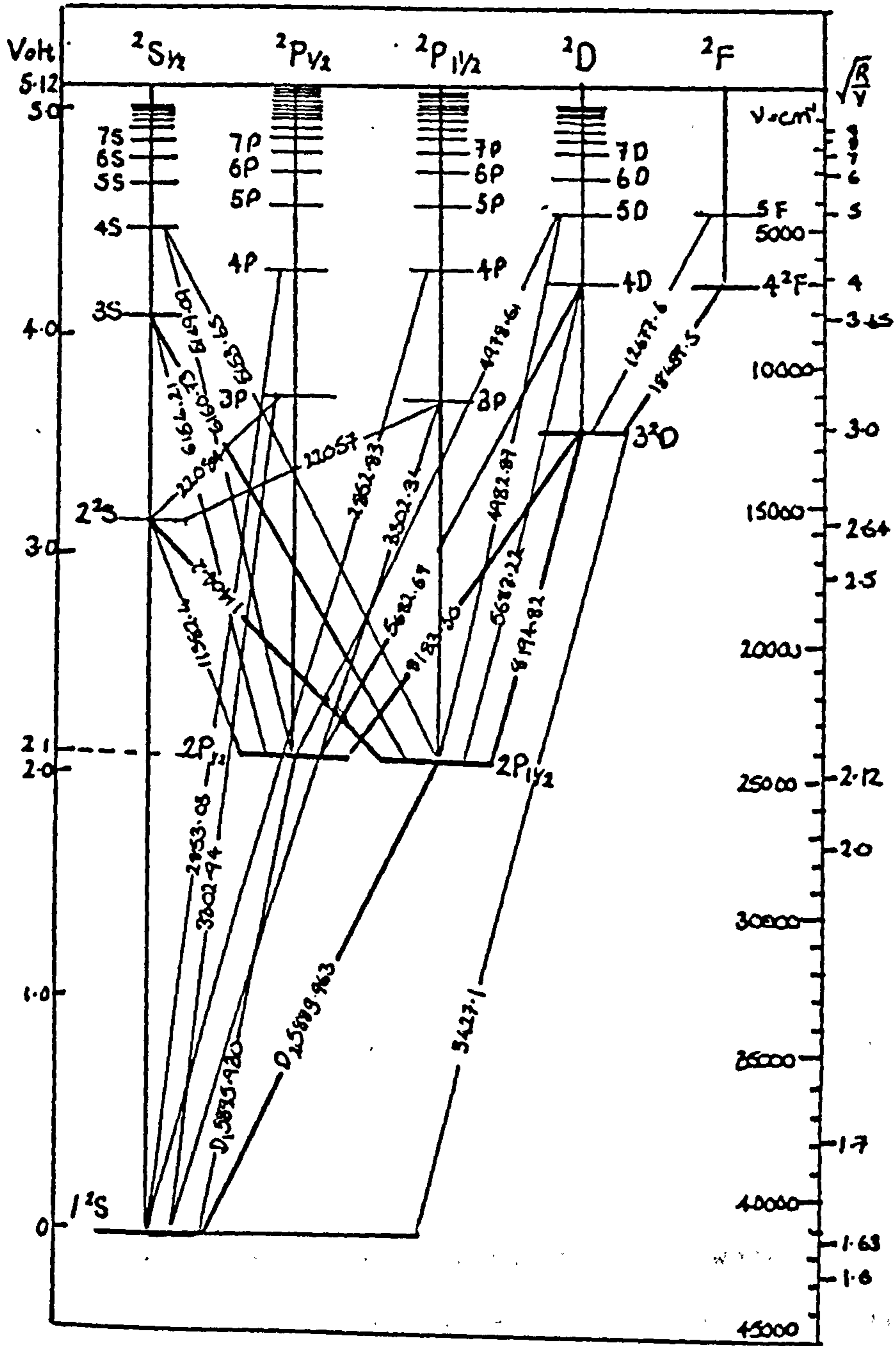


Fig 13 Level diagram for sodium

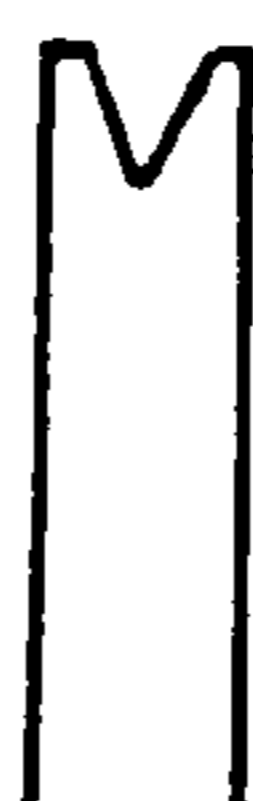


The arc column has a hot core surrounded by a layer of cooler vapour. Both electrodes contribute to the cloud of neutral atoms contained in the arc column. In colliding with fast-moving electrons these atoms gain high velocities and produce the high temperature of the arc column. Most of the excitation is thus thermal and most of it is caused by collisions between the neutral atoms which predominate in the arc column. By raising the temperature in the arc column electrons produce indirect excitation. Around the electrodes excitation is caused by the collision of atoms with electrons.

If what is desired is a simple qualitative analysis, arcing controls may be less stringent than for quantitative analysis, since as long as one or more of the persistent (more sensitive) lines of the element(s) are visible the aims of the analysis will be satisfied. By application of the Hartmann dispersion formula once the wavelength of any three lines on a plate are known, the position and identity of any other line can be calculated. If  $\lambda_1, \lambda_2, \lambda_3$  and  $d_1, d_2$  and  $d_3$  are the respective wavelengths and comparator readings for three lines and  $\lambda_0, d_0$  and  $C$  are constants and  $d$  the comparator reading for the unknown line, the wavelength of this line can be expressed as:

$$\lambda = \lambda_0 + \frac{C}{d_0 - d}$$

In quantitative work on the other hand the work is based on measurement of the energy radiated by excited atoms and ions. It is therefore important that the arcing conditions can be reproduced as accurately as possible so that the standards will produce lines of as similar intensity as possible on each plate and hence allow the line on the calibration graph (see below, Figures 19 and 20) to be drawn as close as

possible to the master line. Ahrens (1970) said that a small sample weight which is totally consumed in the arc and a small diameter electrode help to produce an arc which burns more smoothly and gives better reproducibility. A small diameter electrode reduces the danger of the arc wandering over the electrode surface. Wandering of this sort can cause uneven consumption of the crater walls and of the sample. In pottery analysis, therefore, 5 mg of sample mix is arced for 30 seconds in a carbon electrode and is totally consumed in this time. The electrode used is a type recommended by Ahrens and Tylour (1950 : 58) as a 'general electrode for quantitative work' since it has a small diameter (0.65 cm) and its shape  helps to inhibit the formation of a residual alumina-rich globule in the electrode cavity after firing. In qualitative work an image of the arc is generally produced at the slit but in quantitative work, since what is required is that the slit be evenly illuminated by light from all the desired portions of the arc column a long focus condenser lens is placed c 5 cm in front of the slit to focus the light on to the collimator lens (Calder, 1969 : 19).

When the sample is arced in this way the light passes into an optical spectrograph where a prism (see diagram) separates the light into its component wavelengths or energies and this spectrum can then be recorded on a photographic plate. The different colours of the spectrum are recorded as black lines on the plate.

(2) Internal Standard.

An internal standard is an element which is added to the sample in a fixed amount. It is generally an element which is present in the sample in a negligible amount (under 0.1% in most pottery) which



would be swamped by the amount added thus providing a guideline of constant intensity for use in the calibration of the technique. Use of an internal standard, as Ahrens and Tylour pointed out (1950 : 90) also provides 'compensation for a variety of errors' and provides a significant improvement in accuracy. Such errors include factors influencing arc temperature, inaccurate timing of exposure or development, fluctuations in the source from exposure to exposure and inaccurate weighing of the samples into the electrode cavity. The intensity of the analysis line is thus compared with that of the internal standard line. The internal standard that is chosen needs to have a wavelength close to that of the analysis lines (in this work to appear on the same plate-length as the analysis lines), to be of similar intensity and to have similar excitation potential to the analysis lines. It must be of very high purity with respect to the elements which are being sought in the samples.

Throughout the Optical Emission work done by the laboratories in Oxford and Athens, lithium carbonate has been used as the internal standard.

Since fired clay is rather refractory it needs help to make it volatilize at the temperature reached in the d.c. arc. To this end ammonium sulphate and graphite powder are also added to the sample. The graphite helps to produce a steady arc with the minimum selective volatilization (Ahrens and Tylour, 1950: 83-85) and to prevent formation of a residual alumina-rich globule in the electrode cavity. The ammonium sulphate has similar effects to the graphite but has the added advantage that on arcing there is a quick release of ammonia gas which wafts the specimen into the arc column. These three substances, lithium carbonate, ammonium sulphate and graphite powder, are mixed

together in fixed proportions (see below, Chapter 5.2.6) and added to each sample prior to arcing.

(3) Location Standard.

Three location standards were included in each batch of samples analysed. They were placed in the first, eleventh and last positions on the photographic plate. A location standard was first incorporated into the method by S. J. Freeth (1967). Its function, he said, (p.105) was 'to reduce the effect of instrument drift and between-plate variation'. In this work the location standard consisted of a Mycenaean sherd known as Mycenae 22 which has been analysed many times by scientists at the Oxford laboratory and by wet chemical methods. It was used by the Oxford laboratory as a location standard throughout their work.

During the calculations involved in obtaining quantitative results the average value obtained for the element to lithium ratio for each element is taken for these three location standards. This average value is then used (see below, Chapter 5.2.9) to determine the exact position of the line which will be drawn on the calibration graph. In this way, while the internal standard provides a reference line of constant intensity for each sample on the plate, the location standard provides a means of checking on and compensating for any variation in the emulsion or firing conditions in the different areas of the plate.

(4) Choice of Elements.

The choice of elements to be measured in pottery analysis is influenced by a variety of factors. First and foremost amongst these is the choice of analytical technique used. In Optical Emission Spectroscopy there are 30-40 elements which can be measured. Elements are



precluded which emit light at wavelengths shorter than 200 nm, since light at these wavelengths is strongly absorbed by air. There are thus many non-metals which cannot be measured by OES.

A compromise has to be made between analysing for as many elements as possible in order to get the fullest possible picture of the composition of the pottery and the feasibility of so doing in terms of time, resources and the potential value of the results so obtained. In OES work it is not practical to extend the range of elements beyond those which will fit on one plate-length. By 1963 (Catling et al., 1963) the workers in the Oxford laboratory had selected 9 elements out of the 25 which appeared on one platelength. These 9 were those which they considered to be of the most use in analysis of Bronze-Age Greek pottery. The choice was made "partly on the basis of analyses of clay minerals available in scientific literature and partly on the basis of previous experience with ancient pottery; but mainly as a result of a pilot programme on 40 sherds each from Knossos and Mycenae" (Ibid. : 96). It should however be pointed out that the fact that these 9 elements proved to be the most use in differentiating between Cretan and Argolic pottery does not mean that the same would necessarily be true in other geographical areas. Since the OES analyses for this project were carried out in the Fitch laboratory where the concentrations of these elements have always formed the basis of their composition and provenance work, so that all the comparative Mycenaean pottery data is based on these elements, it was decided that this project too should concentrate on examining their concentrations. However, since parts of Thessaly are rich in mica, which generally has a high potassium content, it was decided to attempt to establish a potassium calibration and to examine

the potassium concentrations. Unfortunately it proved impossible to find a suitable line on the chosen plate-length of the spectrum. These 9 elements can all be examined under one set of analytical conditions and working towards the lower, less cluttered end of the wavelength range, a line was selected for each element which was stable and which was not too close to an intense line of another element which would interfere with it. The lines which are used in this work are:

|    |                                   |
|----|-----------------------------------|
| Al | 257.5 nm                          |
| Mg | 277.7 nm                          |
| Fe | 284.4 nm                          |
| Mn | 293.9 nm                          |
| Ti | 294.2 nm                          |
| Cr | 283.5 nm                          |
| Ca | 318.0 nm                          |
| Na | 330.3 nm                          |
| Ni | 341.5 nm                          |
| Li | 274.1 nm (Internal standard line) |

When the plate is being read the lines are located by reference to a photograph of a spectrum on which the relevant lines have been identified and marked. (See Plate 1).

#### (5) Equipment

The spectrograph used was a Hilger Large Quartz Spectrograph which is of the Littrow type. In a Littrow type spectrograph a 30' prism is aluminized on its back so that the light is reflected and traverses the prism twice. A lens placed in front of the prism acts as both collimator and camera lens (see diagram, Figure 14). At 300 nm the focal



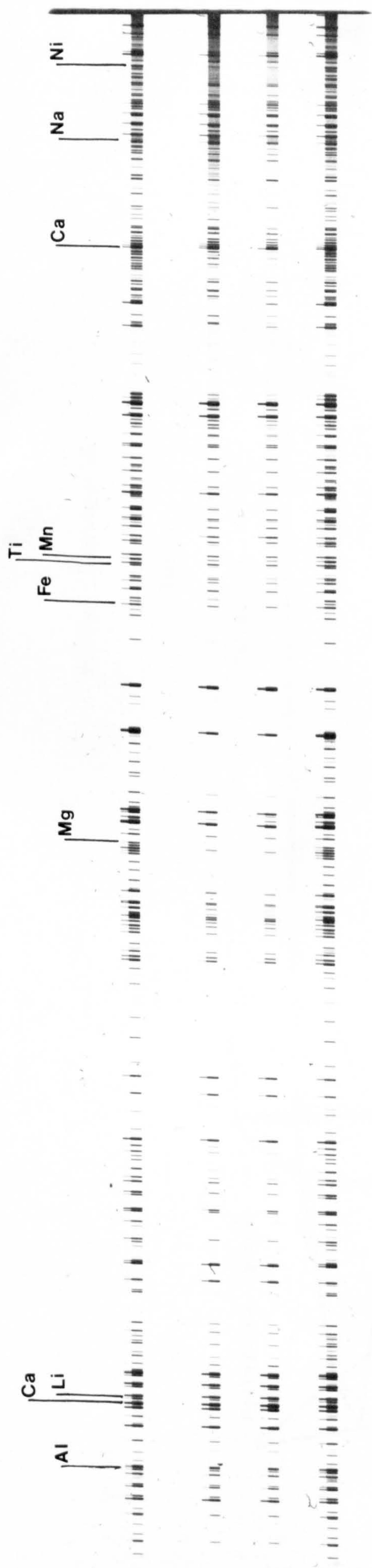


Plate 1 Photographic plate showing spectral lines examined

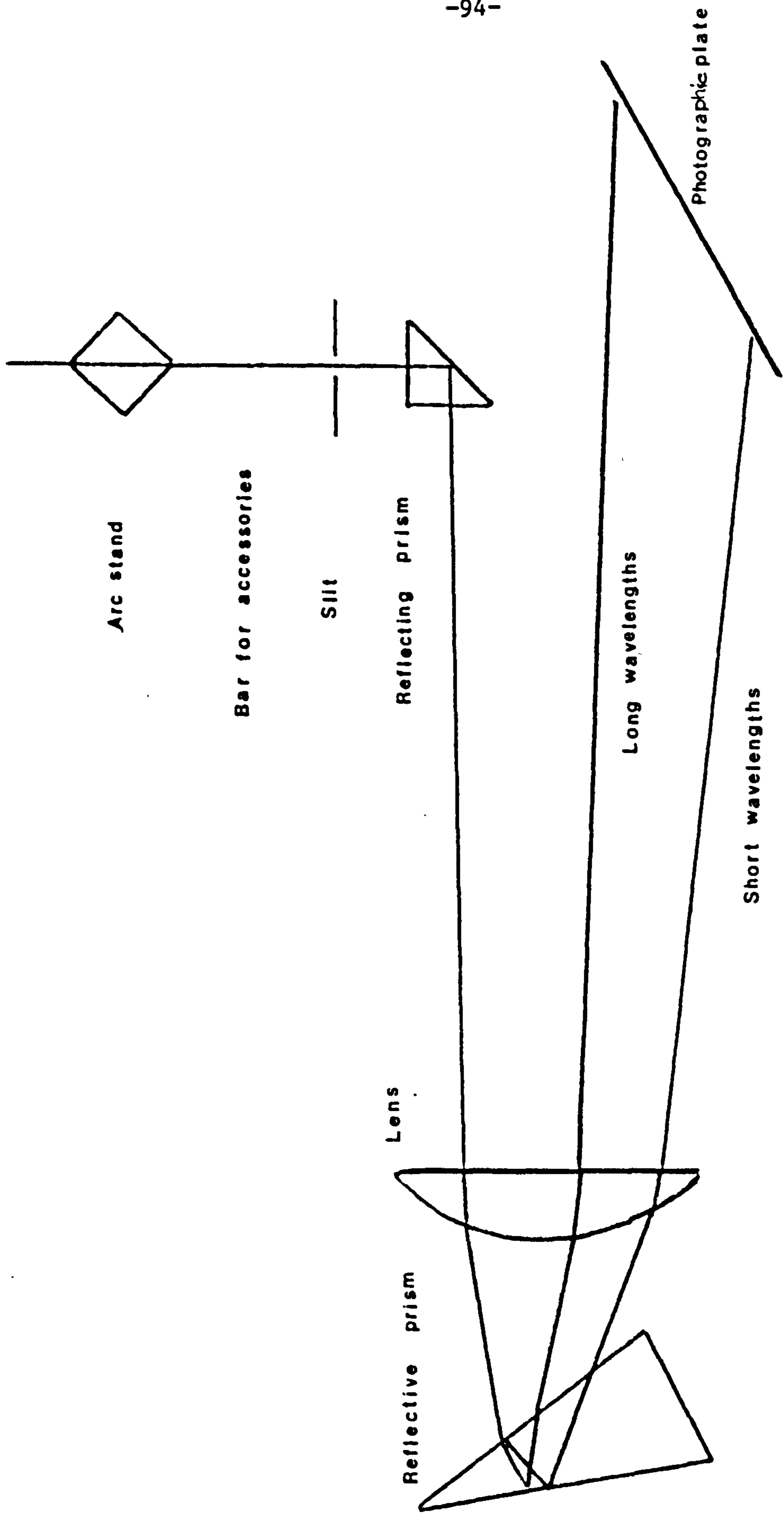


Fig 14 A Large Quartz Spectrograph



length of the spectrograph is 153.2 cm. The length of the complete spectrum is 67 cm (191-800 nm). Ultra-violet and blue light are refracted more than red light. To record the whole spectrum three photographic plate-lengths would be needed. In this work one plate-length has been selected from the lower wavelength part of the spectrum to cover the desired elements which range in wavelength from aluminium, 257.5, to nickel, 341.5 nm. One advantage of using a prism spectrograph rather than one with a diffraction grating is the better dispersion obtained in the ultra-violet region of the spectrum with a prism. The photographic plate, in a holder, slots into position on the back of the spectrograph. The plateholder can be racked vertically.

In the Fitch Laboratory a 10% filter is permanently in place so that each spectral line has two steps. Nineteen samples and the three location standards can be fitted on each plate.

The arc stand is attached to an accessory bar which is fixed to the spectrograph at an angle of 90'. This ensures that the arc can always be focussed correctly on the slit and that the slit to electrode distance of 38 cm is maintained. The electrodes can be separately adjusted both horizontally and vertically. There is a condensing lens fixed to the accessory bar 5 cm from the slit to ensure that all the light from the arc is correctly imaged on the slit.

Once the photographic plate has been exposed and developed the intensity of the blackening of each relevant spectral line must be measured. To do this we use a Hilger L451 non-recording microphotometer with CH350 galvoscale (represented in Figure 15). In this machine the image of a lamp filament is focussed on the plate which is held in a horizontal frame. The length of the image is 2 mm and its width is

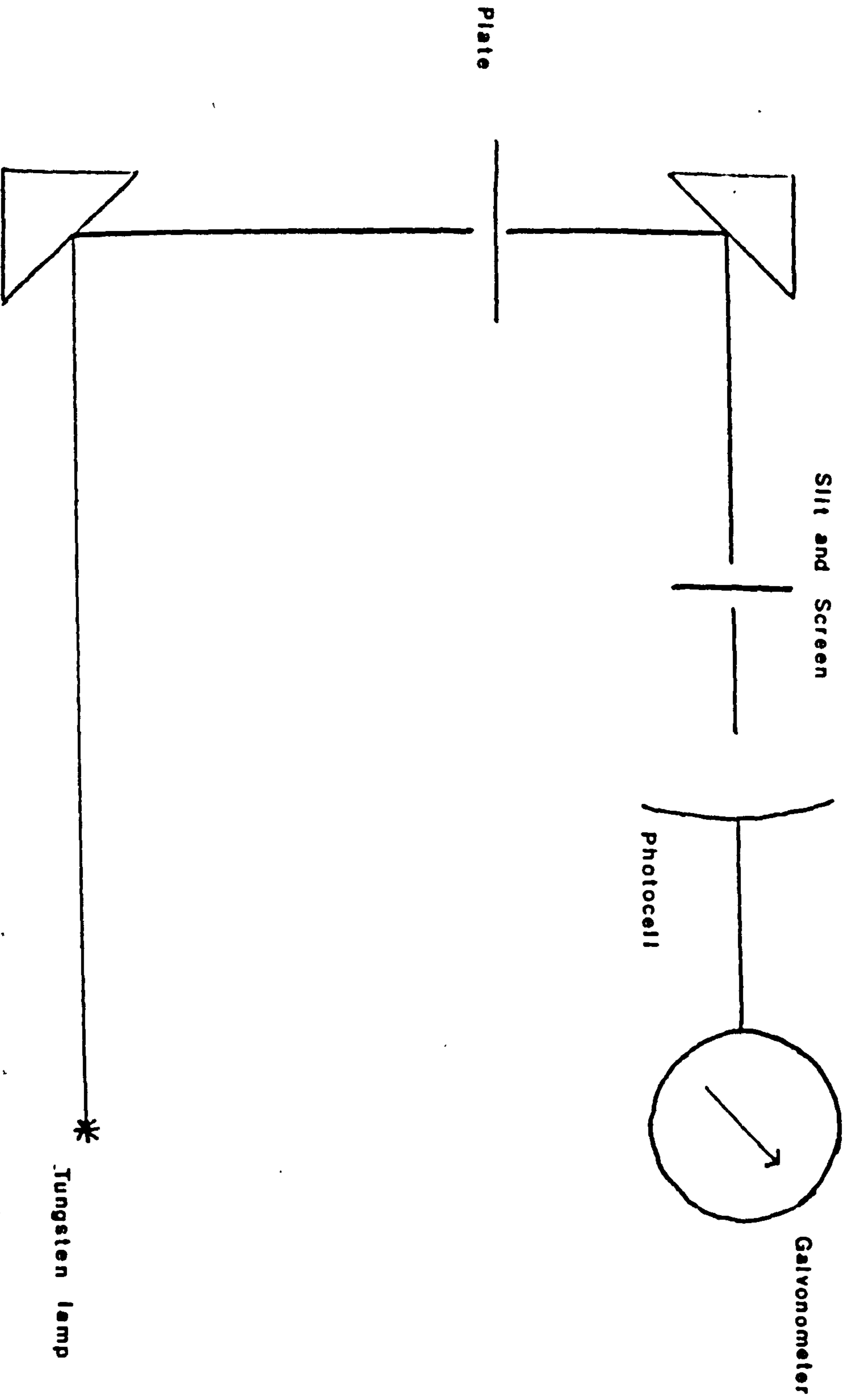


Fig15 Pictorial representation of a Plate Reader (after Calder)



one tenth of that of the filament. The jaws of the slit in front of the photocell form a screen and on to this screen is projected an image of a portion of the plate which is enlarged 10 times. A sphero-cylindrical viewing lens can be moved into the light path and this lens has the effect of flooding a small area of the plate with light so that the image of a short length of the spectrum can be seen on the slit-jaws screen. When this lens is moved aside by means of a lever on the front of the machine, a shutter in front of the photocell opens. In this way the photocell is only exposed to light when readings are being taken. The current response of the photocell is recorded by deflection on the galvoscale. The scale runs from 0-50 with the clear-plate reading at the upper end of the scale.

The position of the plate can be adjusted both in the x and in the y axes and, on the x axis there is a micrometer for movements up to 20 mm. This allows for slow and careful scanning of the spectral lines.

(6) Sample preparation.

All samples were taken in the same way.

- (i) The surface of a small area of the sherds (preferably an area free from characteristic decoration or shape) was scraped away with a scalpel and discarded so that any surface contamination of the sherd was removed.
- (ii) A small piece, about 30 mg, of the cleaned area of the sherd was broken off with a pair of pliers. This piece was then ground to a fine powder with an agate pestle and mortar. Although the whole 30 mg was not used in the actual analysis, it is considered to be the minimum amount of fine pottery needed to ensure that the sample will represent the composition of the sherd as a whole.
- (iii) The powder was wrapped in metal foil and placed in an oven where it was heated for 2 hours at 200°C.

- (iv) 10 mg of this powdered sample was weighed on a Gi Microforce Balance Mk.IIc and tipped into a small glass vial.  
Between each stage of the weighing and mixing the scale-pan and the tools were cleaned with acetone.
- (v) 30 mg of Internal Standard Mix was weighed and added to the sample.

The Internal Standard Mix consisted of:

300 mg Ammonium Sulphate

300 mg Graphite Powder No.1

36 mg Lithium Carbonate.

All these chemicals are in Specpure grades and are prepared by Johnson Matthey Chemicals Ltd.

Before use the Internal Standard Mix was shaken in a small glass vial with two small glass beads on a Wigbug for one minute.

- (vi) The sample and the Internal Standard Mix were shaken with a glass bead on the Wigbug for 30 seconds.

(7) Analytical Procedure.

- (i) 5 mg of the sample/internal standard mixture was weighed into the cavity of a carbon cup. The carbon cups are made by Johnson Matthey Chemicals Ltd. and are 2.25 cm long and 0.65 cm in diameter. The cavity in the top of the electrode is 0.25 cm deep, narrowing to a point. Nineteen archaeological samples and three location standards were thus weighed into cups and placed upright in a box beside the spectrograph.
- (ii) The settings on the spectrograph were checked. The settings were:  
Slit width 0.013 mm  
Diaphragm 3  
Wavelength region c 200-400 nm  
Slit shutter closed (in up position).



- (iii) In a darkroom a Kodak Spectrum Analysis Plate No. 1 (10.2 x 25.4 cm) was loaded into the plateholder.
- (iv) The closed, loaded plateholder was attached to the back of the spectrograph and racked to the first position.
- (v) The laboratory windows were blacked out and all the lights except a small reading light beside the spectrograph were turned off.
- (vi) In order to warm up the arc a used carbon cup containing a small amount of the internal standard mix and a used counter electrode were placed in the arc stand with the cup as the lower electrode. The counter electrodes are cut in the laboratory from carbon rods 0.65 cm in diameter and using a Jarrell Ash Graphite Electrode Shaper. The lower ends of the counter electrodes are polished. The counter electrode was lowered until it touched the top of the cup. The current was turned on and the electrodes separated, striking the arc. After 45 seconds the current was turned off and the electrodes discarded. The voltage used is 220<sup>volts</sup> transformed from the a.c. mains to d.c. and the current is 5.5 amps.
- (vii) The back of the plateholder was raised.
- (viii) The first sample and counter electrode were placed in the arc stand and with the 2 electrodes touching they were aligned using a small screen on the side of the spectrograph on to which an image of the electrodes was projected.
- (ix) The HV was turned on and the reading lamp was turned off.
- (x) The electrodes were separated to a distance of 4 mm, the shutter opened and the stop-watch started simultaneously.
- (xi) After 30 seconds the shutter was closed, the HV turned off, the light turned on and the used electrodes discarded.

(xii) The plateholder was racked to the next position and the analytical procedure repeated until all 22 samples had been analysed. The back of the plateholder was then closed and the plateholder removed to the darkroom.

(xiii) The plate was developed for 3 minutes at 20°C in Kodak D19 Developer, placed in a stop bath of 3% acetic acid for 20 seconds and then fixed for 4 minutes in Kodak Rapid Fix. After washing for 10 minutes in de-ionised water the plate was rinsed in Kodak Fotoflow and left to dry in a dust-free atmosphere.

(8) Reading the photographic plate.

(i) The plater reader was turned on, with the photocell shutter closed, to warm up for 30 minutes before use.

(ii) The settings on the plate reader were checked. They were:

Slit width 5

Diaphragm 10

(iii) The developed plate was placed emulsion side up in the frame of the plate reader.

(iv) The marker on the galvoscale was adjusted to read c 0.05 with the shutter closed.

(v) The marker on the galvoscale for an unexposed (clear glass) portion of the plate was adjusted to read c 48 with the shutter open. These readings were checked after the lines for each element had been read.

(vi) With the shutter closed the plate position was adjusted so that the required spectral line could be seen on the slit-jaws screen. The shutter was opened and, using the fine adjustment wheel, the line was scanned and the galvanometer deflection noted. Each line



was scanned in both directions. These measurements allow the difference between the intensity of the blackening of the line (I) and the clear glass ( $I_0$ ) reading to be taken.

(vii) If the unfiltered line was read, due to low intensity of the filtered line, then a background reading to either side of the line should also be taken.

Li, Al, Mg and Na were always read filtered.

Fe was usually read filtered.

Cr and Ni were usually read unfiltered,

Mn, Ti and Ca were sometimes read filtered and sometimes unfiltered.

(viii) A line was read for all samples for one element before proceeding to the next element.

(ix) When all the relevant lines had been read 2 other lines were taken from the central portion of the plate and read for the filtered, unfiltered and unfiltered background values. The filtered value was selected as being between 35-40 on the galvoscale. These readings were used in the calibration.

(9) Calibration of the technique

The calibration method used in this project to obtain quantitative results was that established in the Oxford laboratory in the early 1960s and then adopted by the Fitch Laboratory. It incorporates the modifications introduced by Schweizer in 1974 (Prag et al., 1974).

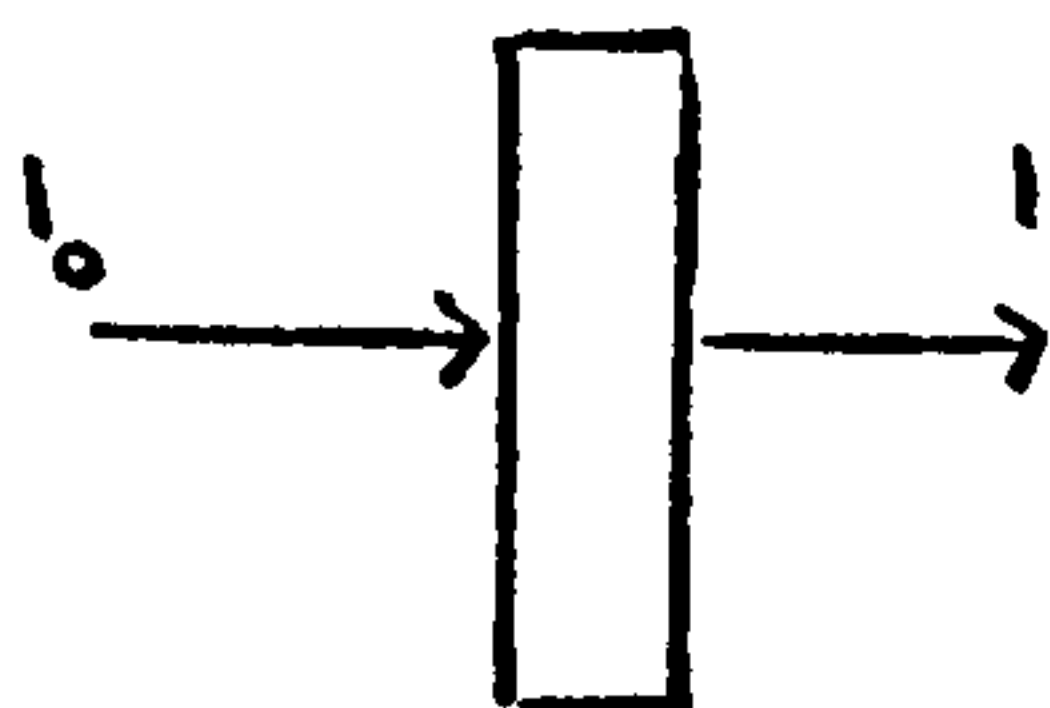
The aim of the calibration is to measure the change in transmission due to spectral blackening of a beam of light passing through the processed plate (the degree of blackening of the line) and hence the intensity of light emitted by the atoms of a particular element in the arc. This provides a measure of the concentration of the element in the sample.

After the photographic plate has been read, the Optical Density 'D' of the spectral lines can be calculated from the formula:

$$D = \log_{10} \frac{I_0}{I}$$

where I is the transmitted intensity of the light represented by the galvanometer deflection for the line with emulsion.

$I_0$  is the incident intensity of the light represented by the galvanometer deflection for the clear glass with emulsion. The clear glass reading makes allowances for light reflection and general scatter on areas of the emulsion which have not been exposed.  $I_0$  is kept constant for each plate by adjustment on the galvanometer and is generally represented by c 48 on the galvoscale (see above, Chapter 5.2.8).



The exposure (E) of the plate can be defined as

$$E = It$$

where I = the intensity of light falling on the plate and

t = the time of exposure (which is constant).

If a graph is plotted of D over  $\log_{10} E$  (see graph, Figure 16a), it can be seen to form an "S" shaped curve. The steepness of the slope of the straight line portion of the graph will vary with development time, becoming steeper with longer development. Since it is often necessary to work on the lower section of the curve which is non-linear, the Seidel Density (S) may be used instead to obtain a more linear calibration curve.

$$S = \log_{10} \left( \frac{I_i}{I} - 1 \right)$$



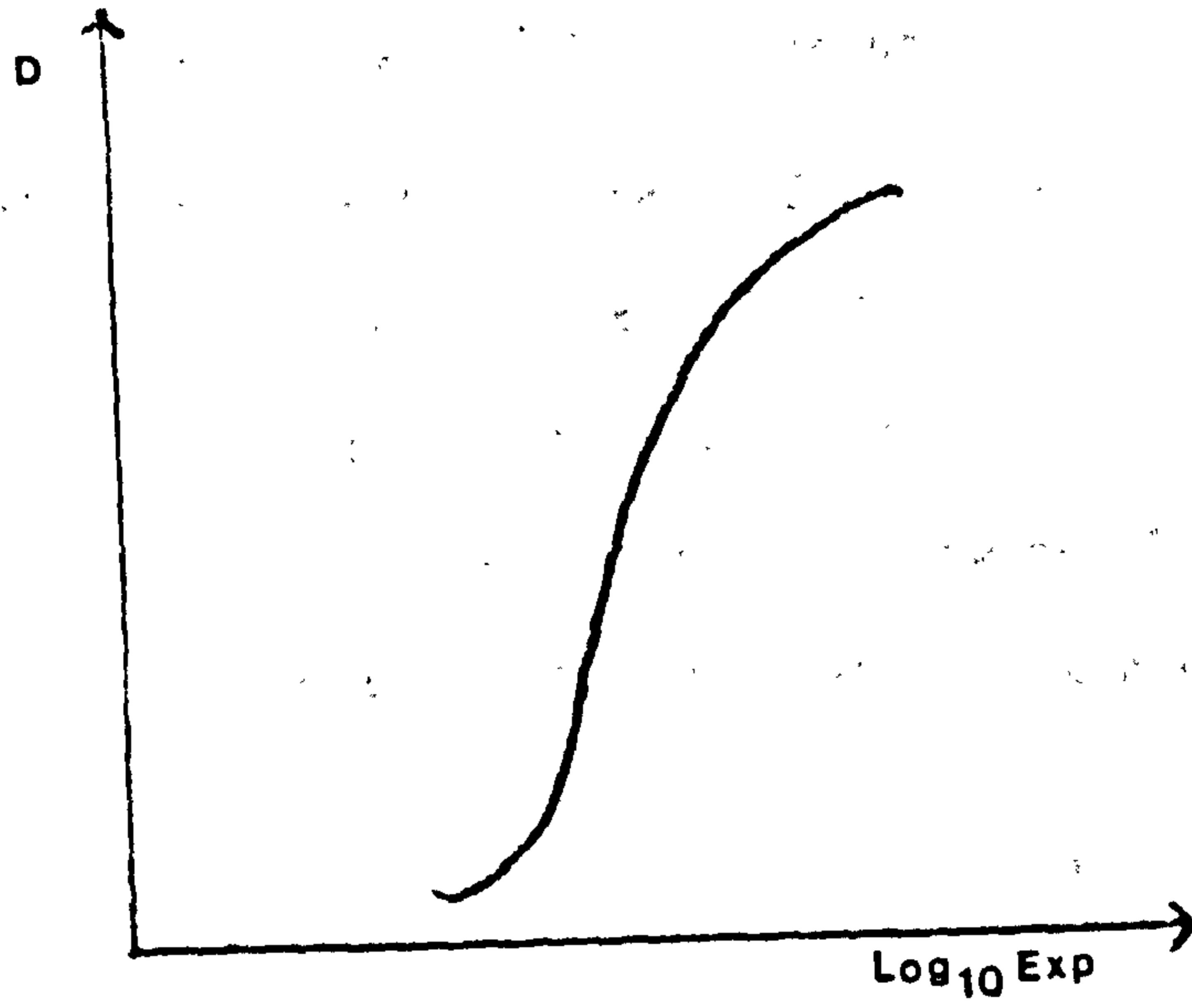


Fig 16 a

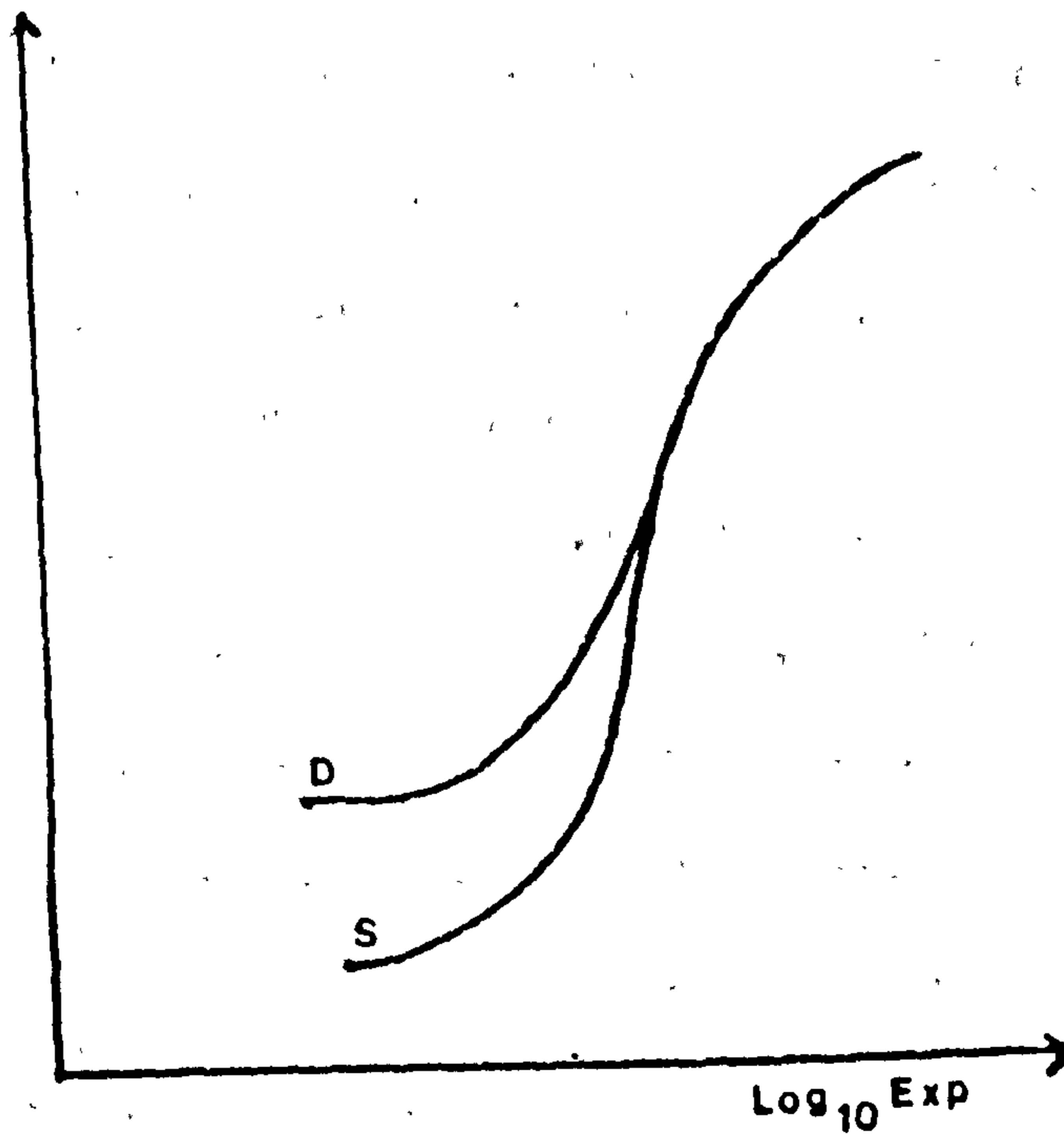


Fig 16 b

FIG. 16. VARIATION IN OPTICAL DENSITY WITH EXPOSURE.

The difference in the values of S and D is most noticeable at low densities but the slope of the two curves is not very different (see graph, Figure 16b).

The maximum slope of the S over  $\text{Log}_{10} E$  curve is defined as  $\gamma$ . This is also known as the contrast factor for the emulsion. It is calculated for each plate. It is defined from the two lines from the central portion of the plate which were read (see Chapter 5.2.8 above) which had galvanometer deflections of between 35-40 for the filtered line.  $\text{Tan}^{-1}$  is usually taken so that  $\gamma$  is expressed in degrees, hence:

$$\gamma = \text{Log}_{10} \left[ \frac{cg}{uf} - \frac{cg}{bkg \ uf} \right] - \text{Log}_{10} \left[ \frac{cg}{f} - 1 \right]$$

where  $cg$  = clear glass deflection = c 48

$uf$  = deflection for the unfiltered line

$bkg \ uf$  = deflection for the background beside the unfiltered line

$f$  = deflection for the filtered line.

As mentioned above (Chapter 5.2.8) it is sometimes necessary to read the unfiltered rather than the filtered line for a particular element. This is the case when a line is of low intensity due to the low concentration of the element in the sample, or to lower sensitivity of a particular line. The filtered line would therefore be too weak to read accurately. When an unfiltered line has to be read for an element it is also necessary to read the unfiltered line for the three location standards on the plate (see above, Chapter 5.2.3). When an unfiltered line is read the adjacent background reading is also taken. Since the filter transmits only 10% of the light falling on it, it is assumed that the background adjacent to the filtered line, which is also filtered, is approximately equal to the clear-glass measurement. The last



part of the above equation is therefore:

$$\left[ \frac{cg}{f} - 1 \right] \text{ rather than } \left[ \frac{cg}{f} - \frac{cg}{bkg f} \right] \text{ since } \left[ \frac{cg}{bkg f} \right] \approx 1$$

The response of the emulsion is not the same at all wavelengths and since  $\gamma$  is defined from two lines which lie roughly centrally on the plate adjustments are made for Na (3302.6)  $\gamma + 2$  and for Ni (3314.8A)  $\gamma + 3$ . The main  $\gamma$  for each plate is generally c  $55^\circ$ .

For plate LKI, for example, which had a clear glass galve deflection of 47.5 the values for the two roughly central lines were:

|                       |      |      |
|-----------------------|------|------|
| Filtered line         | 36.4 | 37.5 |
| Unfiltered line       | 5.8  | 6.3  |
| Unfiltered background | 45.5 | 45.5 |

Substituting these figures in the equation for  $\gamma$  given above the equation reads:

$$\gamma_1 = \log_{10} \left[ \frac{47.5}{5.8} - \frac{47.5}{45.5} \right] - \log_{10} \left[ \frac{47.5}{36.4} - 1 \right] = 1.466$$

$$\tan^{-1} 1.46 = 53.9^\circ$$

$$\gamma_2 = \log_{10} \left[ \frac{47.5}{6.3} - \frac{47.5}{45.5} \right] - \log_{10} \left[ \frac{47.5}{37.5} - 1 \right] = 1.38$$

$$\tan^{-1} 1.38 = 54.1^\circ$$

$$\frac{54.1 + 53.9}{2} = 54.0^\circ$$

Therefore  $\gamma$  for the plate =  $54^\circ$

$\gamma$  for Na =  $56^\circ$

$\gamma$  for Ni =  $57^\circ$

For convenience, tables for each gamma value were generated on a computer in Oxford in the early 1960s. The tables represent the points on a straight line with a slope of the  $\gamma$  in question. The y axis of the graph is the Seidel density calculated for each value on the galve scale when  $l_g = 50$ . The x-axis, which is  $\log_{10} X$  where X is the value on the table corresponding to each galvo deflection, gives  $\log_{10} \exp$  and thus, effectively, the intensity values since  $\exp = It$  where t is a constant (see table, Figure 17 and graph, Figure 18). The tables therefore convert the galvanometer deflections to values for the intensity of the light falling on the plate in arbitrary units and this is roughly equivalent to the light output from the arc.

Once the  $\gamma$  for the plate has been calculated the appropriate  $\gamma$  tables were selected and for each galvanometer deflection the corresponding value of emitted light intensity in the table was noted. For the lines which were read unfiltered the background intensity value was then subtracted from the line with background intensity value. The element to lithium ratio (Relative Intensity) for each pair of values was then calculated, since lithium has been added to each sample in a constant amount. For plate LKI mentioned above the galvanometer deflections |(g.d.)| for the filtered lithium and magnesium and unfiltered line and background nickel lines for the three Mycenae 22 location standards and for three pottery samples are given below together with the appropriate Intensity value.



$\gamma = 54'$ . Clear glass = 50

| Galvo Deflection | X     | $\log_{10} X$ | S      |
|------------------|-------|---------------|--------|
| 49               | 0.592 | -0.228        | -1.690 |
| 48               | 0.994 | -0.003        | -1.380 |
| 47               | 1.355 | 0.132         | -1.195 |
| 46               | 1.696 | 0.229         | -1.061 |
| 45               | 2.092 | 0.321         | -0.954 |
| 44               | 2.351 | 0.371         | -0.865 |
| 43               | 2.674 | 0.427         | -0.788 |
| 42               | 2.998 | 0.477         | -0.720 |
| 41               | 3.325 | 0.522         | -0.659 |
| 40               | 3.652 | 0.563         | -0.602 |
| 39               | 3.987 | 0.601         | -0.550 |
| 38               | 4.323 | 0.636         | -0.501 |
| 37               | 4.677 | 0.670         | -0.454 |
| 36               | 5.035 | 0.702         | -0.420 |
| 35               | 5.403 | 0.733         | -0.368 |
| 34               | 5.768 | 0.761         | -0.327 |
| 33               | 6.176 | 0.791         | -0.288 |
| 32               | 6.583 | 0.818         | -0.250 |
| 31               | 7.007 | 0.846         | -0.213 |
| 30               | 7.448 | 0.872         | -0.176 |
| 29               | 7.910 | 0.898         | -0.140 |
| 28               | 8.398 | 0.924         | -0.105 |
| 27               | 8.900 | 0.949         | -0.070 |
| 26               | 9.435 | 0.975         | -0.035 |
| 25               | 10.00 | 1.000         | 0.000  |
| 24               | 10.59 | 1.025         | 0.035  |
| 23               | 11.24 | 1.051         | 0.070  |
| 22               | 11.92 | 1.076         | 0.105  |
| 21               | 12.65 | 1.102         | 0.140  |
| 20               | 13.43 | 1.128         | 0.176  |
| 19               | 14.27 | 1.154         | 0.213  |

Continued.

| Galvo Deflection | X      | $\log_{10} X$ | S     |
|------------------|--------|---------------|-------|
| 18               | 15.00  | 1.176         | 0.250 |
| 17               | 16.19  | 1.209         | 0.288 |
| 16               | 17.29  | 1.238         | 0.327 |
| 15               | 18.51  | 1.267         | 0.368 |
| 14               | 19.86  | 1.298         | 0.410 |
| 13               | 21.38  | 1.330         | 0.454 |
| 12               | 23.11  | 1.361         | 0.501 |
| 11               | 25.08  | 1.401         | 0.550 |
| 10               | 27.38  | 1.444         | 0.602 |
| 9                | 30.09  | 1.482         | 0.659 |
| 8                | 33.36  | 1.520         | 0.720 |
| 7                | 37.39  | 1.573         | 0.788 |
| 6                | 42.53  | 1.631         | 0.865 |
| 5                | 49.35  | 1.690         | 0.954 |
| 4                | 58.97  | 1.772         | 1.061 |
| 3                | 73.94  | 1.871         | 1.195 |
| 2                | 100.04 | 2.000         | 1.380 |
| 1                | 169.00 | 2.232         | 1.690 |

X = the figure in the  $\gamma$  table for each galvanometer deflection.

Figure 17. Table of galvo deflections and Seidel densities for  $\gamma = 54^\circ$ .



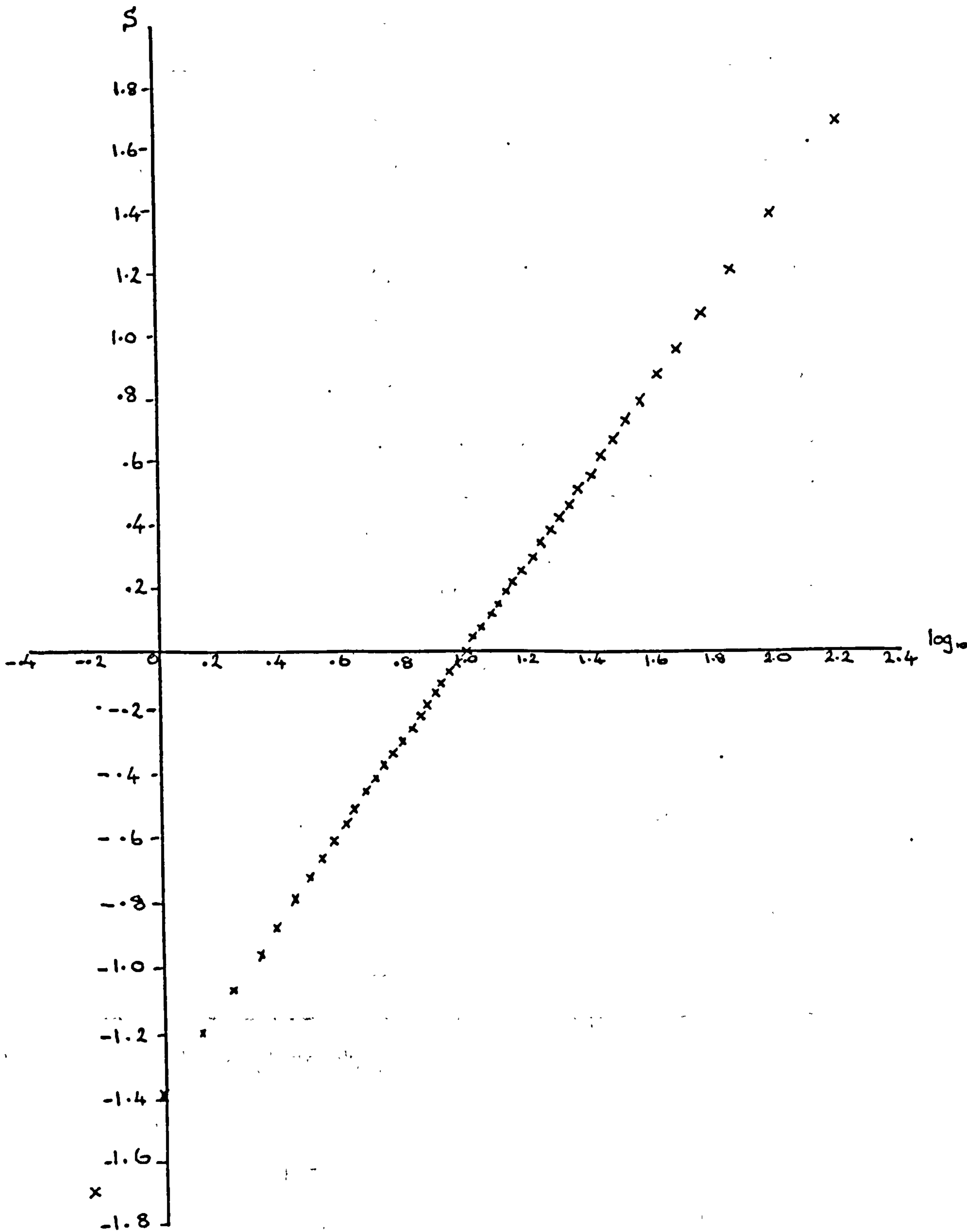


Fig 18 Graph for Seidel densities of galvanometer deflections against  $\log_{10} x$ , where  $x$ : the values from the  $\gamma$  table for each galvanometer deflection.  $\gamma : 54'$

|            | <u>Lithium</u> |      | <u>Magnesium</u> |       |
|------------|----------------|------|------------------|-------|
|            | g.d.           | I.   | g.d.             | I     |
| Myc 22 (1) | 35.0           | 5.36 | 15.3             | 18.13 |
| (2)        | 42.0           | 3.00 | 21.4             | 12.35 |
| (3)        | 43.0           | 2.67 | 25.2             | 9.88  |
| LKLI       | 36.8           | 4.75 | 26.8             | 9.01  |
| 3          | 41.0           | 3.32 | 19.0             | 14.27 |
| 4          | 38.6           | 4.12 | 27.7             | 8.54  |

|            | <u>Nickel</u>         |         |                 |        |
|------------|-----------------------|---------|-----------------|--------|
|            | g.d.<br>line +<br>bkg | g.d.bkg | 1 line +<br>bkg | 1 line |
| Myc 22 (1) | 13.5                  | 39.1    | 19.08           | 4.36   |
| (2)        | 16.7                  | 40.8    | 15.55           | 3.80   |
| (3)        | 11.8                  | 39.4    | 21.60           | 4.26   |
| LK 1       | 8.2                   | 40.2    | 28.80           | 4.00   |
| 3          | 15.7                  | 41.4    | 16.61           | 3.60   |
| 4          | 12.9                  | 38.0    | 19.80           | 4.73   |

Nickel line-bkg 1.

|            |       |
|------------|-------|
| Myc 22 (1) | 14.72 |
| (2)        | 11.75 |
| (3)        | 17.34 |
| LK 1       | 24.80 |
| 3          | 13.01 |
| 4          | 15.13 |



The element to lithium ratios (Relative Intensities) for the above samples are therefore:

|            | Mg/Li | Ni/Li |
|------------|-------|-------|
| MYC 22 (1) | 3.88  | 2.75  |
| (2)        | 4.12  | 3.92  |
| (3)        | 3.70  | 4.39  |
| LK 1       | 1.90  | 5.22  |
| 3          | 4.30  | 3.92  |
| 4          | 2.07  | 3.61  |

When the calibration was originally set up in Oxford a master graph was drawn for each element for Log concentration over Log relative intensity. For the appropriate elements graphs for both the filtered and unfiltered lines were drawn. These graphs were based on analysis by wet chemical methods of pottery standards. Schweizer's recalibration was based on analyses of USGS rock standards and it was the graphs that were drawn after the recalibration which were used in this project. The location standard, 'Mycenae 22', was used as a secondary standard and its concentration is marked on each graph. The average of the relative intensity values for the three location standards was calculated for each element. This value was then used to locate exactly where the working graph for each plate should be drawn parallel to the master line. Although the working line may coincide with the master line, there is generally some horizontal displacement of the line. This displacement is due to variations in plate emulsion and development conditions.

The average of the relative intensity values for the location standards on plate LK 1 was therefore Mg, 3.90 and Ni, 3.67. From the two graphs shown (Figures 19 and 20) it can be seen how the lines were

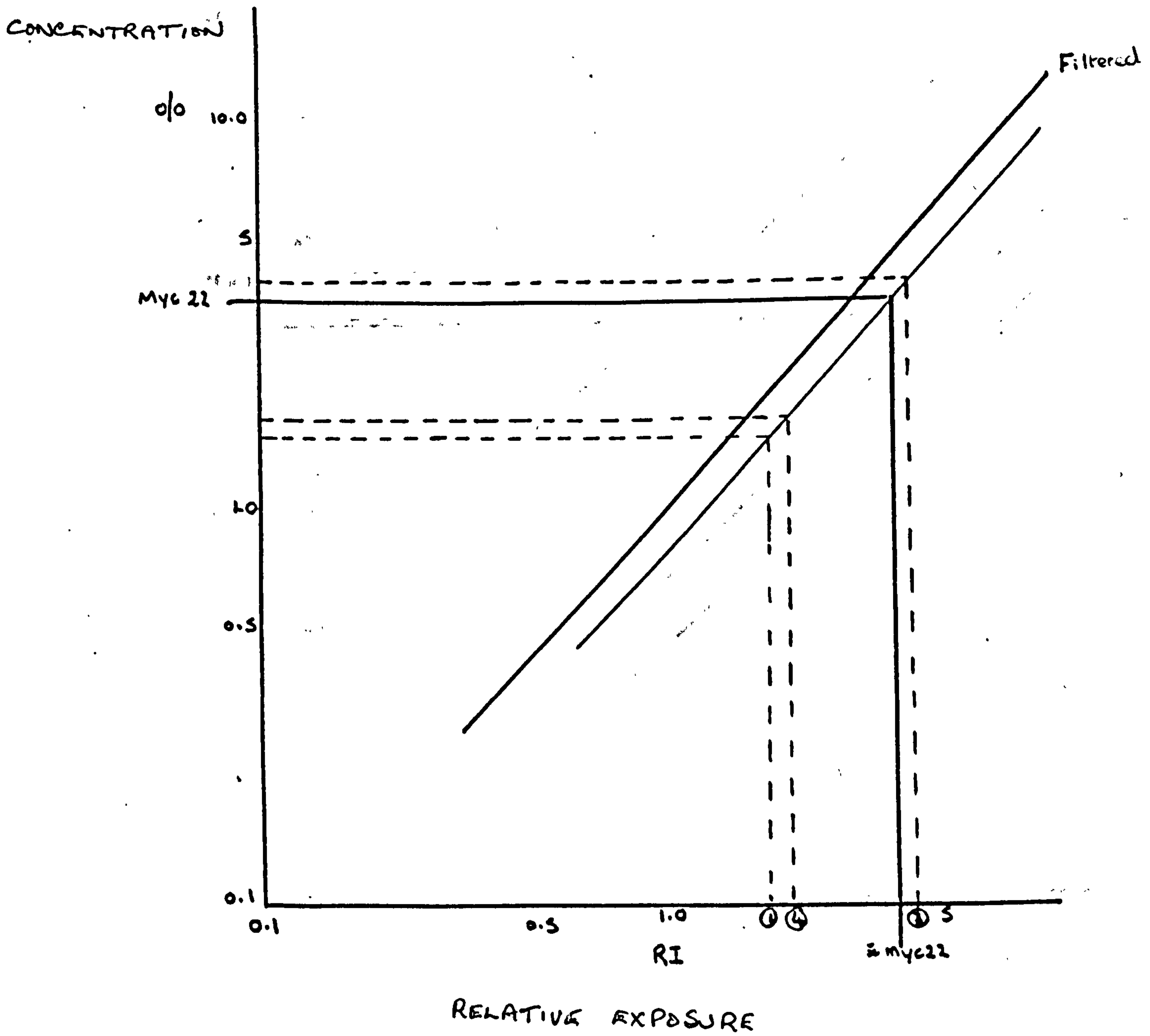


Fig 19 Calibration graph for magnesium

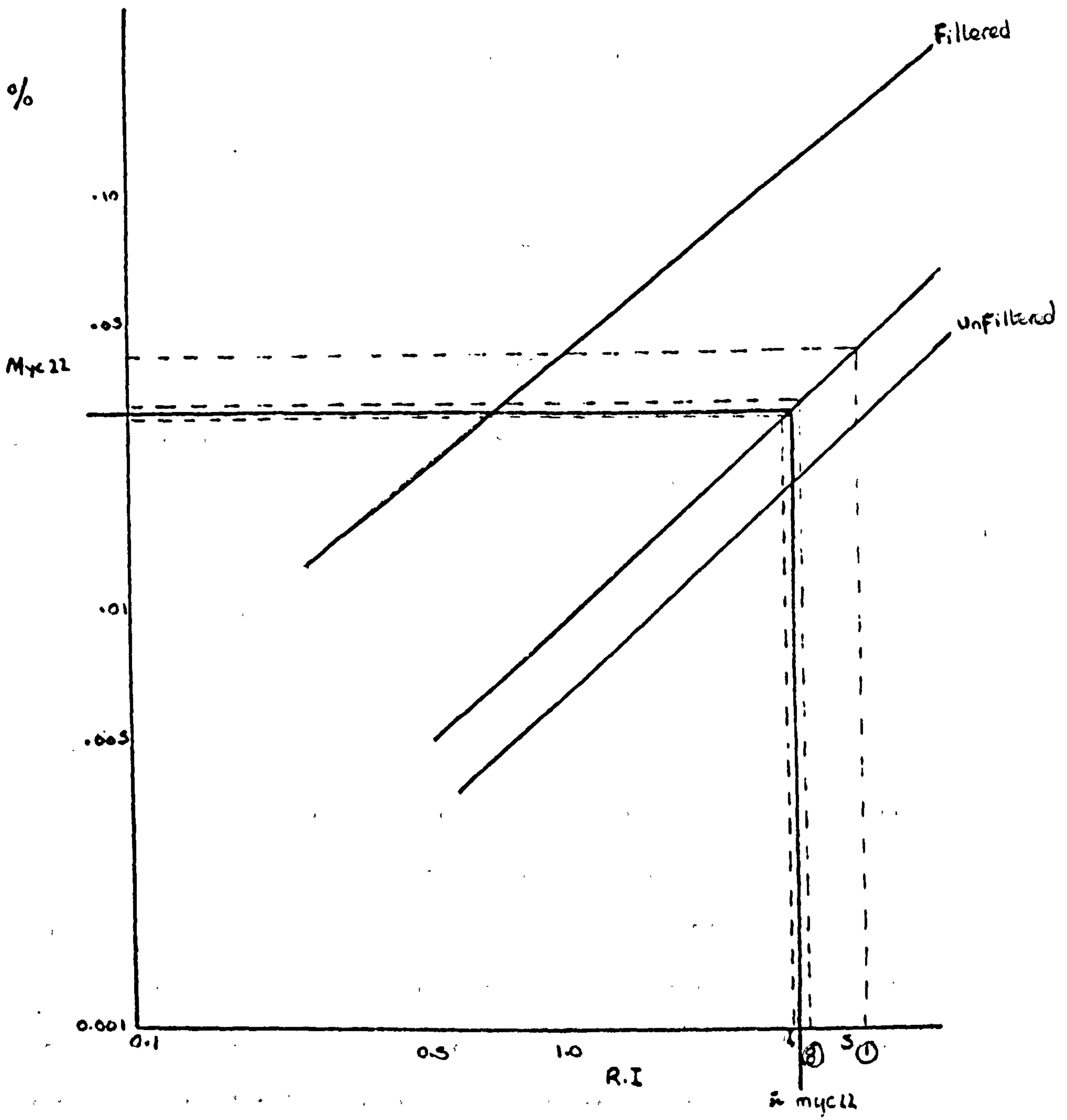


Fig 20 Calibration graph for nickel



then plotted parallel to the master line on each graph. The concentration corresponding to each relative intensity value was then read off from the graphs. The results are expressed in oxides. For the samples LK 1, 3 and 4 the concentrations read off from the graphs were:

|      | <u>MgO</u> | <u>NiO</u> |
|------|------------|------------|
| LK 1 | 1.6%       | 0.042%     |
| 3    | 4.0%       | 0.031%     |
| 4    | 1.7%       | 0.029%     |

For the results of the sherds analysed in this project see Appendix 2.

(10) Reliability of the technique

(10)(i)

Precision

The precision of the analytical technique was measured on 2 separate occasions. The first occasion was in 1978 when 19 samples of a Late Bronze Age sherd called Mycenae Gp.17, No. 19 were analysed on one spectrographic plate and the second was in 1980 when 19 samples of the location standard sherd Mycenae 22 were analysed on one plate. These samples were analysed following the standard procedure given above (Chapter 5.2.6-7). The results of these analyses are given in the Tables below (Figures 21 and 22). For each element on each of these plates the percentage variation (% var.) was calculated where:

$$\% \text{ var} = \text{s.d.}/\bar{x} \times 100$$

The percentage variation for the first plate was 13.29% and for the second it was 11.97%. On the first plate the % var for aluminium

Figure 21. Reproducibility test carried out in 1978 on sherd  
Mycenae Gp. 17 No. 19.

$$\% \text{ variation} = \frac{\sigma}{\bar{x}} \times 100$$

| Sample No. | Al.  | Ca.  | Mg. | Fe. | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|-----|------|------|-------|-------|-------|
| 1          | 11.2 | 13.8 | 2.9 | 7.5 | 0.75 | 1.00 | 0.079 | 0.027 | 0.023 |
| 2          | 18.5 | 16.7 | 3.9 | 6.8 | 0.75 | 1.00 | 0.095 | 0.026 | 0.022 |
| 3          | 17.5 | 16.0 | 3.2 | 7.5 | 0.75 | 0.83 | 0.100 | 0.025 | 0.025 |
| 4          | 18.1 | 14.3 | 3.7 | 7.2 | 0.67 | 0.88 | 0.089 | 0.025 | 0.021 |
| 5          | 22.5 | 17.0 | 4.0 | 8.2 | 0.78 | 1.00 | 0.092 | 0.030 | 0.024 |
| 6          | 22.5 | 20.6 | 3.8 | 7.2 | 0.83 | 0.83 | 0.096 | 0.026 | 0.026 |
| 7          | 20.2 | 19.0 | 3.5 | 7.6 | 0.80 | 1.00 | 0.100 | 0.029 | 0.028 |
| 8          | 11.2 | 9.8  | 3.0 | 6.8 | 0.62 | 0.96 | 0.082 | 0.024 | 0.019 |
| 9          | 20.2 | 14.8 | 3.3 | 7.3 | 0.68 | 0.83 | 0.086 | 0.026 | 0.023 |
| 10         | 22.0 | 18.0 | 3.9 | 7.3 | 0.75 | 0.86 | 0.096 | 0.027 | 0.024 |
| 11         | 24.0 | 22.4 | 3.9 | 7.4 | 0.91 | 0.97 | 0.103 | 0.037 | 0.029 |
| 12         | 18.6 | 12.1 | 3.6 | 6.5 | 0.65 | 0.98 | 0.081 | 0.026 | 0.019 |
| 13         | 21.5 | 17.2 | 3.6 | 7.9 | 0.72 | 0.91 | 0.098 | 0.030 | 0.025 |
| 14         | 16.7 | 12.7 | 3.0 | 6.5 | 0.61 | 0.86 | 0.077 | 0.025 | 0.020 |
| 15         | 20.1 | 15.5 | 3.5 | 7.0 | 0.72 | 0.76 | 0.093 | 0.027 | 0.024 |
| 16         | 18.2 | 11.3 | 3.2 | 6.4 | 0.67 | 0.79 | 0.070 | 0.025 | 0.019 |
| 17         | 24.5 | 18.8 | 4.4 | 8.4 | 0.81 | 0.85 | 0.098 | 0.035 | 0.026 |
| 18         | 23.0 | 21.3 | 4.1 | 7.8 | 0.91 | 0.98 | 0.102 | 0.030 | 0.031 |
| 19         | 10.3 | 10.8 | 2.9 | 7.4 | 0.62 | 0.78 | 0.077 | 0.026 | 0.022 |
| $\bar{x}$  | 19.0 | 15.9 | 3.6 | 7.3 | 0.74 | 0.90 | 0.090 | 0.028 | 0.024 |
| s.d.       | 4.2  | 3.6  | 0.4 | 0.6 | 0.09 | 0.08 | 0.010 | 0.003 | 0.003 |

% variation      22.3      22.6      11.1      8.2      12.2      8.9      11.1      10.7      12.5      x = 13.29%



Figure 22.      Reproducibility test carried out in 1980 on  
sherd Mycenae 22. (Also used as the location standard).

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 1          | 19.0 | 18.1 | 4.2 | 9.1  | 0.92 | 1.20 | 0.130 | 0.049 | 0.035 |
| 2          | 15.7 | 14.4 | 2.5 | 10.3 | 0.80 | 0.96 | 0.115 | 0.051 | 0.045 |
| 3          | 22.4 | 17.6 | 4.1 | 10.2 | 0.90 | 0.95 | 0.125 | 0.051 | 0.036 |
| 4          | 20.8 | 18.4 | 3.7 | 9.1  | 0.87 | 0.85 | 0.110 | 0.046 | 0.035 |
| 5          | 19.0 | 14.7 | 4.0 | 9.2  | 0.88 | 1.40 | 0.117 | 0.045 | 0.032 |
| 6          | 20.5 | 18.5 | 4.3 | 9.7  | 0.90 | 0.93 | 0.140 | 0.046 | 0.033 |
| 7          | 19.6 | 15.7 | 3.5 | 10.1 | 0.88 | 1.10 | 0.117 | 0.046 | 0.036 |
| 8          | 21.6 | 16.6 | 3.5 | 9.1  | 0.86 | 0.77 | 0.102 | 0.039 | 0.033 |
| 9          | 18.3 | 16.6 | 4.0 | 9.1  | 1.01 | 0.99 | 0.117 | 0.044 | 0.034 |
| 10         | 19.0 | 18.4 | 3.8 | 9.6  | 0.81 | 0.65 | 0.137 | 0.060 | 0.029 |
| 11         | 18.9 | 16.2 | 3.6 | 10.6 | 0.90 | 0.81 | 0.132 | 0.045 | 0.034 |
| 12         | 21.5 | 18.5 | 3.7 | 9.7  | 0.98 | 0.96 | 0.107 | 0.044 | 0.035 |
| 13         | 25.5 | 24.9 | 4.2 | 11.7 | 1.09 | 0.81 | 0.145 | 0.055 | 0.042 |
| 14         | 18.9 | 13.5 | 3.4 | 9.1  | 0.83 | 0.88 | 0.105 | 0.041 | 0.029 |
| 15         | 24.4 | 21.4 | 4.3 | 10.8 | 1.00 | 0.96 | 0.137 | 0.049 | 0.034 |
| 16         | 23.9 | 19.6 | 3.8 | 11.0 | 1.04 | 0.92 | 0.112 | 0.047 | 0.036 |
| 17         | 23.1 | 16.9 | 4.4 | 11.4 | 1.04 | 0.96 | 0.125 | 0.055 | 0.034 |
| 18         | 20.5 | 16.0 | 3.6 | 10.2 | 0.90 | 0.88 | 0.112 | 0.048 | 0.032 |
| 19         | 30.4 | 18.4 | 5.6 | 12.9 | 1.30 | 1.30 | 0.150 | 0.054 | 0.041 |
| $\bar{x}$  | 20.1 | 16.9 | 3.8 | 9.8  | 0.90 | 0.93 | 0.118 | 0.047 | 0.034 |
| s.d.       | 2.8  | 2.0  | 0.5 | 0.08 | 0.08 | 0.17 | 0.013 | 0.005 | 0.004 |

% Variation    13.9    11.8    13.2    8.2    8.9    18.3    11.0    10.6    11.8

$\bar{x} = 11.97\%$

and calcium was much higher than on the second plate: 22.3 and 22.6% as opposed to 13.9 and 11.8%. The value for sodium, on the other hand, was much more satisfactory on the first plate: 8.9 as opposed to 18.3%. The values for the other elements varied relatively little between the two plates. The reasons for the size of the variations in aluminium, calcium and sodium is not known since the samples were all prepared and analysed in the same way.

These results compare favourably with those quoted in the literature. Ahrens and Taylour (1950) considered 15-20% variation to be acceptable. The results of 16 analyses of a Bronze Age British sherd conducted by Freeth (1967) are given below (Figure 23a). The average value for the percentage variations he obtained is 13.9%. In 1974 Schweizer (Prag et al., 1974:169) quoted "some typical figures" for their Coefficient of variation. However, they omitted to define this term or to say how many analyses and of what material these values were obtained from. The values they quoted are given below (Figure 23b). They were also quoted by Hatcher et al. (1980) as values for the reproducibility of OES. Without more detailed information, however, their value is limited. Both the tests conducted for this project fall within what can thus be seen as acceptable limits although the percentage variation obtained in 1980 was c 1.5% better than that obtained in 1978.

Since, although the galvanometer deflection on each line was read twice, the possibility existed of an error of up to c 0.2 being made on the readings on the galvo scale. It was decided to test how far an error of -0.2 on the line reading would affect the final result. This was done for both a filtered and an unfiltered line where an error of +0.2 was incorporated in the background reading to maximise the possible



|                                                                                                                                  | Al.  | Ca.  | Mg.  | Fe.  | Ti.   | Na.   | Mn.   | Cr.    | Ni.      |
|----------------------------------------------------------------------------------------------------------------------------------|------|------|------|------|-------|-------|-------|--------|----------|
| $\bar{x}$                                                                                                                        | 14.2 | 4.9  | 1.5  | 7.05 | 0.63  | 0.34  | 0.210 | 0.036  | 43 ppm.  |
| s.d.                                                                                                                             | 1.93 | 0.69 | 0.16 | 0.91 | 0.124 | 0.035 | 0.027 | 0.0052 | 7.1 ppm. |
| $\bar{x} = 13.9\%$                                                                                                               |      |      |      |      |       |       |       |        |          |
| % variation                                                                                                                      | 13.6 | 14.1 | 10.7 | 12.9 | 19.7  | 10.3  | 12.9  | 14.4   | 16.5     |
| <p><u>Figure 23a.</u> Results quoted by Freeth (1967) for reproducibility test on 16 analyses of a Bronze Age British sherd.</p> |      |      |      |      |       |       |       |        |          |
| %                                                                                                                                | 4.8  | 9.3  | 6.8  | 11.0 | 6.8   | 7.0   | 6.3   | 7.2    | 18.6     |
| $\bar{x} = 8.6\%$                                                                                                                |      |      |      |      |       |       |       |        |          |
| <p><u>Figure 23b.</u> Results quoted by Prag et al. (1974:169) as 'some typical figures' for their coefficient of variation.</p> |      |      |      |      |       |       |       |        |          |

effect. The result for the filtered line was 0.55% Ti instead of 1.22%.

It was discovered that if  $\gamma$  was calculated for the location standard for one of the lines that was actually used in the middle region of the plate, like Ti, the  $\gamma$  was not, in many cases, the same as the  $\gamma$  calculated for the plate by the method given above (Chapter 5.2.9). In view of this discovery the  $\gamma$  was calculated for Ti for one plate and using the new  $\gamma$  table (60 as opposed to 56) the concentration of one of the samples was determined. The result was 0.96% as opposed to the original 0.95%.

(ii) Accuracy

The accuracy of the analytical technique was tested by the analysis of ten standards on one plate, under the same analytical conditions as the archaeological samples. Five of these were USGS standards, 3 were from the British Ceramic Research Association and 2 were from the Bureau of Analysed Standards. As usual three location standards of the sherd Mycenae 22 were included on the plate. The results of the analyses are given below (Figure 24) and were quite disappointing in the degree to which they differed from the certificate values for these standards. WI, which was also used as the standard in the atomic absorption analysis (see below, Chapter 5.3.4) was selected as having similar concentrations to Bronze Age Greek pottery for most of the relevant elements. Using the percentage variation obtained for Mycenae 22 in 1980 the acceptable concentration range around the certificate value was calculated. Only the results obtained for magnesium and sodium fell within these limits although iron was only 0.1% outside the acceptable range. When the same test was applied to the other standards magnesium fell within the

| Standard | Al.  | Ca.  | Mg.   | Fe.  | Ti.  | Na.   | Mn.   | Cr.   | Ni.   |
|----------|------|------|-------|------|------|-------|-------|-------|-------|
| PCCI     | -    | -    | 24.0  | 12.3 | 2.0  |       | 0.106 | 0.32  | 0.32  |
| PCCI     | 0.74 | 0.51 | 43.2  | 8.4  | 0.02 | 0.006 | 0.12  | 0.27  | 0.23  |
| CAS7     | 22.8 | 0.78 | -     | -    | 0.33 | 0.59  | -     | -     | -     |
| CAS7     | 18.1 | 0.82 | 0.28  | 0.51 | 0.28 | 0.74  | -     | -     | -     |
| WI       | 18.8 | 9.4  | 6.2   | 12.1 | 1.30 | 2.30  | 0.133 | 0.018 | 0.010 |
| WI       | 15.0 | 11.0 | 6.62  | 11.1 | 1.07 | 2.15  | 0.17  | 0.002 | 0.008 |
| 372      | 9.8  | 52.0 | 1.60  | 3.60 | 0.42 | 0.12  | 0.046 | -     | 0.003 |
| 372      | 5.4  | 65.8 | 0.78  | 2.50 | 0.33 | 0.21  | -     | -     | -     |
| BCRI     | 15.8 | 7.40 | 3.00  | 15.2 | 1.80 | 4.00  | 0.162 | -     | -     |
| BCRI     | 13.6 | 6.92 | 3.46  | 13.4 | 2.20 | 3.30  | 0.18  | -     | -     |
| 2CAS1    | 38.3 | -    | -     | -    | 1.15 | 0.37  | -     | 0.018 | -     |
| 2CAS1    | 32.0 | 0.20 | 0.28  | 1.03 | 1.16 | 0.34  | -     | -     | -     |
| CAS3     | 20.5 | 3.5  | 1.80  | 9.0  | 1.00 | 0.67  | 0.094 | 0.023 | 0.010 |
| CAS3     | 16.3 | 2.73 | 2.11  | 5.89 | 0.85 | 0.63  | 0.070 | -     | -     |
| 269      | 36.0 | -    | 0.085 | 5.20 | 1.30 | 0.81  | 0.052 | 0.054 | 0.014 |
| 269      | 33.9 | 0.22 | 0.93  | 3.30 | 1.50 | 0.36  | -     | -     | -     |

Continued:



| Standard. | Al.  | Ca.  | Mg.  | Fe.  | Ti.  | Na.  | Mn.   | Cr. | Ni. |
|-----------|------|------|------|------|------|------|-------|-----|-----|
| G2        | 14.0 | 1.00 | 0.44 | 2.85 | 0.42 | 5.50 | 0.037 | -   | -   |
| G2        | 15.4 | 1.95 | 0.76 | 2.65 | 0.50 | 4.07 | 0.140 | -   | -   |
| GSPI      | 15.8 | 1.60 | 0.55 | 5.00 | 0.58 | 5.00 | 0.051 | -   | -   |
| GSPI      | 15.3 | 2.02 | 0.96 | 4.30 | 0.66 | 2.80 | 0.042 | -   | -   |

Figure 24. Analysis of standards. (The lower set of figures in each case is the certificate value.)

acceptable levels for BCRI, CAS3 and 269, all of which contain similar amounts of magnesium to the archaeological samples. The error at the extremes of concentration was much greater than within the range of concentrations generally found in Bronze Age Greek pottery. For the other elements in most cases the value obtained in the analysis was outside the acceptable concentration range. For all elements the error was greatest at the extremes of concentration which are generally outside the range used in composition and provenance studies of pottery. Harbottle (1970) commented that values determined by OES are generally higher than those obtained by NAA.

Although it is obviously desirable that an analytical technique has both good accuracy and good precision the precision is more important since if the precision is good results from the same laboratory can then be compared with each other and are consistent within themselves. Poor accuracy, however, makes it impossible to do any direct comparison between results obtained by optical emission and by another technique, or between optical emission analyses done in two different laboratories. The fact that the deviation from the certificate values is not always by the same amount means that it is impossible to apply a single calibration factor to each element to make it compatible with other results. Since the results of similar tests on optical emission spectroscopy have not been published in the past it is not possible to say whether or not the technique has always had poor accuracy and good precision.

As an additional test on the technique a calibration graph was drawn for sodium from the results obtained for this plate with concentration plotted against the Na/Li intensities on a log scale (Figure 25). The best straight line drawn through these points has a slope of  $54^{\circ}$ , and was approximately parallel to the master graph used in Athens.

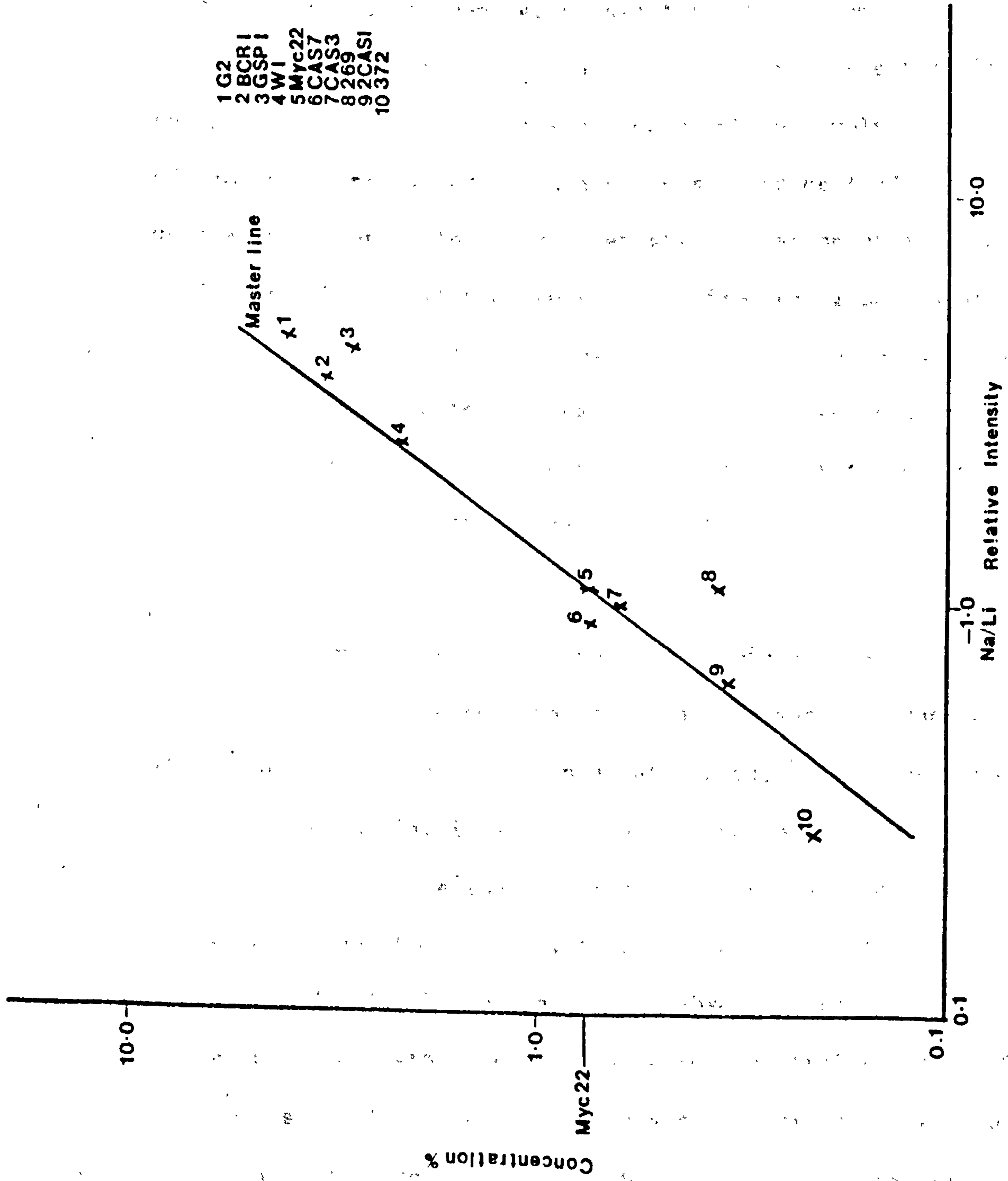


Fig 25 Calibration graph for Na



### 5.3. Atomic Absorption Spectrophotometry.

#### (1) Theory

The structure of atoms and their ability to emit radiation has been described above (Chapter 5.2.1). If we are dealing with unfilled outer energy levels atoms which emit energy at a particular wavelength will also absorb energy at the same wavelength. Theoretically, when light of various frequencies passes through an atomic vapour containing these atoms, the light will be absorbed. At the same time it will excite the atoms. Such absorptions of energy which involve the ground state of the atoms are called resonance lines. Price (1979:14) defined resonance radiation as the "characteristic radiation of an element corresponding to the transfer of an electron from the ground state to a higher energy level". Since the transition involves the ground state and not transitions from excited states the absorption spectra for most elements are less complicated than the emission spectra for the same elements, there is therefore little possibility of coincidence of spectral lines than in OES.

Elwell and Gidley (1966) defined atomic absorption as "a method for determining the concentration of an element in a sample by measuring the absorption of radiation in an atomic vapour produced from the sample at a wavelength that is specific and characteristic of the element under consideration". The sample which is to be analysed must therefore be converted to an atomic cloud, free of atomic bonding. Each constituent of the cloud will then be capable of absorbing radiation at a limited number of wavelengths over a very narrow spectral region. This conversion is usually affected by means of a flame burning in air (an ideal method according to Slavin 1968:36). Flameless atomisers have been

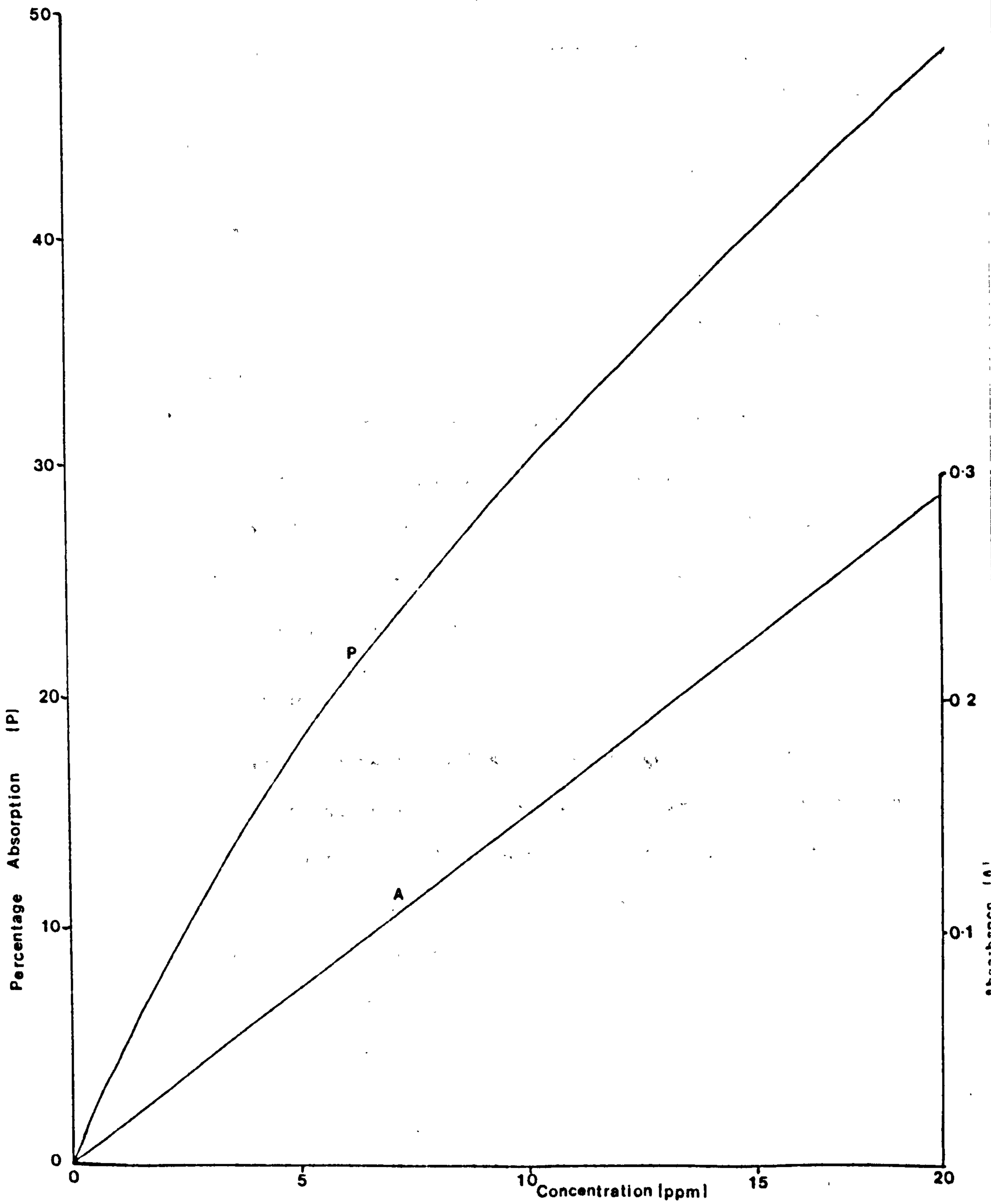


Fig 26 Graph of Percentage Absorption and Absorbance over Concentration

developed but are still less common than the flame variety. Generally either an air/acetylene or a nitrous-oxide/acetylene flame is used (for details see below, Chapter 5.3.2).

Quantitative results in atomic absorption are obtained by measurement of the attenuation of the signal from the source and this is a measure of the concentration of the element in the sample solution. This is the Absorbance (A) which is equal to the Optical density (D) and therefore, by using the same definition of D as in OES

$$A = D = \log_{10} \frac{I_0}{I}$$

Where  $I_0$  = the intensity of the emission line from the lamp that is being used.

$I$  = the intensity of the same line after passage through the flame.

There is a linear relationship between Absorbance and Concentration (C) and the slope of the graph of Absorbance over Concentration is determined by the thickness of the flame path (d) which is constant and the absorbtivity of the sample (k). Thus:

$$A = kdC$$

Some spectrophotometers express results in Percentage Absorption (P) which has a non-linear relationship with Absorbance. The Percentage Absorption is derived from the fractional reduction in intensity of the light beam after it has passed through the flame. At low concentrations Percentage Absorption is approximately proportional to concentration but this does not hold at higher concentrations (see graph of A and P over C, Figure 26). The Percentage Absorption is defined as:



$$P = \frac{\Delta I}{I_0} \times 100\%$$

Where  $\Delta I$  = the change in intensity of the beam during transition of the flame.

Tables have been prepared for conversion of Absorbance to Percentage Absorption and vice versa and are provided by the manufacturers of spectrophotometers.

Once the atomic vapour has been produced a powerful beam of monochromatic radiation characteristic of the element being measured is passed through the vapour. The atoms of that element which are present in the flame will then be excited, moving from the ground state to an excited state by absorbing the requisite amount of radiation for the transition. The atoms then re-emit this radiation in all directions. A detector placed in the light path to receive the light after it has passed through the flame will therefore record the diminished intensity of the transmitted light. The decrease in light intensity depends on the number of atoms of the element in question that are present in the flame and hence on the concentration of the element in the sample. Quantitative results are obtained by comparing the results to those of standard solutions of known concentrations (see below, Chapter 5.3.8).

## (2) Equipment.

The equipment used in this project was a Perkin Elmer 305 double-beam atomic absorption spectrophotometer with attached chart recorder (see schematic diagram, Figure 27).

The first component of the instrument is a monochromatic light source which must be designed to give narrow spectral lines and high

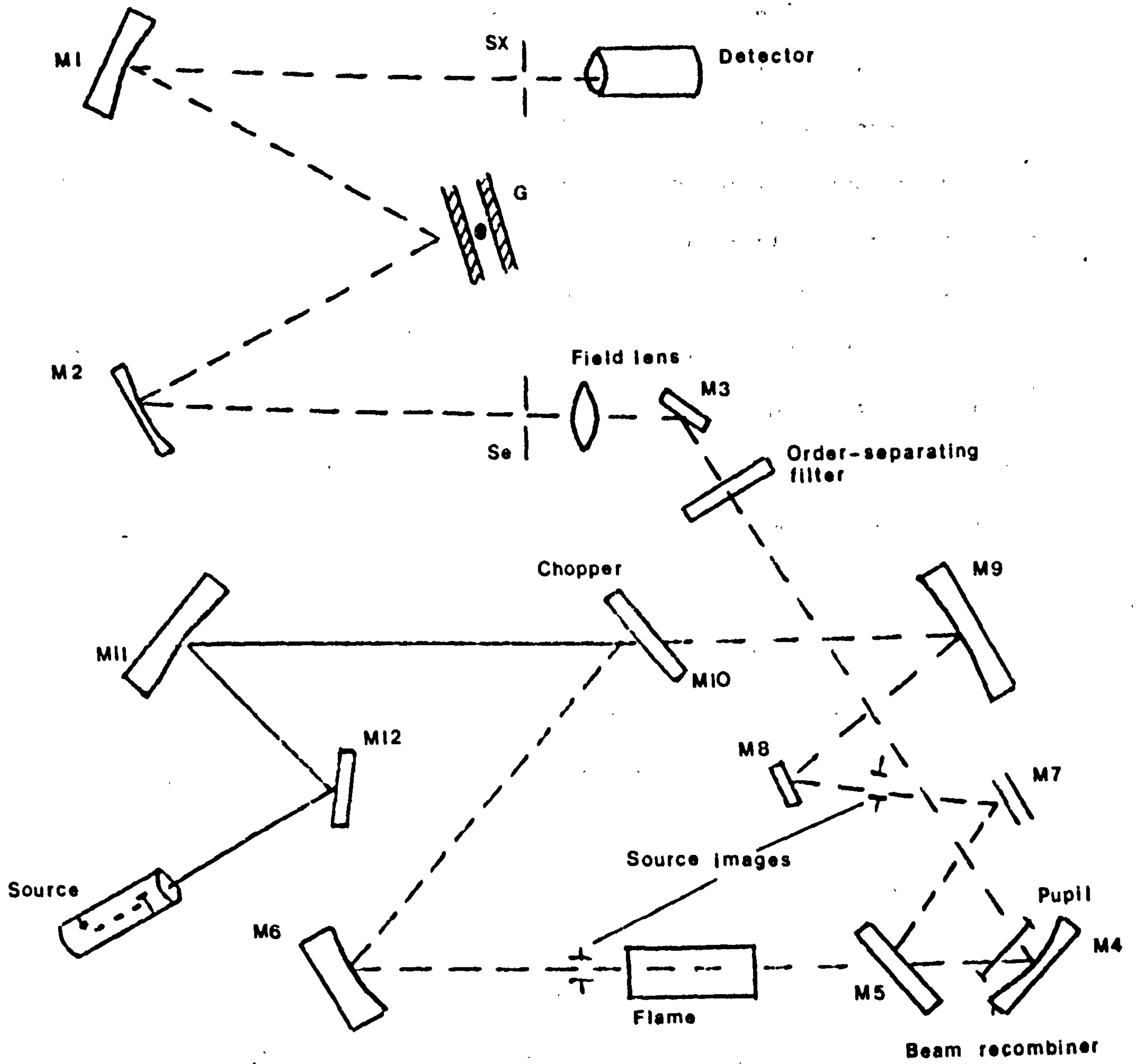


Fig 27 Optics of a Perkin-Elmer 305 Spectrophotometer

intensity emission for transitions which terminate in the ground state, since the majority of the atoms in the sample vapour will be in the ground state. Two kinds of light source were used in this project. Arc Discharge lamps were used for determinations of Sodium and Potassium. They consist of a silica or glass tube containing an inert gas under pressure and also containing a quantity of the metal of interest. The oxide-coated electrodes are sealed into the tube. These lamps have a separate power supply which is connected to the back of the spectrophotometer. They should be run at the lowest current that will sustain the discharge (500 millamps). When the lamp is switched on there is a gas discharge which warms and vapourizes the metal which is sealed into the lamp. Gradually the metal vapour takes over the discharge until the radiation consists almost exclusively of the metal spectrum. The lamps slot into the lamp chamber of the spectrophotometer and should need no further alignment.

The second kind of light source used were Hollow Cathode lamps. They were used for all the other elements that were measured. A Hollow-cathode lamp consists of a glass envelope with an optical window of silica. The envelope is filled with argon or neon under low pressure. The hollow cathode is a cylinder a few millimetres in diameter coated with the element, or, in the case of multielement lamps elements in question. The anode is tungsten. The atoms of the cathode are bombarded and excited by argon ions and electrons and emit light. A maximum operating current is recommended for each lamp and generally a lamp should be run at the lowest current that gives adequate sensitivity. This both improves results and increases the life of the lamp. Multi-element lamps are only economically viable if all the elements in a lamp



are likely to be needed with approximately equal frequency since, once one element fails the whole lamp is useless. In this project a calcium/magnesium lamp and a Fe/Cr/Ni/Mn/Cu/Co lamp were used. For the other elements single element lamps were used. Since hollow-cathode lamps are each fitted into a separate holder which slots into the lamp chamber, once aligned, the lamps should not need realigning unless they have been mishandled.

Once a sample has been put into solution it must be nebulized (broken up into fine droplets), mixed with a fuel and an oxidant and atomised (dissociated in the burner). The sample is drawn up through a fine polythene capillary into a nebuliser where the flow of oxidant causes a reduction in pressure at the end of the capillary which breaks the solution up into fine droplets. The droplets should be under 5 $\mu$ m in diameter in order to prevent faulty atomisation. In this spray chamber the fuel, oxidant and sample solution are mixed together in a rotary movement caused by the inflow of gases from opposite sides of the chamber. By this action the larger droplets are separated and removed down the drain trap. The nebuliser and burner assembly are set at an angle to facilitate this drainage. The nebuliser efficiency is c 15% with the sample solution being aspirated at a rate of c 5ml/minute.

Two types of burner head were used in this project, each having a single slot. The slot in the head used with the air/acetylene flame was 10 cm long and 0.5 mm wide and that which was used with the nitrous-oxide/acetylene flame was 5 cm long and 0.5 mm wide. The air/acetylene flame reaches a temperature of 2300' K and the nitrous-oxide/acetylene flame 3220' K. The hotter flame was used for elements which tend to produce refractory oxides in a cooler flame. The optimum oxidant to

gas ratios in the flame vary from element to element but for the elements determined in this work the air/acetylene flame was always oxidising and the nitrous-oxide/acetylene flame reducing. The exact flame conditions are given below (Chapter 5.3.6). The gases were controlled by a gas control unit beside the spectrophotometer which was fitted with an electronic ignition device. The monochromatic radiation from the lamp passes through the flame and the resultant absorption is then measured.

In a double-beam instrument a light-chopper modulates and divides the light before it reaches the flame. Half of the light passes through the flame (see diagram, Figure 27). The other half, the reference beam, bypasses the flame and is recombined with the sample beam by means of a semi-silvered mirror. The recombined beam then passes to the monochromator and detector where the two halves of the beam are compared. The beam is focussed on the entrance slit of the monochromator. Inside the monochromator there are 2 diffraction gratings, back to back which cover the wavelength range 188-900 nm. The 'Ultra-violet' grating covers the range 188-420 nm and the 'Visible' grating covers the wavelengths above 420 nm. If wavelengths over 600 nm are used an order-separating filter is placed in the light path. Selection of the wavelength for each element is achieved by rotation of the grating by adjustment of a dial on the front of the spectrophotometer. The wavelength is displayed on a digital counter. A system of concave mirrors ensures that the light is collimated and that after dispersion it is focussed on the exit slit which has a spectral width of only a few nanometres. The radiation then passes to a photomultiplier and amplifier where the radiation falling on the photosensitive cathode releases electrons which

are then accelerated. The amplified signal is thus dependent on the light intensity at the cathode. The signal is then given in terms of absorbance and transmitted to a chart recorder for graphical output.

The advantage of a double-beam system is that by comparing the sample and reference beams it avoids problems caused by the fluctuation in the radiation output from the lamp.

(3) Choice of elements.

According to Price (1979:ii) 69 elements can be determined by atomic absorption. In practice this is restricted by the range of lamps available in any one laboratory, and since lamps are expensive and have a limited shelf-life the range of lamps available is likely to be geared to the elements which are going to be measured most often.

In optical emission analysis of pottery 9 elements are usually measured (see Chapter 5.2.4 above for reasons). With atomic absorption it was possible to measure the same 9 elements and also to include potassium. Potassium was included because it was felt that the geology of Thessaly indicated that some areas have a higher mica and therefore potassium content than others and that this might be reflected in the composition of pottery from different areas. Within the original 9 there were some difficulties in the accurate measurement of nickel and chromium. They are only present in trace quantities in pottery and this meant working very close to the limits of detection, where the sample signal was not much larger than the background noise.

It was also decided to attempt to measure the zinc, lead, cobalt and copper content of the samples to see if they were present in measurable quantities and if so, whether the amount of the element present



varied enough from sample to sample to make measurement on a routine basis worthwhile. Unfortunately these 4 elements are only present in trace amounts which appeared to be very consistent in samples from the different areas being studied. Bower, Bromund and Smith (1975) measured 15 elements by atomic absorption of which 8 proved to be of use. Seven of these 8 were also used in this project. The eighth, zinc, was tested and rejected. The elements measured by atomic absorption were therefore Al, Ca, Mg, Fe, Ti, Na, Mn, Cr, Ni, and K.

(4) Sample Preparation.

Before a sample can be analysed by atomic absorption its silicate structure has to be broken down by being dissolved in acid. The sample must then stay in solution. With silicates and with pottery in particular this can be a problem and various methods of sample preparation which will achieve this have been developed. Broadly speaking they divide into two categories: those in which the silicon is lost and those in which it is retained. Loss of the silicon can be useful since then the number of inter-element interferences which have to be considered are reduced. Silicon is not used as a discriminant in composition and provenance work on pottery and the silicon content can in fact be estimated once the content of the other major and minor constituents has been determined. All the methods which eliminate the silicon have the disadvantage for the analyst that they involve the use of concentrated hydrofluoric and perchloric acids which can be extremely unpleasant to use. The methods which retain the silicon are generally more successful at dissolving all the clay minerals in the sample (Hughes et al. 1976: 29).

When this project was started the method of sample preparation which was selected was that recommended by Price and Whiteside (1977: 664) and Price (1979: 321-2). Price has particularly recommended this technique for application to the small samples which are all that are generally available in archaeological work. In this method 10-30 mg of finely powdered sample was placed in a p.t.f.e. vessel. To this were added, in the following order (to prevent the sample spitting when the hydrofluoric acid was added):

1.5 ml deionized water

0.5 ml concentrated nitric acid (Aristar grade)

1.0 ml 42% hydrofluoric acid (Aristar grade)

The vessel was covered with a p.t.f.e. lid and sealed in a stainless steel pressure bomb. The bomb was placed in an oven and heated to 150°C for 45 minutes. It was then removed from the oven and cooled. Three millilitres of saturated boric acid solution was added to the sample and then the bomb was resealed and returned to the oven to be heated for another 15 minutes. The bomb was then removed from the oven and cooled. Two and a half millilitres (10% of the final volume) of 2% CsCl solution was placed in a 25 ml volumetric flask. The sample solution was added and diluted to volume with deionised water. All standard solutions also contained 0.2% CsCl.

Unfortunately extensive trials with this technique showed that the results obtained were very inaccurate and completely unreproducible and an alternative technique of sample preparation had to be found. Analysis of USGS standards WI, AGVI and BCRI using this method produced the following results. The second row of figures for each standard is the quoted certificate value.

|      | Al.  | Mg.  | Fe.  | Mn.  | Ca. |
|------|------|------|------|------|-----|
| WI   | 12.8 | 1.1  | 18.5 | 0.15 | 7.7 |
| WI   | 8.0  | 4.0  | 7.8  | 0.19 | 7.8 |
| AGVI | 4.8  | 0.57 | 11.9 | 0.09 | 3.1 |
| AGVI | 9.1  | 0.92 | 4.7  | 0.08 | 3.5 |
| BCRI | 3.2  | 0.73 | -    | 0.17 | 2.5 |
| BCRI | 7.2  | 2.1  | -    | 0.14 | 4.9 |

It was then decided to follow the sample preparation method advocated by Dr. M. J. Hughes at the British Museum Research Laboratory. This method involves the fusion of the powdered sample using lithium metaborate as a flux and the dissolution of the resultant glass in dilute nitric acid. This method, like that first tried, retains the silicon in the sample and is relatively simple and rapid to use. In this method the sample all goes into solution without any problems. Since the lithium metaborate fuses at  $842^{\circ}\text{C}$  the process can be carried out in the flame of an ordinary bunsen burner which reaches  $900^{\circ}\text{C}$ , and it involves the use of only nitric acid rather than hydrofluoric or perchloric acid. Tests showed that the results obtained after sample preparation by this method had an acceptable precision and accuracy. They are discussed below (Chapter 5.3.9).

The method used was as follows:-

- (i) A powdered sample was obtained in the same way as that detailed above for OES.
- (ii) Approximately 15 mg of the powdered sample was weighed into a 15 ml



platinum crucible and the sample weight was noted.

- (iii) 100 mg of Specpure lithium metaborate (Spectroflux 100A by Johnson Matthey) was added to the sample and the two powders were thoroughly mixed together with a spatula.
- (iv) The crucible was placed on a pipe-clay triangle in the hottest part of a bunsen burner flame for c 5 minutes until the sample and the lithium metaborate had fused to form a clear glass in the bottom of the crucible.
- (v) The crucible was removed from the heat and allowed to cool.
- (vi) c 10 ml of Aristar grade 3% nitric acid was poured into the crucible. A p.t.f.e. coated magnetic stirrer bead was placed in the crucible which was then placed on a magnetic stirrer. The sample was gently stirred for c 15 minutes until the glass had completely dissolved.
- (vii) The sample solution was then transferred to a 25 ml volumetric flask and made up to volume with 3% nitric acid.
- (viii) The samples were stored in screw-topped polythene bottles and analysed within three days of preparation.

Samples were prepared in batches of c 20 and with each batch were included a 'blank' which was prepared in the same way as the samples but which contained only lithium metaborate and nitric acid, and a USGS or British Chemical Standard to provide a check on the accuracy of the method. The standard was treated in the same way as the samples.

Twenty-five millilitres of sample solution is adequate for more than 11 analyses and while ensuring that the minor elements are present in large enough quantities to be measured it also allows for an aliquot

of the solution to be diluted for the determinations of the major elements. Perkin-Elmer recommend c 2 ml of solution per element determination.

(5) Standardisation

Each time that analysis is carried out by atomic absorption a calibration graph has to be prepared for each element being measured. This is done with the use of aqueous standards which are run on the spectrophotometer at the same time as the sample solutions.

The standards, three per element is usually adequate, must be of concentrations which will bracket the concentrations of the samples. Initially this must be done by running a few of the samples and standards and comparing the resultant peak heights on the chart output but once this has been done the range of standard concentrations needed for pottery of the same broad type will be known.

A calibration graph can be divided into three sections (see diagram, Figure 28). From the origin to '1' corresponding to concentration  $C_1$  the graph is linear with absorbance (signal) proportional to concentration. '1' is thus the limit of linearity. From '1' to '2' is the area where the graph becomes decreasingly linear but up to concentration  $C_2$  the graph is still usable. This is the limit of the working range. Beyond this point the graph curves to reach a plateau and is unusable since there is very little signal increment for change in concentration. Ideally only the linear part of the graph should be used but it is sometimes necessary to use a graph up to the limit of the working range. If the samples are likely to be more concentrated than  $C_2$  one of two steps must be taken. Either the burner head should be rotated so that

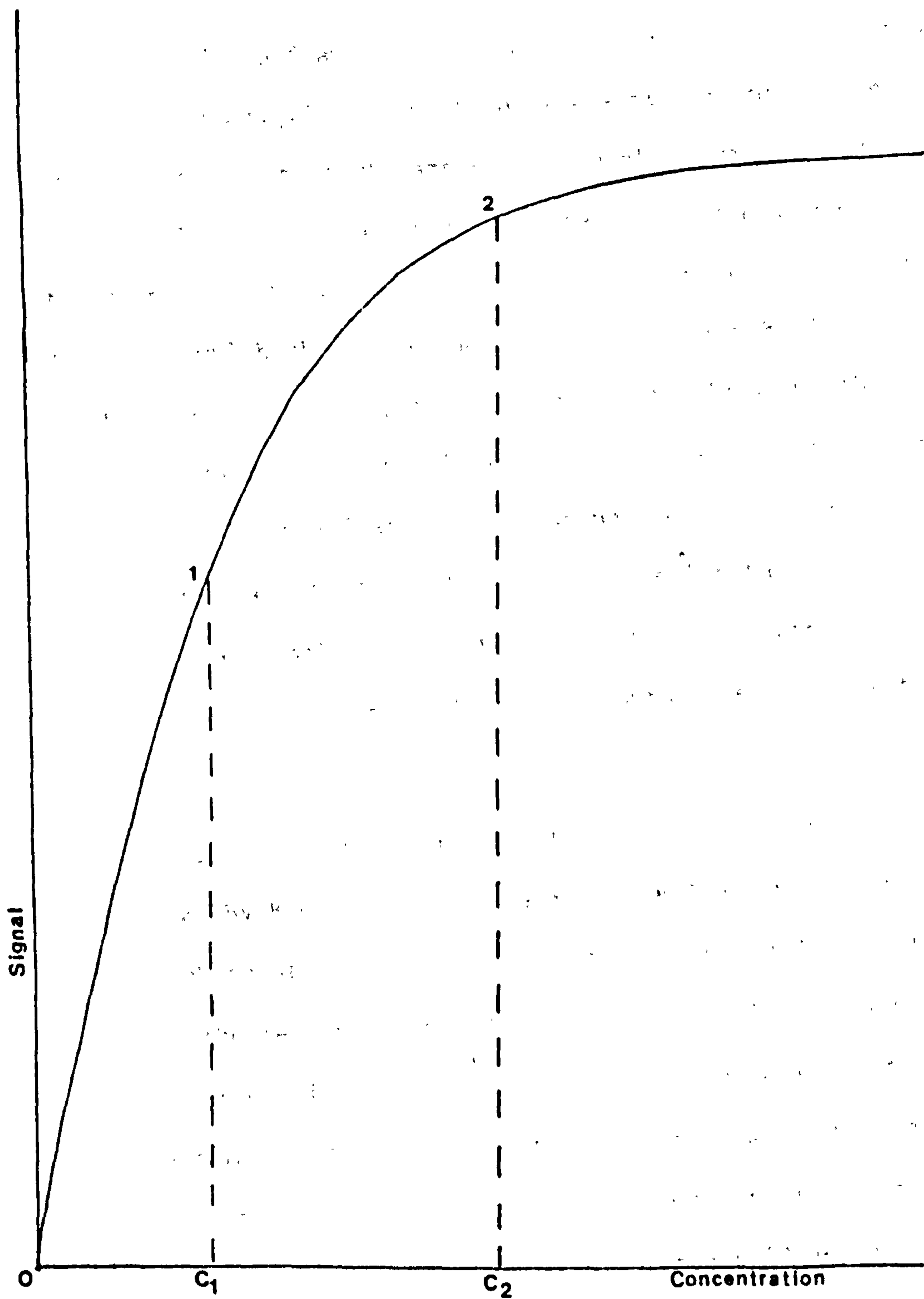


Fig 28 General shape of curve of peak signal over concentration



the path length through the flame is reduced or the sample concentration should be reduced by taking aliquot parts of the sample solutions and diluting them. Two millilitres of sample in a total volume of 10 ml, for example, is a dilution of ten times. Theoretically the burner head could be rotated any amount but in practice this is limited to  $30^{\circ}$ ,  $60^{\circ}$  or  $90^{\circ}$  by slots into which the burner head fits. Rotation by  $30^{\circ}$  should reduce the flame length to 8.6 cm, rotation by  $60^{\circ}$  should halve the flame length and rotation by  $90^{\circ}$  should reduce it to zero. However this would only be the case if the flame itself had no width. In reality therefore at a rotation of  $90^{\circ}$  from the original the length of the flame path is equal to its original width above the slot in the burner head. This also has to be taken into account when the burner head is rotated by  $30^{\circ}$  or  $60^{\circ}$ .

Standards are prepared from stock solutions of the element in nitric acid prepared by BDH Chemicals Ltd. specifically for atomic absorption. The stock solutions are generally at 1000 ppm and must therefore be diluted to the required concentrations. When the lithium metaborate fusion method of sample preparation has been used all the standards must contain the same proportions of lithium metaborate and nitric acid as the samples. A solution was therefore prepared containing 2% wt/vol of lithium metaborate and 3% vol/vol nitric acid and each standard solution contained 5 ml per 50 ml volume of this solution. The same batch of lithium metaborate and nitric acid was used for the samples and standards being used at any one time. A table is given for the dilution of the stock standard solutions to the required concentrations (Figure 29). Standards were made up in volumes of 50 ml in order to avoid using the smallest of the micropipettes wherever possible

| Final volume of standard ml | <u>Required concentration of working standard ppm.</u> |     |     |     |     |     |     |      |      |      |      |
|-----------------------------|--------------------------------------------------------|-----|-----|-----|-----|-----|-----|------|------|------|------|
| 50                          | 0.1                                                    | 0.2 | 0.5 | 1.0 | 2.0 | 3.0 | 5.0 | 10.0 | 20.  | 50.  | 100. |
|                             | <u>Quantities of stock solution required, l</u>        |     |     |     |     |     |     |      |      |      |      |
| 50                          | 5                                                      | 10  | 25  | 50  | 100 | 150 | 250 | 500  | 1000 | 2500 | 5000 |

Figure 29. Dilutions for the preparation of working standards from 1000 ppm Stock Solutions.

since it was considered less accurate than the larger ones. Standards were made up weekly since it was discovered that they became unreliable if stored much longer, Al and Na being especially bad in this respect. The very dilute standards, those under 1 ppm, for determinations of the trace elements were made up afresh for each batch of determinations. The standards were stored in screw-topped polythene bottles.

It is when making up the standard solutions that precautions must be taken to counteract any likely interference effects which might make the determinations inaccurate. When the fusion method of sample preparation is used there are not many interference effects which must be considered. If the nitrous-oxide/acetylene flame is used for determinations of magnesium and calcium they should be free from interference. Silicon and aluminium interfere with each other. Each silicon standard therefore contained 20 ppm Al so that the effects would be the same in standards and samples and so that the results would therefore be correct. All of the aluminium standards needed to contain approximately the same amount of silicon as the samples. A range of aluminium standards was therefore mixed with 50, 100 and 150 ppm aluminium standards containing 150 ppm silicon. Standards containing 100 ppm aluminium and also containing 100 and 200 ppm silicon were also prepared so that a correct curve could be extrapolated from these standards if the samples proved to contain much more or less than 150 ppm silicon (c 45%).

(6) Analytical Procedure.

Once the samples had been put into solution the analytical procedure followed was that recommended by the manufacturers of the spectrophotometer (Perkin-Elmer) and are given in Appendix 3. Included below (Figure 30) is a table of the analytical conditions which experience showed produced the best results.



| Element | Flow rates |       |      |                       |     |            |              | Standard Range |
|---------|------------|-------|------|-----------------------|-----|------------|--------------|----------------|
|         | Wavelength | Range | Slit | Oxidant               | Gas | Flame type | Lamp current |                |
| Si      | 252 nm     | UV    | 3    | (N <sub>2</sub> O) 32 | 60  | R          | 15 milliamps | 100-200 ppm    |
| Al      | 309 nm     | UV    | 4    | (N <sub>2</sub> O) 33 | 57  | R          | 10           | 50-150 ppm     |
| Ca      | 211 nm     | VIS   | 4    | (N <sub>2</sub> O) 30 | 52  | R          | 10           | 5-20 ppm       |
| Mg      | 285 nm     | UV    | 4    | (N <sub>2</sub> O) 35 | 53  | R          | 10           | 1-10 ppm       |
| Fe      | 248 nm     | UV    | 3    | (AIR) 55              | 35  | 0          | 30           | 5-15 ppm       |
| Ti      | 365 nm     | UV    | 3    | (N <sub>2</sub> O) 33 | 57  | R          | 40           | 5-50 ppm       |
| Na      | 295 nm     | VIS   | 4    | (AIR) 55              | 35  | 0          | 500          | 0.5-3 ppm      |
| Mn      | 279 nm     | UV    | 3    | (AIR) 55              | 35  | 0          | 30           | 0.4-3 ppm      |
| Cr      | 358 nm     | UV    | 4    | (AIR) 50              | 35  | 0          | 30           | 1-5 ppm        |
| Ni      | 232 nm     | UV    | 3    | (AIR) 55              | 35  | 0          | 30           | 1-3 ppm        |
| K       | 383 (f) nm | VIS   | 4    | (AIR) 55              | 35  | 0          | 500          | 1-15 ppm       |

The gas used in each case was acetylene.

0 = Oxidising

R = Reducing

f = Order separating filter

The lamps used for Na and K were arc discharge lamps. The lamps used for all other elements were hollow cathode lamps.

For all elements except calcium the light path was 1.5 cm above the burner head. For calcium the distance was 2.5 cm.

Slit widths Setting: 1 - 0.03; 2 - 0.10; 3 - 0.30; 4 - 1.00; 5 - 3.00.

Figure 30. Analytical Conditions for atomic absorption spectroscopy.

(7) Interference Effects

Spectral interference is less of a problem in atomic absorption than in atomic emission analysis. This is largely due to the fact that the absorption measured in atomic absorption is generally that of the resonance line (see above, Chapter 5.3.1). These resonance lines are about 0.001 nm wide and their narrowness reduces the danger of interference from neighbouring spectral lines. Depending on how long an electron occupies an energy level and on the energy of the level there will be a small amount of natural broadening of the energy level. In atomic absorption this broadening is in fact negligible. What must be taken into consideration are two other types of line broadening. The first of these is Doppler broadening. It occurs when there is relative movement between the atom and the detector. Movement towards the detector reduces the wavelength and vice versa. The spread of wavelengths in atomic absorption is significant since the atoms have very high velocities at the high temperature of the flame. At 2500 K for example, the Doppler width is c  $8 \times 10^{-4}$  nm. The second kind of broadening which should be considered is Pressure broadening, also known as Lorentz broadening. This is the result of the interaction of atoms colliding with each other. At low pressures this broadens the line. At high pressures the line shifts towards the ultra-violet in light gases and towards the infra-red in heavy gases. The shift is about a factor of three less than the magnitude of the broadening. The broadening is about  $1.4 \times 10^{-3}$  nm at 250 nm at atmospheric pressure. Other possible sources of spectral interference are impurities in multi-element lamps, or multi-element lamps the elements of which have adjacent spectral lines. This problem is generally overcome by careful selection of the



combination of elements used in a multi-element lamp by the manufacturers. Spectral interference is generally negligible in atomic absorption.

The second class of interference which must be considered is chemical. Chemical interferences most frequently result in the occurrence of less than the maximum possible absorption. Chemical interferences can be a problem in atomic absorption, especially in silicate analysis and a variety of steps can be taken to minimise or overcome them. Tests showed that when the lithium metaborate fusion method of sample preparation was used no problems were encountered in the determination of iron, manganese, chromium, nickel, sodium or potassium. The presence of lithium in the samples prevented depression of aluminium by calcium. It was found that the problems which occur in determinations of calcium and magnesium due to their tendency to form refractory compounds in the flame could be overcome by switching from the air/acetylene to the hotter nitrous-oxide/acetylene flame. The hotter flame also prevents sodium and potassium enhancing the absorption of calcium. Silicon and aluminium interfere with each other even in the nitrous-oxide/acetylene flame and the composition of the standard solutions must be adjusted so that the effects are the same in both standard and sample solutions (see above, Chapter 5.3.5 for details).

Matrix effects may occur if the acidity of the standard and sample solutions is not the same since this would affect the viscosity and the surface tension of the solutions. Viscosity affects the rate of uptake of the solution and the surface tension affects the size distribution of the droplets which in turn affects the efficiency of the nebulisation.

As mentioned above (Chapter 5.3.4) a 'blank' was included in each batch of samples. This provided a means of checking that neither the



lithium metaborate nor the nitric acid contained any of the elements which were being measured and hence that the point 0.0 on the calibration graphs was a true point. It also ensured that the occurrence of any background scatter would be noticed and the origin of the graph adjusted accordingly. In this project the blanks always proved to be free of any of the elements which were being measured.

The final class of interference effects is that caused by ionization in the flame. They are largely overcome in atomic absorption by the use of an ionization buffer. The interference is caused by ionized atoms returning to their ground state. An ionization buffer provides an excess of electrons and stabilises the ionization curve at a higher temperature than the flame thus minimising the effects of other factors on the degree of ionization. Lanthanum is commonly used as a buffer but lithium has a very similar ionization potential (Price, 1979:136) and while it plays an integral part in the sample preparation can also act as an ionization buffer. Ionization occurs most readily in the nitrous-oxide/acetylene flame which should therefore be avoided for elements which ionise easily like sodium, potassium and iron.

The inclusion of USGS standard WI in each batch of analysis, while providing a check on the overall precision of the technique also allowed interference effects to be recognised and dealt with at an early stage of analysis and thus avoided in subsequent analysis.

(8) Calibration.

Quantitative results were obtained from the output on the chart recorder (see Figure 31). This was the method used in this project. Calibration graphs were drawn each time analysis for a particular element was carried out. The peak heights for all the standard solutions

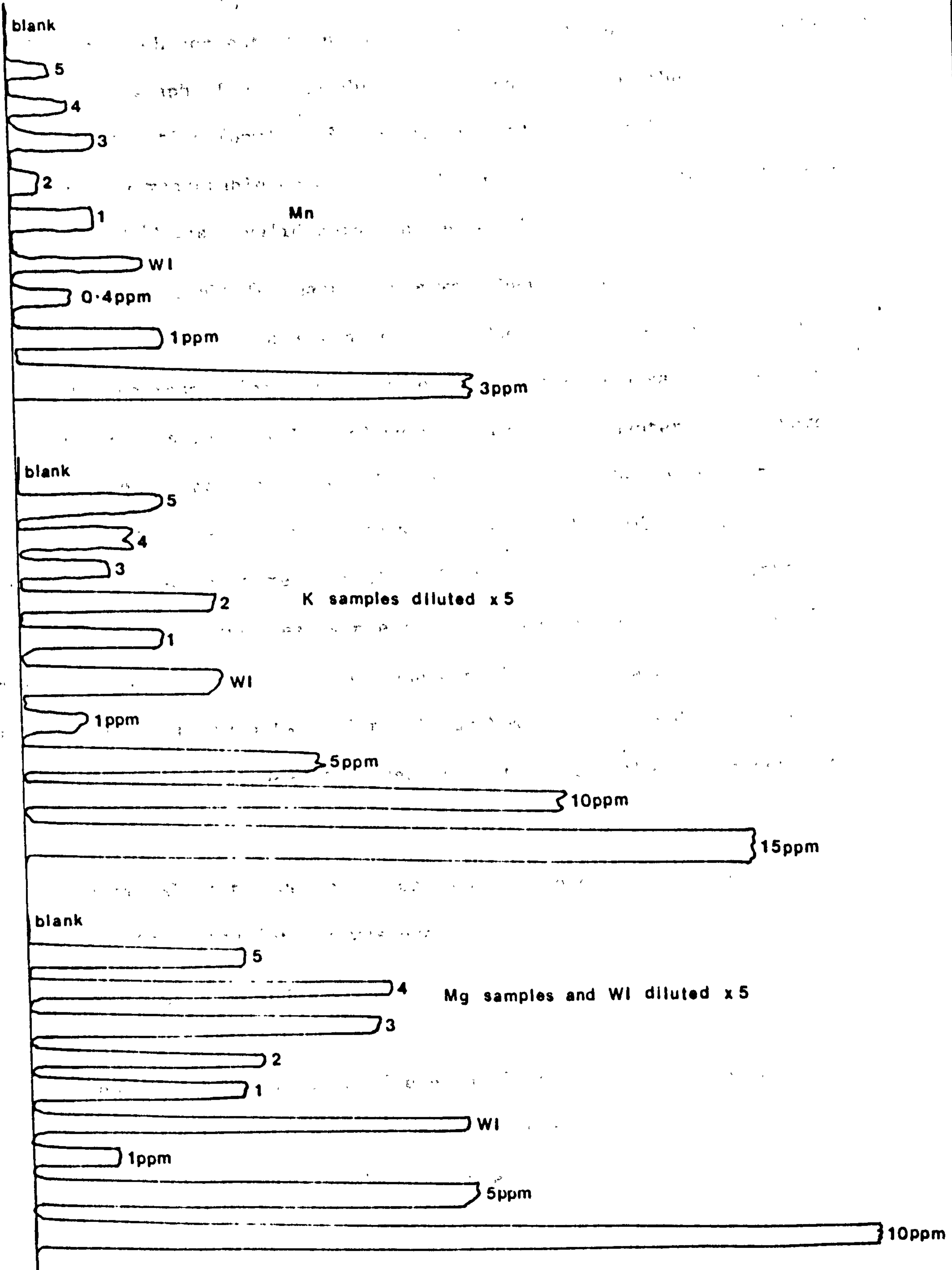


Fig 31 Print-out from chart recorder

(run before, in the middle of and after the sample solutions) were measured to the nearest half millimetre and the average height for the standard of each concentration was calculated. These heights were then plotted on a graph of peak height over concentration of the element in the sample solution (ppm). See examples for Mg, K and Mn (Figure 32). The lack of a measurable peak for the 'blank' solution in each case confirmed that 0/0 was a valid point on the graph.

The peak height for each sample was then measured as accurately as possible, allowing for signal noise. The graphs were then used to obtain the corresponding concentration in ppm for each sample solution. For the sample solutions diluted by a factor of 5 (Chapter 5.3.5 above) a correction was made at this point by multiplying the concentration by 5. The sample solutions which were used for determinations of Si, Mg, Ca, Fe, K and Na were generally diluted. Dilution was preferred to rotation of the burner head since it was necessary for half of the elements that were measured and because experience indicated that this gave more satisfactory results. For calcium however, although a dilute solution was used, it was still necessary to rotate the burner head by 30°.

To calculate the weight percentage of the element in the solid sample the following formula was used:

$$\text{Wt \%} = \frac{CV}{10W}$$

Where C = concentration of element in the solution in ppm

V = volume of sample solution in ml

W = weight of powdered sample in mg.



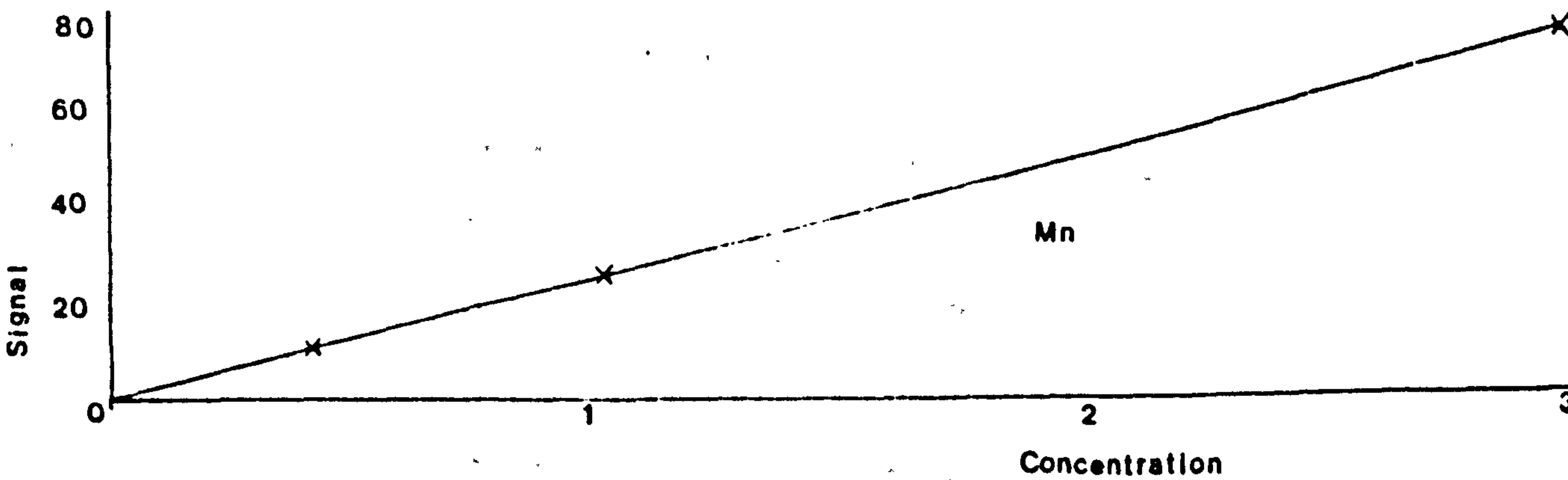
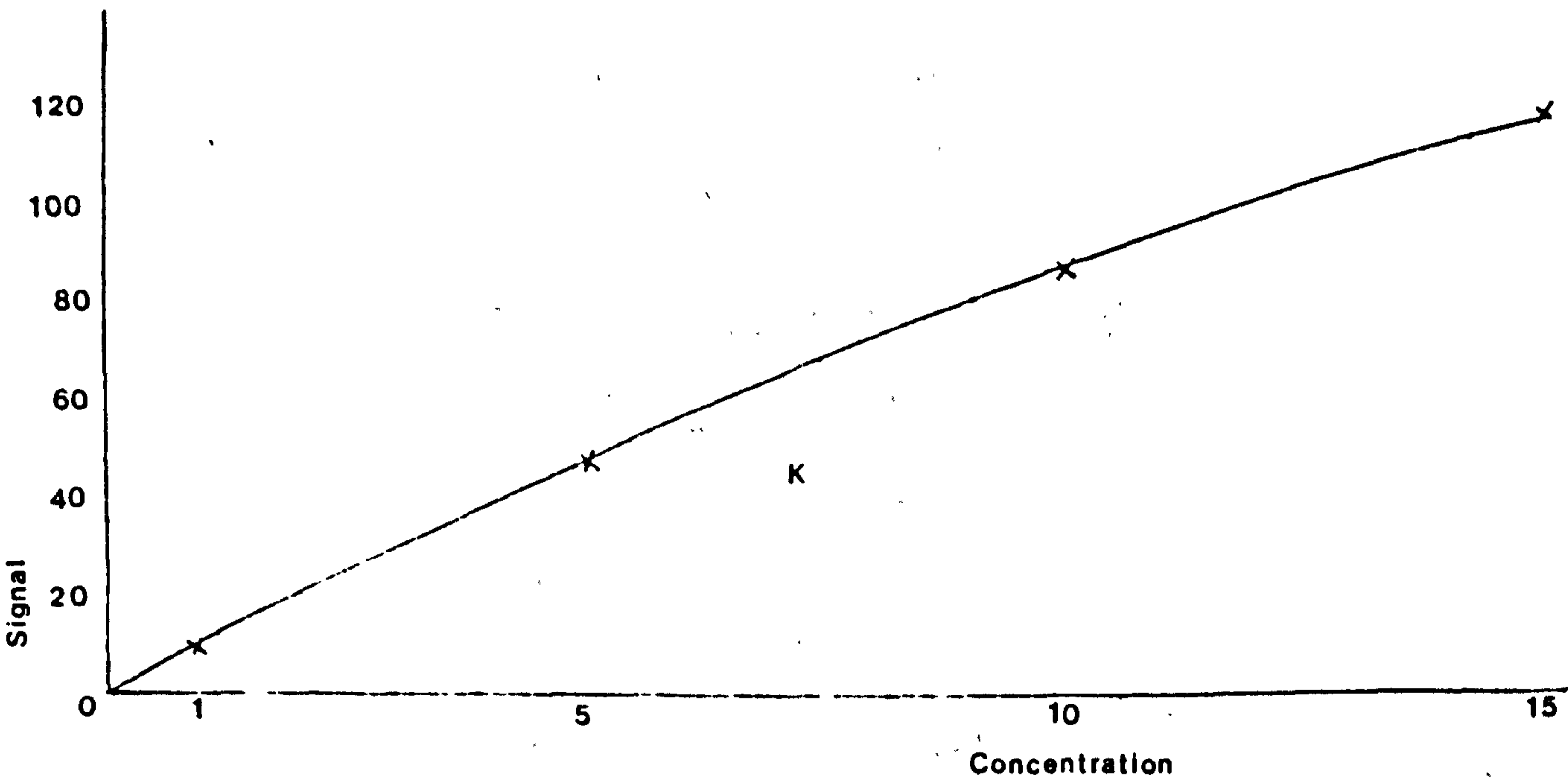
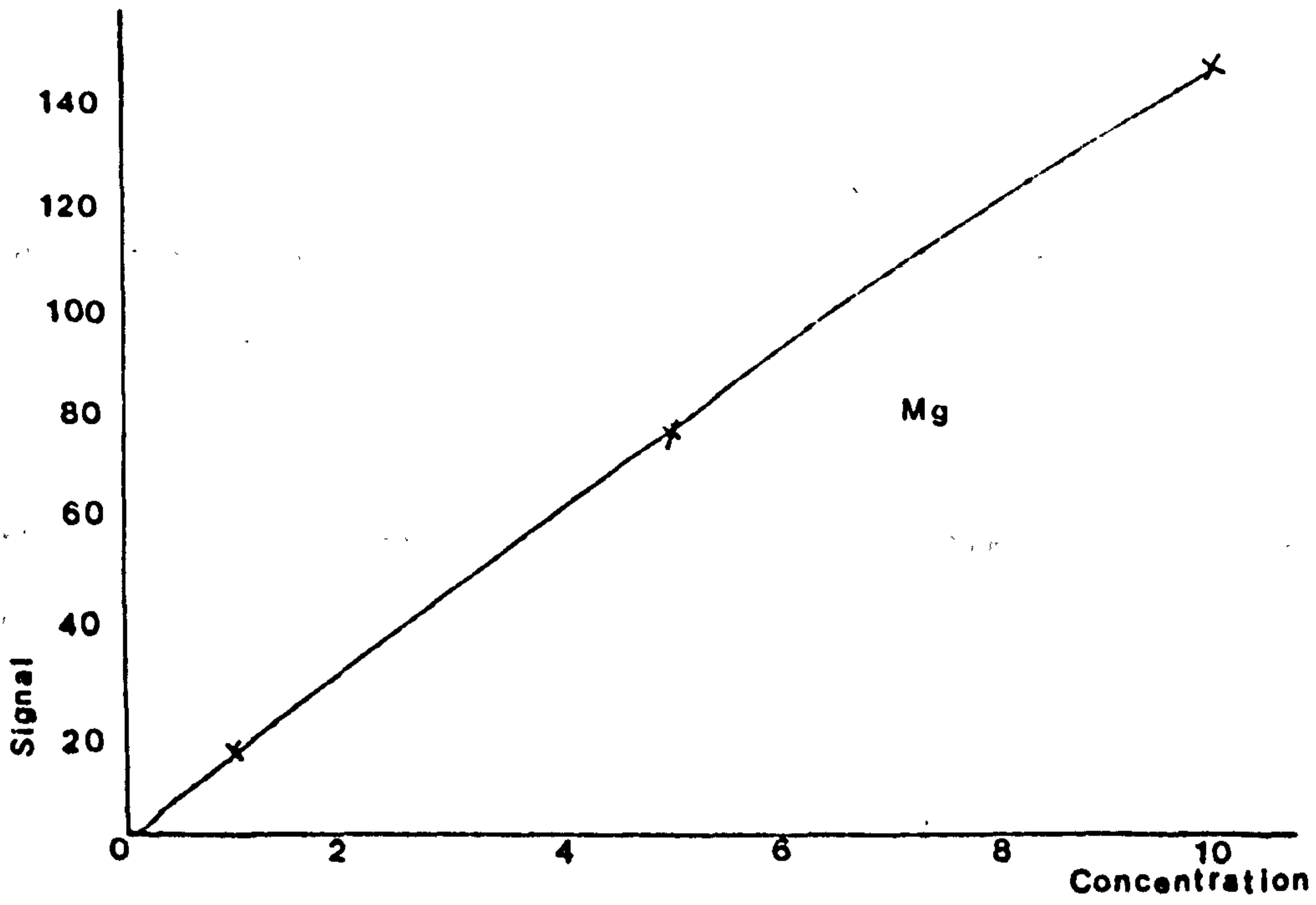


Fig 32 Calibration graphs for Mg, K, Mn

The examples given below show the stages in the calculation of the concentrations for 5 Euboean samples and USGS standard W1 for Mg, K and Mn. They relate to the graphs shown above (Figure 32).

Mg.

| <u>Sample</u> | <u>ppm (corrected)</u> | <u>% of element in sample</u> |
|---------------|------------------------|-------------------------------|
| WI            | 25.0                   | 3.83                          |
| 1             | 11.5                   | 2.00                          |
| 2             | 13.0                   | 2.21                          |
| 3             | 20.0                   | 3.38                          |
| 4             | 21.0                   | 3.48                          |
| 5             | 12.0                   | 2.10                          |

K.

| <u>Sample</u> | <u>ppm (corrected)</u> | <u>% of element in sample</u> |
|---------------|------------------------|-------------------------------|
| WI            | 3.6 (not diluted)      | 0.55                          |
| 1             | 13.0                   | 2.26                          |
| 2             | 17.0                   | 2.89                          |
| 3             | 8.5                    | 1.44                          |
| 4             | 9.5                    | 1.57                          |
| 5             | 13.0                   | 2.27                          |

Mn.

| <u>Sample</u> | <u>ppm</u> | <u>% of element in sample</u> |
|---------------|------------|-------------------------------|
| W1            | 0.92       | 0.140                         |
| 1             | 0.60       | 0.104                         |
| 2             | 0.18       | 0.031                         |
| 3             | 0.60       | 0.101                         |
| 4             | 0.60       | 0.099                         |
| 5             | 0.30       | 0.052                         |

The elemental concentrations were then converted to oxides by multiplication by the factors given below. For the samples quoted above the results were therefore as given below.

Conversion factors from elemental concentrations to oxides

|                                |             |      |
|--------------------------------|-------------|------|
| Al <sub>2</sub> O <sub>3</sub> | Multiply by | 1.89 |
| SiO <sub>2</sub>               | "           | 2.14 |
| MgO                            | "           | 1.66 |
| CaO                            | "           | 1.40 |
| Fe <sub>2</sub> O <sub>3</sub> | "           | 1.43 |
| K <sub>2</sub> O               | "           | 1.20 |
| MnO                            | "           | 1.29 |
| Na <sub>2</sub> O              | "           | 1.35 |
| TiO <sub>2</sub>               | "           | 1.67 |
| NiO                            | "           | 1.27 |
| Cr <sub>2</sub> O <sub>3</sub> | "           | 1.46 |

| <u>MgO</u> | <u>%</u> | <u>K<sub>2</sub>O</u> | <u>MnO</u> |
|------------|----------|-----------------------|------------|
| W1         | 6.36     | 0.66                  | 0.18       |
| 1          | 3.32     | 2.71                  | 0.134      |
| 2          | 3.67     | 3.47                  | 0.040      |
| 3          | 5.61     | 1.73                  | 0.130      |
| 4          | 5.78     | 1.88                  | 0.128      |
| 5          | 3.49     | 2.72                  | 0.067      |

For the results of the samples analysed in this project see Appendix 4.



(9) Reliability of the Technique.

(i) Precision.

All the atomic absorption analyses were carried out within a period of 5 months. The precision of the technique was tested for 9 of the elements measured by the analysis of ten samples of the USGS standard WI which were prepared and analysed in the same way as the archaeological samples. The results of these analyses are given below (Figure 33), together with the percentage variation for each element and the overall average percentage variation calculated as described above (Chapter 5.2.10). The overall average percentage variation was 5.5% although without titanium and sodium with 12.5 and 10.2% variation respectively this could be reduced to 3.8%.

It is not easy to compare these figures with those obtained in other laboratories due to the inadequacy of published information. Van Loon and Parissis (1969:1062) analysed each of twelve standards once and quoted the amount by which they deviated from the certificate values. Bower, Bromund and Smith (1975) merely stated (p.392) that "a few sherds were analysed in replicate" and they presented their data. Hughes et al. (1976:34) obtained under 5% variation for all elements except aluminium (5.3%) in ten replicate analyses of standard glasses. Price (1979:164) said that a coefficient of variation of  $\pm 1\%$  should be possible but gave no data to illustrate this, nor did they say on what kind of material it could be obtained. Silicates generally have a higher percentage variation than metals. Tubb et al. (1980) presented the mean and percentage standard deviation for 8 analyses of BCS standard 269 for 10 elements, 8 of which were also measured in this project. Unfortunately they omitted to say how they calculated their percentage standard deviation. The paper

| Sample No.  | Si.  | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | K.   | % oxide       |
|-------------|------|------|------|-----|------|------|------|-------|------|---------------|
| 1           | 53.1 | 13.9 | 9.0  | 5.9 | 10.4 | 1.39 | 1.61 | 0.18  | 0.60 |               |
| 2           | 55.2 | 13.8 | 10.7 | 6.8 | 11.7 | 1.19 | 2.07 | 0.19  | 0.61 |               |
| 3           | 51.4 | 13.6 | 10.1 | 6.7 | 11.5 | 1.34 | 2.05 | 0.18  | 0.61 |               |
| 4           | 50.7 | 14.2 | 10.2 | 6.8 | 12.1 | 1.39 | 2.19 | 0.19  | 0.62 |               |
| 5           | 50.1 | 13.6 | 9.7  | 6.9 | 11.8 | 1.44 | 2.25 | 0.19  | 0.64 |               |
| 6           | 54.8 | 13.1 | 9.9  | 6.7 | 11.6 | 1.44 | 2.27 | 0.18  | 0.60 |               |
| 7           | 49.6 | 13.6 | 10.0 | 6.4 | 11.0 | 1.37 | 1.88 | 0.18  | 0.59 |               |
| 8           | 49.9 | 13.8 | 10.9 | 6.8 | 11.5 | 1.04 | 2.04 | 0.19  | 0.61 |               |
| 9           | 50.7 | 13.9 | 11.0 | 6.8 | 11.7 | 1.09 | 2.25 | 0.19  | 0.62 |               |
| 10          | 65.3 | 13.7 | 11.3 | 6.7 | 11.5 | 1.09 | 1.96 | 0.19  | 0.62 |               |
| $\bar{x}$   | 52.2 | 13.7 | 10.3 | 6.6 | 11.5 | 1.28 | 2.06 | 0.19  | 0.61 |               |
| $\sigma$    | 2.5  | 0.3  | 0.7  | 0.3 | 0.5  | 0.16 | 0.21 | 0.005 | 0.01 |               |
| % variation | 4.8  | 2.2  | 6.8  | 4.5 | 4.3  | 12.5 | 10.2 | 2.6   | 1.6  | $\bar{x}$ 5.5 |
| Cert. value | 52.6 | 15.0 | 11.0 | 6.5 | 11.1 | 1.07 | 2.15 | 0.17  | 0.64 |               |

Average Percentage variation over 7 elements (without Si + K) = 6.16%

Average Percentage variation over 8 elements (without Si) = 5.59%

Figure 33. Reproducibility test on USGS standard WI.

by Hatcher et al. (1980) includes the mean and standard deviation of 30 replicate analyses of a 'standard' Knossian sherd over 10 batches of samples. However, since they removed any sample which was "more than three times the standard deviation from the mean" and then recalculated the mean and standard deviation and since they did not present all their raw data the percentage variation for four out of the 9 elements measured (Mg, Fe, Ca, Na) the values they quote are somewhat misleading. It was also unfortunate that they chose to use this sherd as a standard. As a certificate value they quote the result of what appears to have been only one analysis using X-ray fluorescence analysis by the British Ceramic Research Association. One analysis can hardly be considered conclusive. Also, as reference to Figure 34 shows, a considerable range of values has been obtained for this sherd and it would have been better if they had used a USGS or BCS standard. However, the average percentage variation for 7 elements (Al, Ca, Mg, Fe, Ti, Na and Mn) in Oxford is 6.3% (Figure 36a) and the result for the same elements measured on standard W1 in this project was also 6.2%.

As mentioned above (Chapter 5.3.4) a sample of USGS standard W1 and a 'blank' were included with each batch of samples analysed. This enabled a check to be kept on the long-term precision of the technique. The results for 6 such analyses of W1 are given below (Figure 35). When the standard deviations for the results are compared with those for the 10 analyses in one batch (Figure 33) it can be seen that the standard deviations for Mg, Fe, Ti and Na are better or unaltered, for Ca it is a little larger and for Al, Mn and K it is much larger for the analyses done over the five-month period.



|                          | Al.  | Ca.  | Mg.  | Fe.  | Ti.  | Na.  | Mn.   | K.   |
|--------------------------|------|------|------|------|------|------|-------|------|
| AAS Bradford<br>(x of 2) | 13.2 | 11.2 | 5.63 | 8.66 | 0.93 | 0.69 | 0.108 | 1.90 |
| AAS Oxford<br>(x of 2)   | 13.6 | 10.1 | 5.27 | 7.65 | 0.86 | 0.88 | 0.093 |      |
| OES Athens               | 16.4 | 11.1 | 5.40 | 7.80 | 0.83 | 1.05 | 0.075 |      |
| OES Oxford               | 18.0 | 15.0 | 5.40 | 10.0 | 0.95 | 1.30 | 0.086 |      |
| XRF.BCRA.                | 14.2 | 11.2 | 5.57 | 7.65 | 0.73 | 0.86 | 0.10  | 2.56 |

Figure 34. Analysis of 'standard' Knossian sherd. (BCRA - British Ceramin Research Association).

| Sample No.  | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.  | K.   |
|-------------|------|------|-----|------|------|------|------|------|
| 1           | 14.2 | 10.8 | 6.2 | 11.9 | 1.25 | 1.56 | 0.19 | 0.54 |
| 2           | 14.5 | 10.6 | 6.7 | 11.6 | 1.44 | 1.57 | 0.16 | 0.62 |
| 3           | 13.6 | 9.9  | 6.4 | 11.8 | 1.54 | 1.62 | 0.18 | 0.66 |
| 4           | 14.5 | 9.7  | 6.2 | 11.6 | 1.41 | 1.66 | 0.18 | 0.65 |
| 5           | 16.8 | 8.5  | 6.4 | 11.4 | 1.29 | 1.44 | 0.19 | 0.65 |
| 6           | 12.5 | 8.8  | 6.4 | 11.5 | 1.67 | 1.76 | 0.18 | 0.66 |
| $\bar{x}$   | 14.4 | 9.7  | 6.4 | 11.6 | 1.43 | 1.60 | 0.18 | 0.63 |
| s.d.        | 1.4  | 0.9  | 0.2 | 0.2  | 0.16 | 0.11 | 0.01 | 0.05 |
| Cert. value | 15.0 | 11.0 | 6.5 | 11.1 | 1.07 | 2.15 | 0.17 | 0.63 |

Figure 35. Typical values obtained for USGS standard WI analysed with separate batches of samples over 5 months.

(ii) Accuracy.

Using the percentage variation obtained for the replicate analyses of standard W1 shown in Figure 33, the acceptable range of concentrations around the certificate value were calculated. The mean result for 5 out of the 9 elements measured (Si, Ca, Mg, Fe and Na) fell within the acceptable range. Potassium, Manganese and Aluminium, which had the best precision, had poor accuracy. Titanium also had poor accuracy but it also had the highest percentage variation (12.5%). Since considerable care was taken to counteract any interference effects the cause of this lack of accuracy is unclear. There were always problems associated with the determinations of chromium and nickel (not present in W1), since the background noise was high and was almost the same height as the signal for the samples, even when the damping was high. The titanium and sodium signals were also generally noisy which could have affected the accuracy of the measurements to a small extent, but not by enough to cause the misallocation of a sample. Titanium was rarely used as a discriminant between pottery groups.

Two samples of sherd Mycenae 22 which is used as the location standard in optical emission were also analysed and the results are given in Figure 36b. There are marked differences between the AAS and the certificate values for the sherd. This was disquieting. Since the magnitude of the differences between the measured and certificate values was greater in each case than for standard W1 this may cast some doubts on the original analysis of Mycenae 22 which has never been detailed in publication. However, firm conclusions cannot be drawn after only two analyses of the sherd.



| Al.                                                                   | Ca. | Mg. | Fe. | Ti. | Na. | Mn. | Cr.  | Ni. |
|-----------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|------|-----|
| 9.3                                                                   | 5.1 | 5.5 | 3.0 | 6.8 | 7.3 | 6.5 | 17.3 | 8.9 |
| Average percentage variation over 9 elements - 7.74%                  |     |     |     |     |     |     |      |     |
| Average percentage variation over 7 elements (without Cr and Ni) 6.2% |     |     |     |     |     |     |      |     |

Figure 36a. Percentage variation obtained in the Oxford Laboratory from replicate analysis of a Knossian 'standard' by AAS. (Hatcher et al. 1980).

| Al.        | Ca.  | Mg. | Fe. | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|-----|-----|------|------|-------|-------|-------|
| x of 2     | 13.9 | 4.5 | 8.1 | 1.22 | 0.45 | 0.128 | 0.075 | 0.037 |
| Cert.value | 19.0 | 3.4 | 8.8 | 0.80 | 0.76 | 0.104 | 0.039 | 0.030 |

Figure 36b. Analysis of OES 'location standard' Mycenaee 22 by AAS.

Comparison of the results obtained in Oxford for the Knossian 'standard' and in Bradford on standard WI reveals that in both cases the measured titanium values were higher than the certificate values and the aluminium values were lower than the certificate values. It is possible that the titanium values were enhanced by the presence of a large amount of iron especially as WI has a high iron content. Since it is higher than in the majority of the Late Bronze Age sherds analysed it is possible that the determinations of titanium in the samples were less affected by iron than in the samples. In the paper by Popham et al. (1980) on analysis of pottery from Al Mina and Euboea the titanium values were again higher than the certificate value and the consistency of the inaccuracy may indicate that there is some interference which has not yet been identified. In commenting that their calcium and magnesium values were also higher than the certificate values the authors commented that good precision was more important than good accuracy in this kind of work but this is only true so long as comparison of their results with those from other laboratories is not going to be attempted.

CHAPTER 6.

INTERPRETATION AND TREATMENT OF THE DATA



CHAPTER 6.

INTERPRETATION AND TREATMENT OF THE DATA

6.1. General Comments.

As in the previous composition and provenance studies done in Athens and Oxford, the initial step in the interpretation of the data was based on an evaluation of the spread in the composition of each group of sherds. However, as the volume of data increased to over 7000 elemental compositions, a computer file was opened. The use of a computer not only meant that it was easier to handle the large volumes of data involved but also that the data could be examined using the multivariate methods now available in standard computer programme packages.

Both visual and multivariate interpretations of the data are founded on the assumption that the data are normally distributed. Different authors have argued that the data are normally (Catling et al., 1963), or log-normally distributed (Harbottle, 1970; Bieber et al., 1976). A normal curve is symmetrical and is defined by the mean and the standard deviation of the data with 68% of the data falling within  $\pm 1$  s.d. of the mean, 95% within  $\pm 2$  s.d. of the mean and 99.7% within  $\pm 3$  s.d. of the mean. Harbottle (1970) suggested that distributions for elements present in concentrations lower than calcium and magnesium are more log-normally than normally distributed. Pollard and Jones advocate the log-transformation of the trace elements (Mn, Cr and Ni) concentrations (Jones pers. comm. 1980). This question has also been debated extensively in the geochemical literature without any firm and universally applicable conclusions being reached. As Shaw wrote (1961: 117): "geological considerations indicate clearly that the theoretical distribution

law will differ according to the situation: i.e. no single law applies to all situations". For additional papers on this question see references in Shaw (1961) and also Durovic (1959) and Jizba (1959).

For volumes of data of the magnitude produced in this project it was decided that the best approach would be to attempt a classification of the data using the evaluation of the mean and standard deviation of each group of data and then to use a combination of hierarchical cluster analysis and multiple discriminant analysis. The computer-based methods were performed on the ICL 1900 series computer at the University of Bradford Computer Centre and on a link with the CDC 7600 computer at Manchester University.

It was hoped that it would be possible to identify a number of distinct pottery production groups within the data. A production group was a group of sherds of the composition type which was predominant at a particular site, or, failing that, in a particular area rather than any other and where its existence could also be proposed on archaeological grounds. A production group is assumed to have been made either from one clay bed or from several beds within such a small area and with such similar geochemistry that there is little difference in their composition. Where control groups from an area had already been defined by the Fitch Laboratory, like those from Thebes and from the area around Mycenae, it was hoped that these groups could be related to those identified in this project. In the absence of kilns and the analysis of associated pottery it is not possible to say with absolute certainty where pots were made, and groups established in projects such as this one are valid until proved otherwise by the analysis of kiln material.



## 6.2. Initial Classification of the Data.

The initial classification of the data was carried out site by site, or, in the cases of Pevkakia and Velestino, sub-group by sub-group following the methods adopted in all previous projects in Oxford and Athens. When dealing with groups of more than 20 samples these methods rapidly become less successful and cumbersome to use. The mean and the standard deviation for the concentrations for each element were calculated for each site group omitting any sherds which were clearly different in composition on several elements. The concentration ranges at an 80% level of confidence were calculated, corresponding to  $\pm 1.28$  s.d. from the mean (Catling et al., 1961). The ranges for the separate groups were then compared and any two groups for which the ranges for 3 or more elements did not overlap were deemed distinct. In some cases it was not possible to assign sherds to a group with any confidence. On this basis magnesium, chromium and nickel were the most use as discriminants on the Euboean and Boeotian material and magnesium, manganese and nickel on the Thessalian material. This approach was worthwhile in that it provided a rough guide to the homogeneity of the sherd groups as analysis progressed, but the groupings obtained were not regarded as conclusive. This method of data handling came under criticism from Wilson (1976 and 1978) and McArthur (1976 and 1978) and with the development of computer packages for multivariate analysis is no longer the basis for the classification of data in composition and provenance work. It is, however, also of use when comparing composition groups with those obtained some years ago when only these methods of data handling were readily available.



### 6.3. Cluster Analysis.

Hierarchical cluster analysis was performed using Release 2 of the CLUSTAN IC package developed by Wishart (1978) in which cluster analysis is defined as "an exploratory method for helping to solve classification problems". The data used for cluster analysis consisted of the oxide percentage for each element with those for manganese, chromium and nickel in log form as mentioned above in order to maintain comparability with the work done in Oxford and Athens. All the elements were equally weighted. All the data were standardised as is widely accepted in multivariate analysis (Stoodley, 1974:60; Davis, 1973: 76; Doran and Hodson, 1975:39; Everitt, 1974: 48). This was done by the computer using the formula:

$$x_{ij}^+ = \frac{(x_{ij} - \bar{x}_j)}{s.d.j.}$$

where  $x_{ij}$  = the standardised score

$\bar{x}_j$  = the mean value for variable j

s.d.j.: = the standard deviation for variable j.

Standardisation avoids similarity coefficients being biased towards variables with large variances and, although Cherry wrote that it "moves the distribution of data values for each element into closer conformity with that on a normal curve", (In: Catling et al., 1980:68), there is no reason why this should be true. Histograms were plotted for both raw and log data and neither a consistent improvement nor worsening in the normal distribution of the data was shown.

During cluster analysis a table is produced which shows the overall interelement correlations for each pair of measured elements. These are shown in Figures 37-42 for the results for Euboea with Boeotia and for Thessaly by optical emission (261 and 531 samples), for Euboea with Boeotia and for Thessaly by atomic absorption (119 and 73 samples) and for these same 119 and 73 samples by optical emission. With over 100 pairs of samples in the analysis in most cases any values for the correlation coefficient of over  $\pm 0.1946$  are highly significant at a 0.05 probability level and for the 2 batches of 73 samples from Thessaly a coefficient of  $\pm 0.2319$  would be highly significant at the same level (Murdoch and Barnes, 1974). Any values over  $\pm 0.1942$  and  $\pm 0.2319$  for the 73 Thessalian samples are underlined on the tables. From these tables it can be seen that the majority of the 36 element pairs (45 in the atomic absorption analyses) has a very significant correlation. In each set of the optical emission data one of the strongest correlations was between chromium and nickel. Unfortunately, due to the errors associated with the measurement of chromium and nickel by atomic absorption, it is not possible to say if the same correlation would be shown by atomic absorption analysis. In Euboea and Boeotia, whether all 261 or only 119 samples were considered, magnesium and nickel, magnesium and chromium and magnesium and titanium were also strongly correlated. These elements had less significant correlations in Thessaly where after magnesium and nickel iron and nickel and iron and titanium were the next most important correlations. These were all very strong positive correlations (between 0.5332 and 0.7638). In the two sets of atomic absorption data (Euboea with Boeotia and Thessaly), the significantly correlated



element pairs varied. In Euboea and Boeotia the strongest was between potassium and aluminium (0.7124) with magnesium and potassium and magnesium and aluminium also important. In Thessaly magnesium was less important and the iron and titanium correlation was the strongest followed by sodium and potassium and magnesium and manganese. Examination of the atomic absorption data shows a larger number of negative correlations than the optical emission data, especially in Euboea and Boeotia where half of the element pairs have a negative correlation.

Systematic errors in the weighing or mixing of the sample and the internal standard mix could lead to a general enhancement and thus a positive correlation between the elements and therefore perhaps only element pairs with a very strong positive correlation or a negative correlation can be considered significant. A very strong correlation between a pair of elements throughout the data would probably indicate that only one of the element pair was worth including in the analysis. The negative correlations are generally smaller than the positive ones, in the Euboean and Boeotian data, both in the larger and in the smaller batches of samples, and on the 73 samples by atomic absorption the negative correlations between calcium and sodium, magnesium and sodium and sodium and nickel were especially strong (from -0.3914 to -0.5954). In Thessaly, in the atomic absorption and in the smaller batch of optical emission analyses calcium and sodium still had a strongly negative correlation. In the Thessalian group of 73 samples by both techniques the negative correlations were almost all between calcium and other elements and most of them were quite strong.

It is known from geochemistry that in certain types of rocks some correlated element pairs may be expected. These were surveyed by Gold-



|     | Al.           | Ca.            | Mg.            | Fe.            | Ti.            | Na.            | Mn.           | Cr.           |
|-----|---------------|----------------|----------------|----------------|----------------|----------------|---------------|---------------|
| Ca. | 0.1363        |                |                |                |                |                |               |               |
| Mg. | 0.0641        | <u>0.5591</u>  |                |                |                |                |               |               |
| Fe. | <u>0.2725</u> | <u>0.2551</u>  | <u>0.5388</u>  |                |                |                |               |               |
| Ti. | <u>0.4706</u> | <u>0.3331</u>  | <u>0.5821</u>  | <u>0.5173</u>  |                |                |               |               |
| Na. | -0.0110       | <u>-0.4996</u> | <u>-0.4314</u> | <u>-0.0534</u> | <u>-0.2034</u> |                |               |               |
| Mn. | 0.0895        | <u>0.2376</u>  | <u>0.3483</u>  | <u>0.5485</u>  | <u>0.2055</u>  | 0.0023         |               |               |
| Cr. | -0.0975       | <u>0.3016</u>  | <u>0.5953</u>  | <u>0.4634</u>  | <u>0.3767</u>  | <u>-0.2631</u> | 0.1404        |               |
| Ni. | -0.1464       | <u>0.4216</u>  | <u>0.6823</u>  | <u>0.4994</u>  | <u>0.3507</u>  | <u>-0.3914</u> | <u>0.2081</u> | <u>0.7319</u> |

Figure 37. Euboea and Boeotia. Optical emission interelement correlations.  
(261 samples)

|     | Al.           | Ca.            | Mg.           | Fe.           | Ti.           | Na.     | Mn.           | Cr.           |
|-----|---------------|----------------|---------------|---------------|---------------|---------|---------------|---------------|
| Ca. | <u>0.2706</u> |                |               |               |               |         |               |               |
| Mg. | <u>0.2528</u> | <u>0.3541</u>  |               |               |               |         |               |               |
| Fe. | <u>0.2171</u> | 0.1160         | <u>0.3981</u> |               |               |         |               |               |
| Ti. | <u>0.5387</u> | 0.1655         | <u>0.4729</u> | <u>0.5332</u> |               |         |               |               |
| Na. | -0.0143       | <u>-0.3191</u> | -0.1286       | -0.0140       | -0.0552       |         |               |               |
| Mn. | -0.0061       | 0.1901         | <u>0.4413</u> | <u>0.5033</u> | <u>0.2894</u> | 0.0178  |               |               |
| Cr. | 0.0894        | 0.1802         | <u>0.4016</u> | <u>0.5291</u> | <u>0.3998</u> | -0.1139 | <u>0.3421</u> |               |
| Ni. | -0.0391       | 0.2280         | <u>0.5151</u> | <u>0.6525</u> | <u>0.3778</u> | -0.1471 | <u>0.5208</u> | <u>0.6665</u> |

Figure 38. Thessaly. Optical emission interelement correlations. (531 samples).

|     | Al.            | Ca.            | Mg.            | Fe.            | Ti.            | Na.            | Mn.           | Cr.           |
|-----|----------------|----------------|----------------|----------------|----------------|----------------|---------------|---------------|
| Ca. | <u>0.2222</u>  |                |                |                |                |                |               |               |
| Mg. | <u>0.2174</u>  | <u>0.6382</u>  |                |                |                |                |               |               |
| Fe. | <u>0.4822</u>  | <u>0.3192</u>  | <u>0.5534</u>  |                |                |                |               |               |
| Ti. | <u>0.5393</u>  | <u>0.3877</u>  | <u>0.6636</u>  | <u>0.5861</u>  |                |                |               |               |
| Na. | <u>-0.1426</u> | <u>-0.5954</u> | <u>-0.4861</u> | <u>-0.0016</u> | <u>-0.2022</u> |                |               |               |
| Mn. | <u>0.1531</u>  | <u>0.2466</u>  | <u>0.3186</u>  | <u>0.6173</u>  | <u>0.2580</u>  | <u>0.1933</u>  |               |               |
| Cr. | <u>0.0023</u>  | <u>0.3562</u>  | <u>0.6726</u>  | <u>0.4828</u>  | <u>0.4871</u>  | <u>-0.2784</u> | <u>0.2345</u> |               |
| Ni. | <u>-0.0227</u> | <u>0.5027</u>  | <u>0.7272</u>  | <u>0.4755</u>  | <u>0.4346</u>  | <u>-0.4876</u> | <u>0.1803</u> | <u>0.7224</u> |

Figure 39. Euboea and Boeotia. Optical emission interelement correlations for the same samples as AAS. (119 samples).



|     | Al.           | Ca.            | Mg.           | Fe.           | Ti.           | Na.           | Mn.           | Cr.           |
|-----|---------------|----------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Ca. | <u>0.3738</u> |                |               |               |               |               |               |               |
| Mg. | 0.0136        | -0.0914        |               |               |               |               |               |               |
| Fe. | <u>0.2492</u> | -0.2265        | <u>0.2775</u> |               |               |               |               |               |
| Ti. | <u>0.4135</u> | -0.1253        | 0.2155        | <u>0.7651</u> |               |               |               |               |
| Na. | 0.1307        | -0.1229        | <u>0.4715</u> | 0.1881        | <u>0.2715</u> |               |               |               |
| Mn. | 0.1320        | <u>-0.3814</u> | <u>0.5159</u> | <u>0.4622</u> | <u>0.3964</u> | <u>0.2615</u> |               |               |
| Cr. | 0.0930        | 0.0614         | 0.1535        | <u>0.5687</u> | <u>0.3627</u> | 0.0605        | 0.0949        |               |
| Ni. | 0.0775        | -0.0045        | <u>0.3471</u> | <u>0.7638</u> | <u>0.5260</u> | 0.1073        | <u>0.3131</u> | <u>0.6976</u> |

Figure 40. Thessaly. Optical emission interelement correlations for the same samples as AAS.  
( 73 samples)

|     | Al.            | Ca.            | Mg.            | Fe.           | Ti.            | Na.            | Mn.     | Cr.            | Ni.            |
|-----|----------------|----------------|----------------|---------------|----------------|----------------|---------|----------------|----------------|
| Ca. | <u>-0.5737</u> |                |                |               |                |                |         |                |                |
| Mg. | <u>-0.6681</u> | <u>0.4735</u>  |                |               |                |                |         |                |                |
| Fe. | 0.1713         | -0.1478        | <u>0.3039</u>  |               |                |                |         |                |                |
| Ti. | <u>0.2127</u>  | <u>-0.2953</u> | <u>-0.2044</u> | <u>0.2481</u> |                |                |         |                |                |
| Na. | <u>0.4352</u>  | <u>-0.5966</u> | <u>-0.3978</u> | 0.0991        | <u>0.3507</u>  |                |         |                |                |
| Mn. | <u>-0.2132</u> | 0.1184         | <u>0.2768</u>  | <u>0.2844</u> | -0.1207        | -0.1621        |         |                |                |
| Cr. | -0.1059        | 0.1089         | <u>0.2965</u>  | <u>0.3070</u> | -0.0988        | <u>-0.3403</u> | 0.0774  |                |                |
| Ni. | <u>-0.4022</u> | <u>0.3236</u>  | <u>0.6720</u>  | 0.1043        | <u>-0.2137</u> | <u>-0.3005</u> | 0.1317  | 0.1573         |                |
| K.  | <u>0.7124</u>  | <u>-0.4980</u> | <u>-0.6614</u> | 0.0622        | <u>0.3223</u>  | <u>0.4781</u>  | -0.1511 | <u>-0.2123</u> | <u>-0.5616</u> |

Figure 41. Euboea and Boeotia. Atomic absorption interelement correlations (119 samples).

|     | Al.            | Ca.            | Mg.            | Fe.           | Ti.           | Na.            | Mn.            | Cr.            | Ni.            |
|-----|----------------|----------------|----------------|---------------|---------------|----------------|----------------|----------------|----------------|
| Ca. | -0.2304        |                |                |               |               |                |                |                |                |
| Mg. | 0.2191         | -0.0278        |                |               |               |                |                |                |                |
| Fe. | <u>0.3514</u>  | <u>-0.2673</u> | 0.2097         |               |               |                |                |                |                |
| Ti. | <u>0.4452</u>  | <u>-0.5894</u> | 0.0945         | <u>0.7490</u> |               |                |                |                |                |
| Na. | <u>0.3830</u>  | <u>-0.3894</u> | <u>0.4544</u>  | -0.1801       | 0.1033        |                |                |                |                |
| Mn. | 0.1655         | <u>-0.2374</u> | 0.6136         | 0.2123        | 0.1601        | <u>0.3899</u>  |                |                |                |
| Cr. | <u>-0.2370</u> | <u>0.2607</u>  | 0.0169         | <u>0.3434</u> | 0.0124        | <u>-0.6342</u> | 0.0720         |                |                |
| Ni. | 0.0478         | <u>0.3999</u>  | <u>-0.5192</u> | -0.1494       | -0.1798       | <u>-0.3753</u> | <u>-0.6986</u> | -0.0018        |                |
| K.  | <u>0.3686</u>  | <u>-0.4864</u> | <u>0.4406</u>  | 0.1139        | <u>0.2505</u> | <u>0.6309</u>  | <u>0.5190</u>  | <u>-0.5191</u> | <u>-0.5848</u> |

Figure 42. Thessaly. Atomic absorption interelement correlations. (73 samples).



schmidt (1958). In igneous rocks and serpentine magnesium and iron and magnesium and nickel are closely correlated as are magnesium and calcium in dolomitic limestone. In dolomitic limestone magnesium is generally associated with elements of similar ionic size including iron and manganese. As mentioned above, these correlations all occur in the data for this project, except in the smaller batch of Thessalian samples by both optical emission and atomic absorption where the magnesium to calcium correlation is lacking. Calcium and sodium are often negatively correlated but there are not many correlations in rocks and sediments which are known to involve calcium and it is not obvious why the Euboean and Boeotian samples (all three batches) and the Thessalian samples analysed by atomic absorption show so many correlations involving calcium. Since they are apparent in both techniques it is unlikely that their occurrence can be attributed to experimental error. In highly magnesian, olivene rocks and in bauxite a negative correlation between aluminium and magnesium has been noticed. In the analysis this was only picked up in the atomic absorption analysis of Euboean and Boeotian material where the correlation coefficient was  $-0.6681$ , possibly partly due to the large bauxite deposits and the serpentine in Euboea and Boeotia. There is also a correlation between titanium, iron and nickel in iron-nickel ores such as those which occur in eastern Boeotia and Euboea. These correlations were noted throughout the analyses.

It was stated above that when a pair of elements has a very high correlation coefficient there is little or no point in analysis for both elements. Unfortunately, since the different correlations vary in significance from area to area, a blanket decision to remove certain elements from those generally measured is not possible. From the 9 elements

measured in the optical emission and the IO in the atomic absorption analysis it seems that chromium and possibly titanium could be dispensed with in analysis of pottery from the mainland of Greece since both elements are strongly correlated with nickel and titanium is also strongly correlated with iron and they do not act separately as discriminants. Magnesium, iron, nickel, sodium and manganese, despite their correlations in some areas, have proved their value in others. Manganese, for example, is used as a discriminant in Thessaly but not in Euboea and Boeotia. However, in optical emission and atomic absorption work the inclusion of only 2 elements whose contribution is dubious does not involve a great deal of extra work and further checks on the importance of the correlations would need to be done before they were excluded.

Two methods of clustering were tried in this project, Nearest Neighbour and Ward's Method's, but the groups obtained from Ward's Method were more meaningful than those using Nearest Neighbour. As Wishart said (1978:133) Nearest Neighbour analysis "finds straggling clusters and often fails with large populations due to chaining". The majority of the samples were therefore only clustered using Ward's Method. In Hierarchic cluster analysis there are initially  $n$  clusters, each of which consists of one sample. There are then  $n-1$  fusion steps and at each step the two most similar clusters are combined. In Ward's Method (Everitt, 1974:15) at each step of the analysis the sum of the squared deviations of every point from the centroid of the cluster is calculated (the error sum of squares ESS). The 2 clusters which are then joined are those whose fusion results in the smallest increase in the ESS. The ESS is defined as:

$$ESS = \sum_{i=1}^n x_i^2 - \frac{1}{n} (\sum x_i)^2$$



where  $x_i$  is the concentration of the  $i^{\text{th}}$  individual in a series of  $n$  variables.

Ward's Method finds minimum variance spherical clusters. It was used with the Euclidean distance as the dissimilarity coefficient where the distance between 2 objects/groups  $i$  and  $j$  is  $D_{ij}$  which is given by:

$$D_{ij} = \left\{ \sum_{k=1}^n (x_{ik} - x_{jk})^2 \right\}^{\frac{1}{2}}$$

where  $x_{ik}$  is the value of the  $k^{\text{th}}$  variable for the  $i^{\text{th}}$  sample

$x_{jk}$  is the value for the  $k^{\text{th}}$  variable for the  $j^{\text{th}}$  sample

the summation is over a series of  $n$  variables (after Everitt 1974:56).

The computer produces the resultant groupings both as tables and as a dendrogram. The dendrogram for the Revmatia samples is shown below (Figure 43). The number of groups is taken from the final level of clustering before a large jump in the coefficient (twice the ESS). This dendrogram was interpreted to give one large group with 3 separate and distinct sherds, numbers 615, 620 and 631, with the cut-off being at coefficient 2.968 after which the next fusion was at 5.936. CLUSTAN IC also has an option RELOCATE in which the  $k$  clusters obtained after initial clustering are re-examined and for each sample its similarity to each of the  $k$  clusters is computed. If the similarity to a new cluster exceeds that to the parent cluster the sample is relocated in the new group and the centroids of the groups are recalculated accordingly. In the next stage the similarities between all pairs of clusters are computed and the two most similar clusters are fused, leaving  $k - 1$  clusters. The process is then repeated to obtain  $k - 2$  clusters and so on down to the



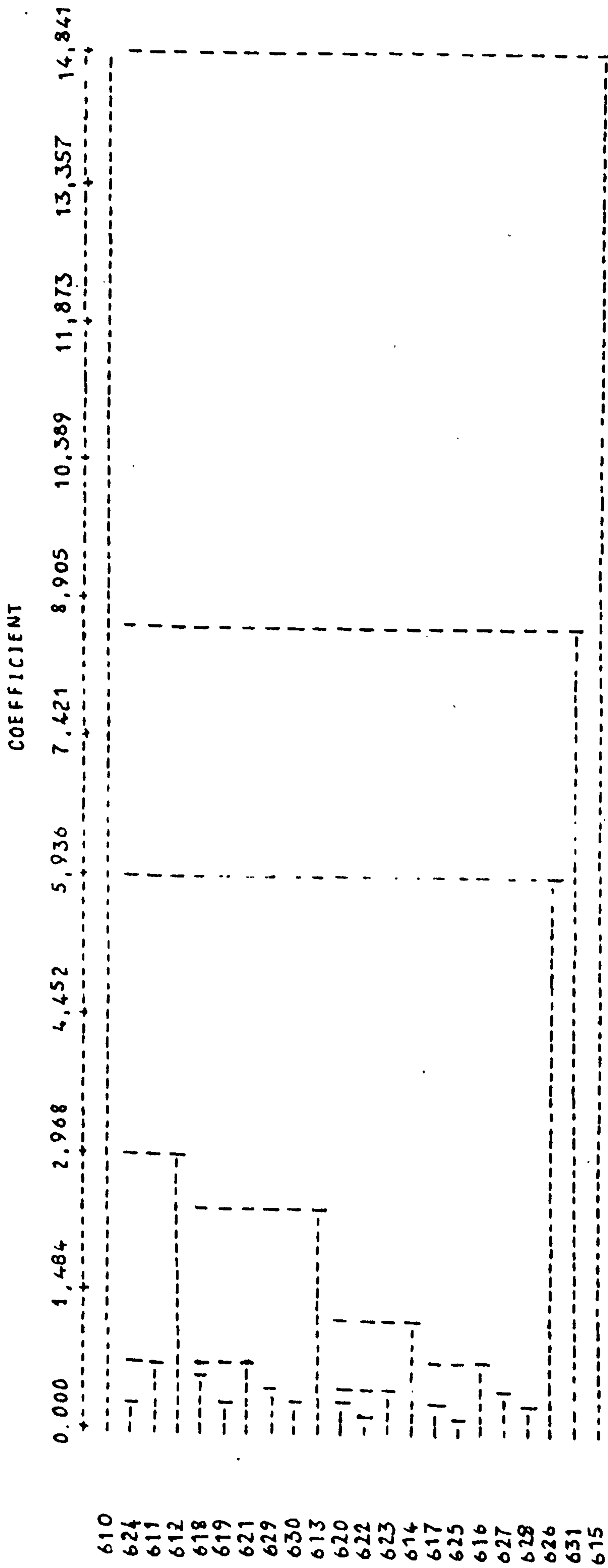


Fig 43 Dendrogram of samples from Revmatia

minimum number of clusters specified by the user (Wishart 1978:43). In a tight set of data with well-defined groups the relocation procedure would make little difference to the original groupings.

#### 6.4. Multiple Discriminant Analysis.

Discriminant analysis was performed using the Discriminant option of the SPSS package developed by Nie et al. (1975).

Discriminant analysis is designed to test the statistical separation of 2 or more groups of cases (Klecka in Nie et al., 1975: 435). The technique "attempts to weight and linearly combine the discriminant variables (here, the elemental concentrations) in a way that maximises the statistical separation of these prior groups" (Cherry in Catling et al., 1980:70).

Each of the series of discriminant functions (or axes through the data), accounts for a smaller proportion of the separation between the group centroids. The first few functions generally account for the majority of the total variance between the groups. The data are then plotted in 2 or more dimensions with the minimum distortion of the original concentration data and with the degree of separation of the groups elucidated. The functions take the form:

$$D_i = d_{i1}Z_1 + d_{i2}Z_2 + \dots + d_{ip}Z_p$$

where  $D_i$  is the score on the discriminant function  $i$ , the  $d$ 's are the weighted coefficients and the  $Z$ s are the standardised values of the discriminant variables used.

The package also contains methods for the statistical evaluation of the success with which the discriminating variables can distinguish between groups and for the identification of the most and least useful

discriminating variables. The method used was step-wise discriminant analysis in which the variables are entered one by one in decreasing order of discriminant power.

The package can also be geared to produce scatter plots for pairs of variables, but this, when tried, did not help in the classification of the data. The computer produces a plot of the samples on the two most discriminating scores, as shown in Figure 44 of the optical emission data for Thessaly; a list of the samples and the probability that they belong to the group they were assigned to or to another group; the overall percentage of the assignments that was correct, the importance of the variables and the proportion of the total variance accounted for by each discriminating function.

Wilks' lambda method was selected for the step-wise discriminant analysis in which the test for differences among the group centroids is done using the overall multivariate F ratio. This takes into account the differences between the centroids and the homogeneity within the groups (Nie et al., 1975:447).



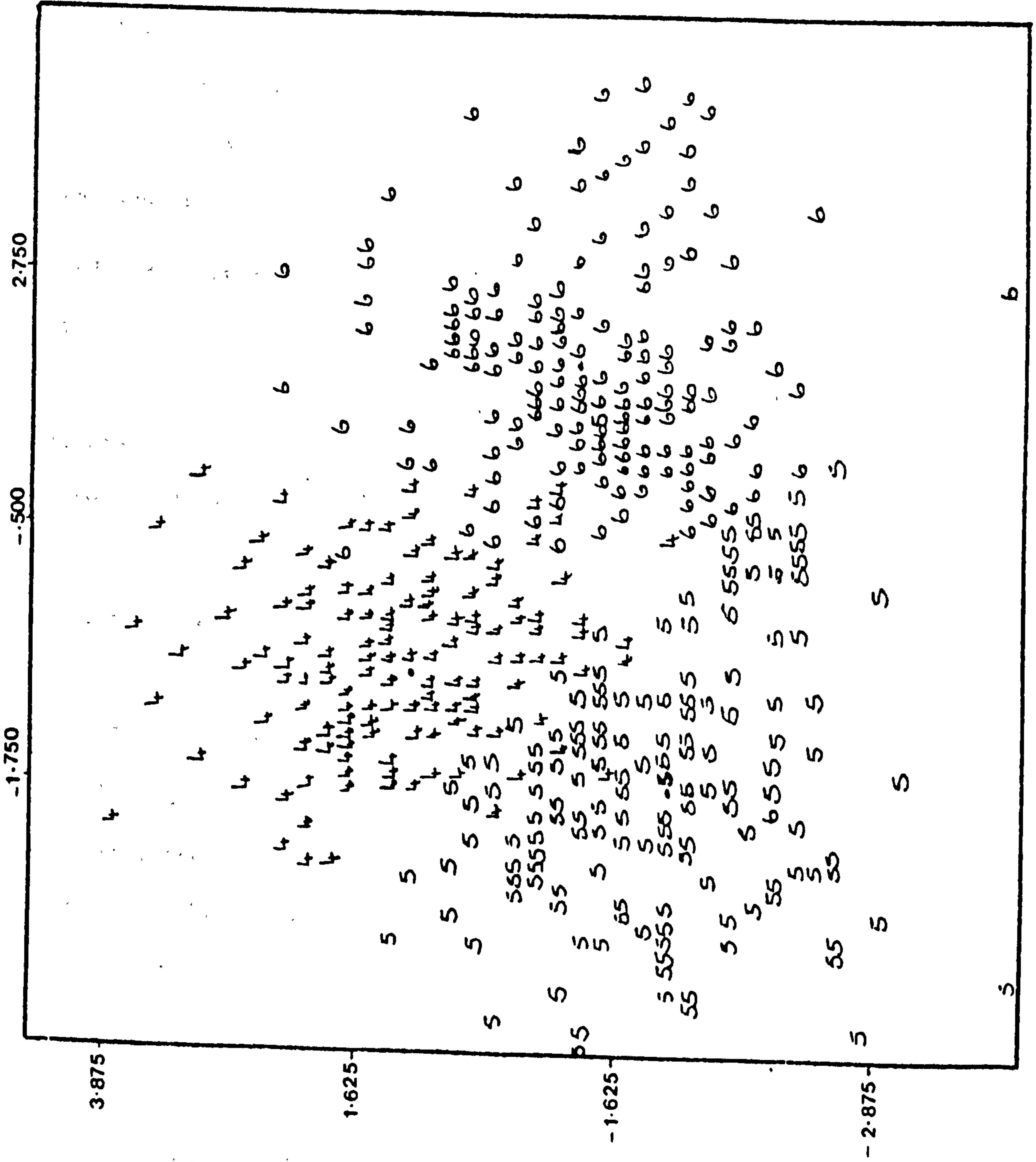


Fig 44 Discriminant plot for Thessaly

6.5. Interpretation of the optical emission data.

6.5.1. The data from Euboea and Boeotia.

Initially the groups and sub-groups of sherds from each site were subjected to cluster analysis. It became clear from this that none of the site groups in Euboea and Boeotia consisted of one clear composition group which was unique to that site and that in many cases it was not possible to say whether there were two or more composition groups represented at each site or whether the clay beds throughout the area were inhomogeneous but broadly similar in composition.

Cluster analysis was then applied to the larger groups of data from Euboea and from Boeotia. From this analysis a picture began to emerge of 3 composition groups and when all the Euboean and Boeotian data were submitted to the computer in one batch (since they are so close geographically), this picture was confirmed. The groups were defined by the criteria mentioned above (Chapter 6.1). The groups fused at a coefficient of 26.963 after which the next possible fusion was at 43.326. Composition groups 1 and 3 were predominantly Boeotian although each of them contained about 20% of the material from the Euboean sites. They were therefore identified as Boeotian composition groups. Group 1 was concentrated on the Theban area and group 3 on the coast of Boeotia opposite Chalkis. The rest of the Euboean material and about 20% of the Boeotian sherds fell in group 2 which was therefore considered Euboean.

The next stage was to test these groups for validity with discriminant analysis to see if the groups would hold or whether many samples would be assigned to different groups with a greater probability than that with which they could be assigned to their original group.

All the 261 Euboean and Boeotian samples were submitted to discriminant analysis in the three groups mentioned above and as 96.6 % of the samples were assigned to the suggested groups with only 13 sherds being reassigned these groupings can be seen to be confirmed. Of the reassignments, 9 were between the 2 Boeotian groups and only 4 between a Boeotian group and the Euboean group. The groupings of the sherds from Lefkandi and Psakhna were unaltered. It should, however, be borne in mind that with discriminant analysis the computer has to assign the samples to one of the existing groups that have been defined rather than creating new groups. A plot of the group centroids for groups 1-3 and the area occupied by 90% of the samples in each group on the first two discriminant functions is shown in Figure 45.

#### 6.5.2. The data from Thessaly.

When each of the groups of Thessalian material was subjected to cluster analysis the situation was a little clearer than in Euboea and Boeotia and it appeared that, broadly speaking, the north and south could be distinguished from each other.

The data were then submitted in 2 groups (north and south) and then all together in one large group. There appeared to be three groups (groups 4-6). When all the samples were submitted together the clusters fused at a coefficient of 55.277 after which the next fusion would have been at 83.181. Broadly speaking, these three groups came from the three areas of Late Bronze Age settlement in Thessaly, and were probably made in these areas. Group 4 came from the Pharsala area in the western plain with most of the Revmatia and Yephyria sherds. Group 5 was mainly north Thessalian and group 6 was concentrated on the area around the



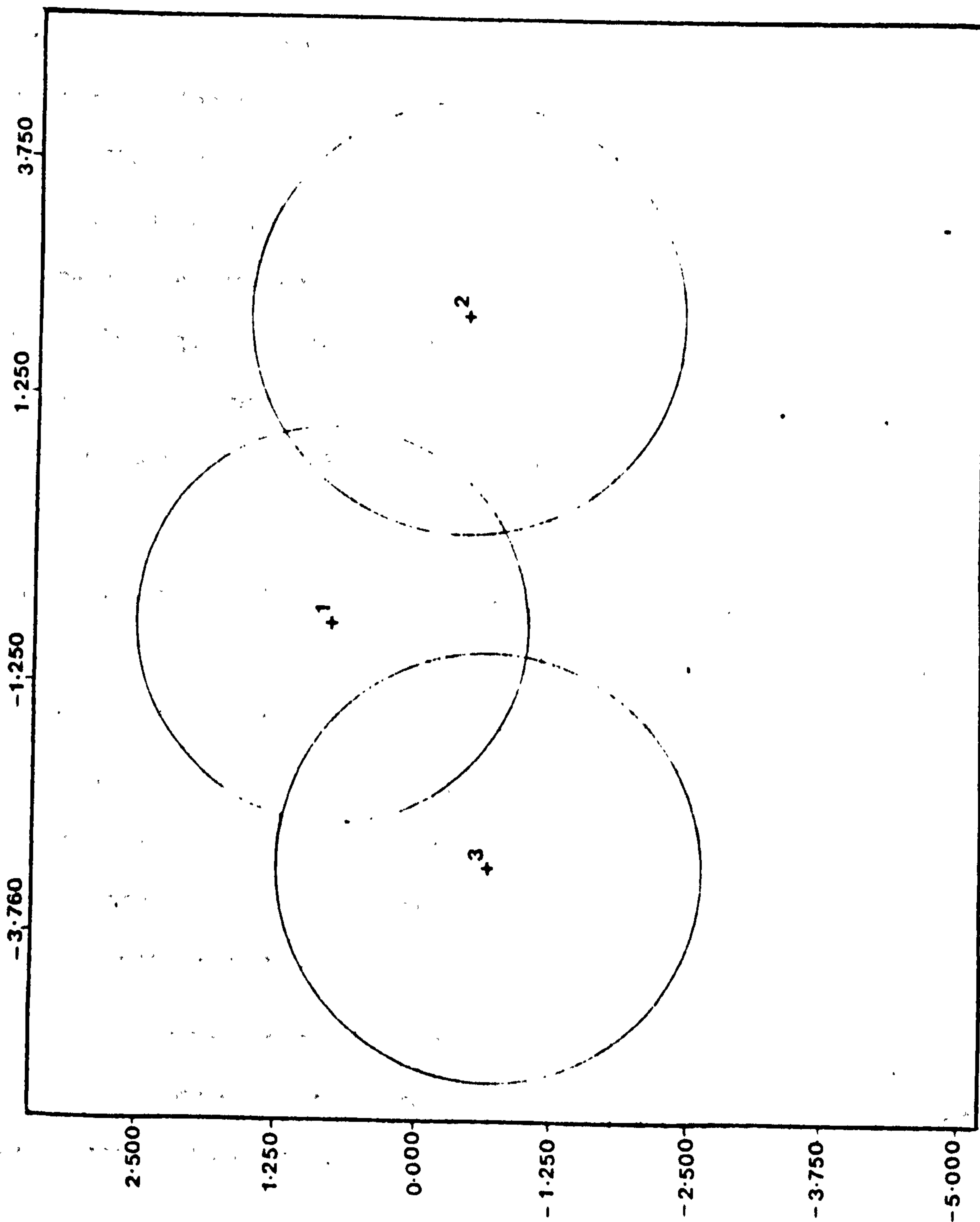


Fig 45 Plot of the area occupied by 90% of the samples in each group of the Euboean and Boeotian data on the first 2 discriminant functions

Gulf of Volos with the bulk of the material from Iolkos, Pevkakia and Velestino. Groups 4-6 are therefore identified with these areas. All of these groups contained some 'imports' from the other areas.

When the three Thessalian groups were subjected to discriminant analysis 88.2% of the cases were correctly classified. Bearing in mind the proviso mentioned above (Chapter 6.5.1) that the computer has to assign the samples to one of the existing groups, this was a satisfactory result. The division of the data from Revmatia, Velestino (Iolkos) and Pevkakia LH Sub-groups II and 12 was unaltered. Over half of the alterations made were between groups 4 and 5, the western and the northern groups. It began to appear that the proportion of imports at Pevkakia increased with the passage of time since group 6 which is centred on Volos contained 70% (18/29) of the Early Bronze Age sherds with 61% (21/36) and 44% (64/174) of the Middle and Late Helladic sherds respectively.

The group of sherds from Velestino which was thought to have been imported from the Argolid was tested against the Mycenae LHIIIA-B control data from the Fitch Laboratory with the Velestino sherds in one group irrespective of how they had been classified in the cluster analysis. The discriminant analysis showed that these sherds could not be identified with those from Mycenae as Figure 46 of the separation on the first discriminant function shows.

Figure 47 shows the plot of the group centroids and the areas occupied by 90% of the samples in each group for groups 4-6 plotted on the first two discriminant functions.

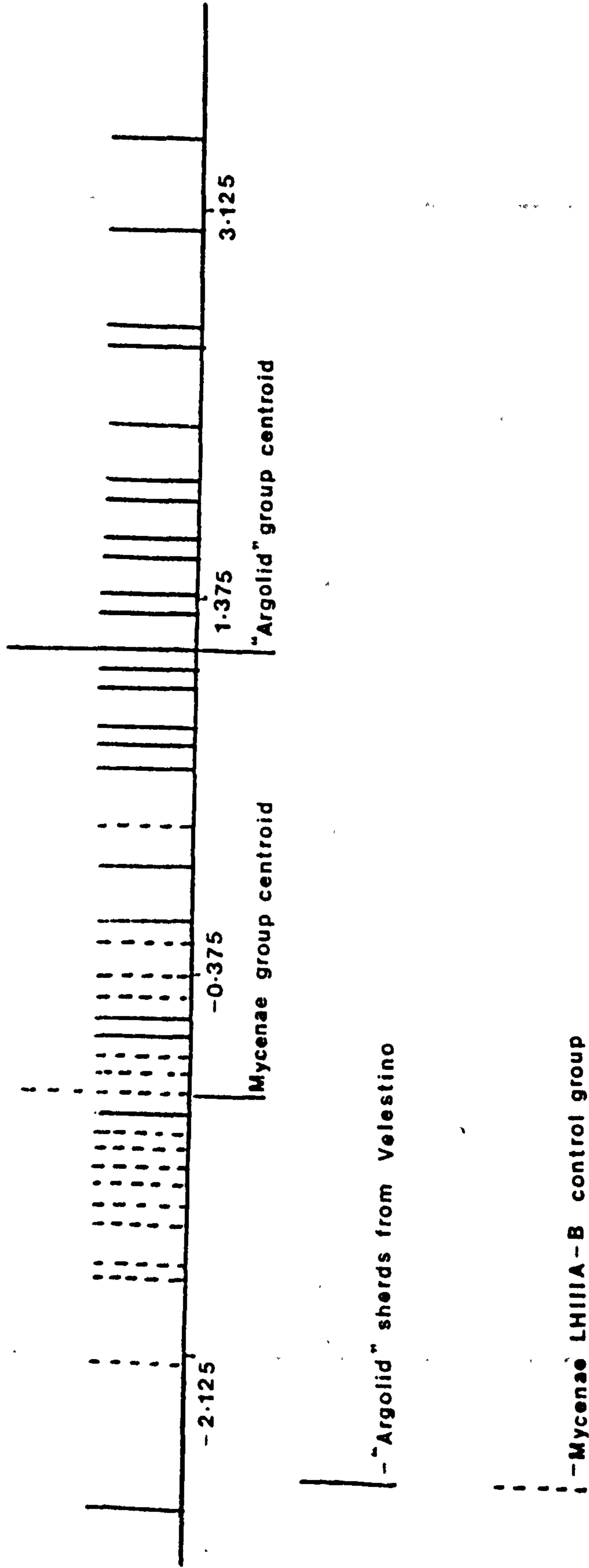
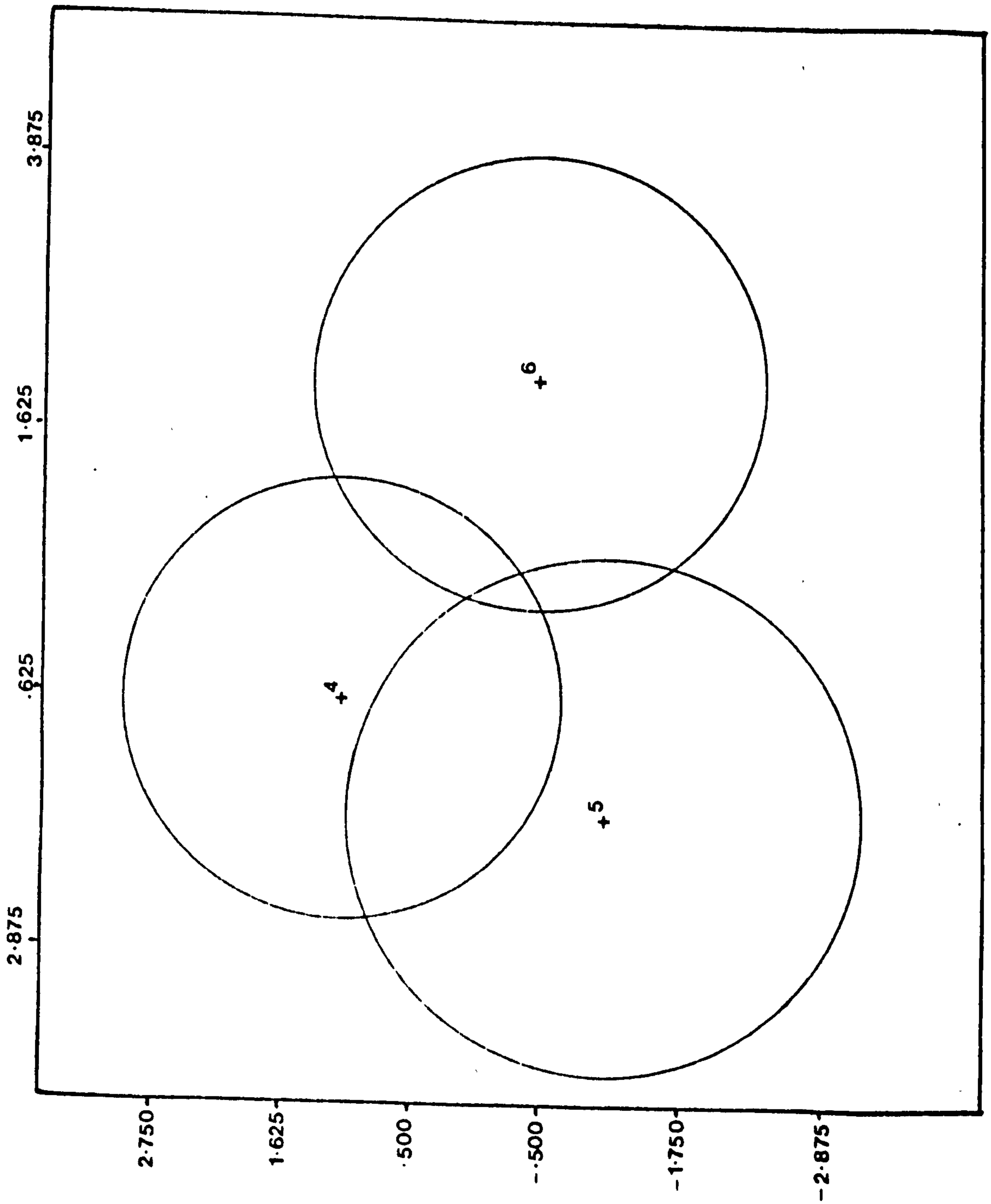


Fig 46 Discriminant plot. "Argolid" and Mycenae groups





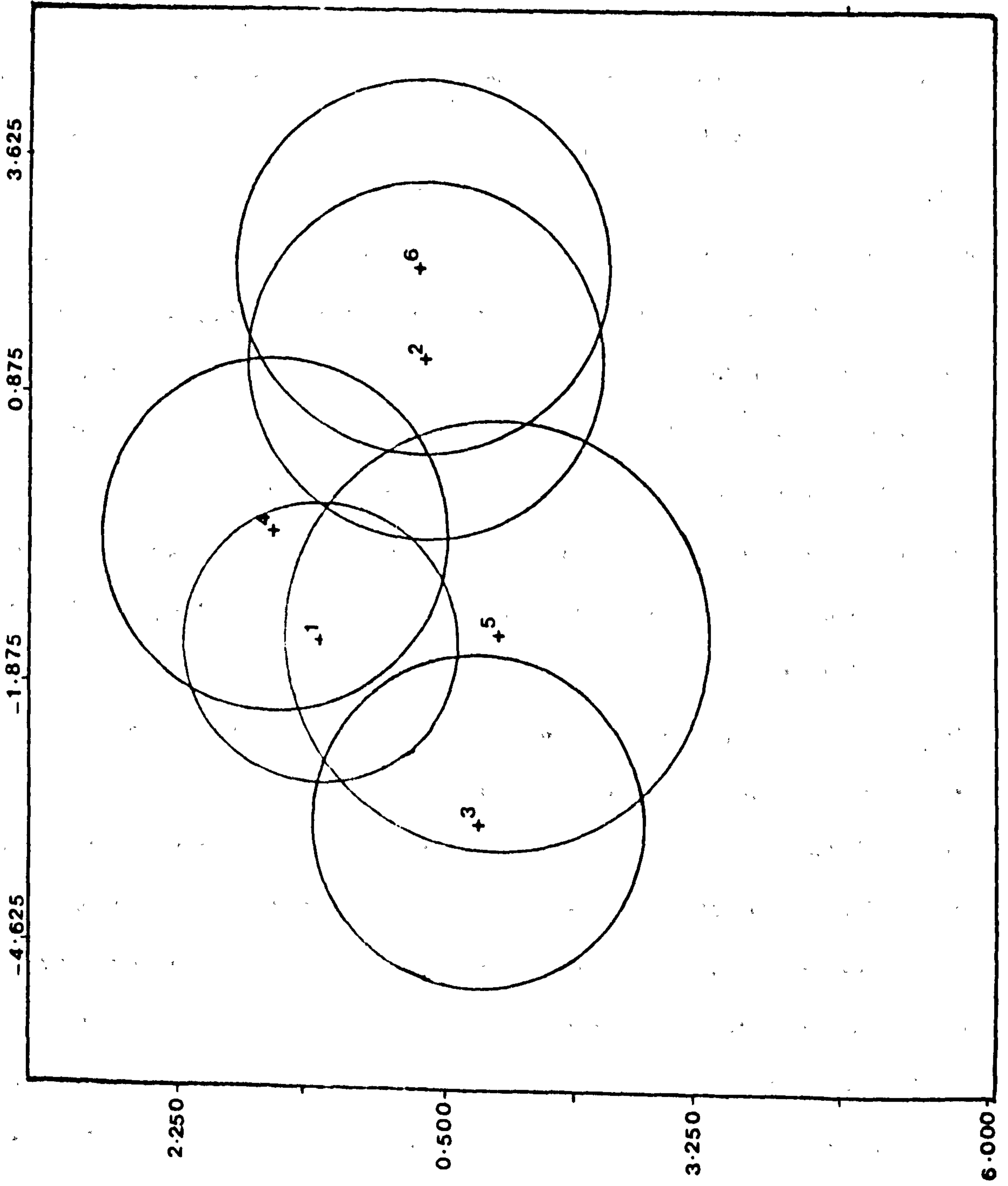


Fig 48 Plot of the area occupied by 90% of the samples in each group of data on the first 2 discriminant functions

6.5.3. The data from Euboea, Boeotia and Thessaly.

Cluster analysis is very cumbersome for more than about 200 samples and the resultant dendrograms are not easy to interpret. Since the Thessalian material alone consisted of over 500 sherds it was decided not to submit all the 800 samples to the computer for cluster analysis in one batch.

All the samples were submitted in one batch for discriminant analysis in the six groups mentioned above and Figure 48 shows the group centroids and the area occupied by 90% of the samples in each group on the first two discriminant functions. The success rate for the groupings was inevitably lower this time, but at 71% correct was still pleasing. As Figure 48 shows, the closest similarity is between groups 2 and 6 and the computer moved 14 sherds from group 2 to group 6 and 40 sherds from group 6 to group 2. Groups 1 and 4 also had a considerable overlap and 18 sherds from group 1 were moved to group 4 and 25 from group 4 to group 1. Nine sherds were moved from group 3 to group 5 and 25 from group 5 to group 3. The final groupings of the sherds is given in Appendix 5. In each case more of the sherds found in Thessaly were attributed to a Boeotian or Euboean origin than the other way round, and this cannot simply be accounted for by the greater volume of material from Thessaly. There is no overlap on the diagram of groups 2 and 3, 4 and 3, 6 and 3, or 6 and 1. The 'Argolid' group from Velestino was divided between several groups but over half of the sherds were divided between the two Boeotian groups. Figure 49a shows the percentage of the sherds from each area in each group and Figures 50-51 show the percentage of the sherds from each site which fell in each group. If all probabilities were equal 16.7% of the sherds from each region might be expected to



fall in each of the 6 composition groups ( $16.7 = 100/6$ ). The significance of the percentage of the sherds from each area that actually did fall in each group was tested with the formula:

$$\text{s.d.} = \sqrt{npq}$$

where  $n$  = the number of samples from each region

$p$  = the probability of a sample falling in a particular group =  
=  $1/6$

$q$  = the probability against a sample falling in a particular  
group =  $5/6$

If the percentage of sherds in a particular group well within  $\pm 1$  s.d. of 16.7 this was not regarded as significant. If it was within  $\pm 1-2$  s.d. of 16.7 it was regarded as significantly high or low and if the difference was greater than  $\pm 2$  s.d. this was regarded as very significant. Figure 49b shows the significance of the percentage of sherds in each group as shown in Figure 49a. Since, as was mentioned above (Chapter 6.1), in a set of data which follows a normal distribution on 32% of the samples will have values which are more than  $\pm 1$  s.d. from the mean and only 5% will have values more than  $\pm 2$  s.d. from the mean, only 16% of the values will therefore be over  $+ 1$  s.d. and only 2.5% over  $-2$  s.d. from the mean (and the same percentage on the negative side), the significance of the data shown in Figures 49a and b is highlighted. It can be seen from these figures that a significantly high percentage of the Euboean sherds fell in group 2 and a significantly low percentage in groups 4-6. For Boeotia the percentage in groups 1 and 3 was significantly high and in groups 5 and 6 significantly low. The Thessalian material was less clear but a significantly high percentage fell in groups 4 and 6 and a significantly low percentage in group 3. This

|          | 1       | 2      | 3       | 4          | 5          | 6             |
|----------|---------|--------|---------|------------|------------|---------------|
|          | Boeotia | Euboea | Boeotia | W.Thessaly | N.Thessaly | S.E. Thessaly |
| Euboea   | 20.3    | 33.6   | 18.2    | 6.3        | 13.3       | 8.4           |
| Boeotia  | 30.5    | 15.3   | 31.4    | 13.6       | 7.6        | 1.7           |
| Thessaly | 8.7     | 10.0   | 4.9     | 26.0       | 21.3       | 27.5          |

Figure 49a. The percentage of the sherds from each area in each composition group from the optical emission results after discriminant analysis (792 sherds).

|          | 1       | 2      | 3       | 4          | 5          | 6             |
|----------|---------|--------|---------|------------|------------|---------------|
|          | Boeotia | Euboea | Boeotia | W.Thessaly | N.Thessaly | S.E. Thessaly |
| Euboea   | 0       | ++     | 0       | --         | -          | --            |
| Boeotia  | ++      | 0      | ++      | 0          | --         | --            |
| Thessaly | 0       | 0      | -       | +          | 0          | +             |

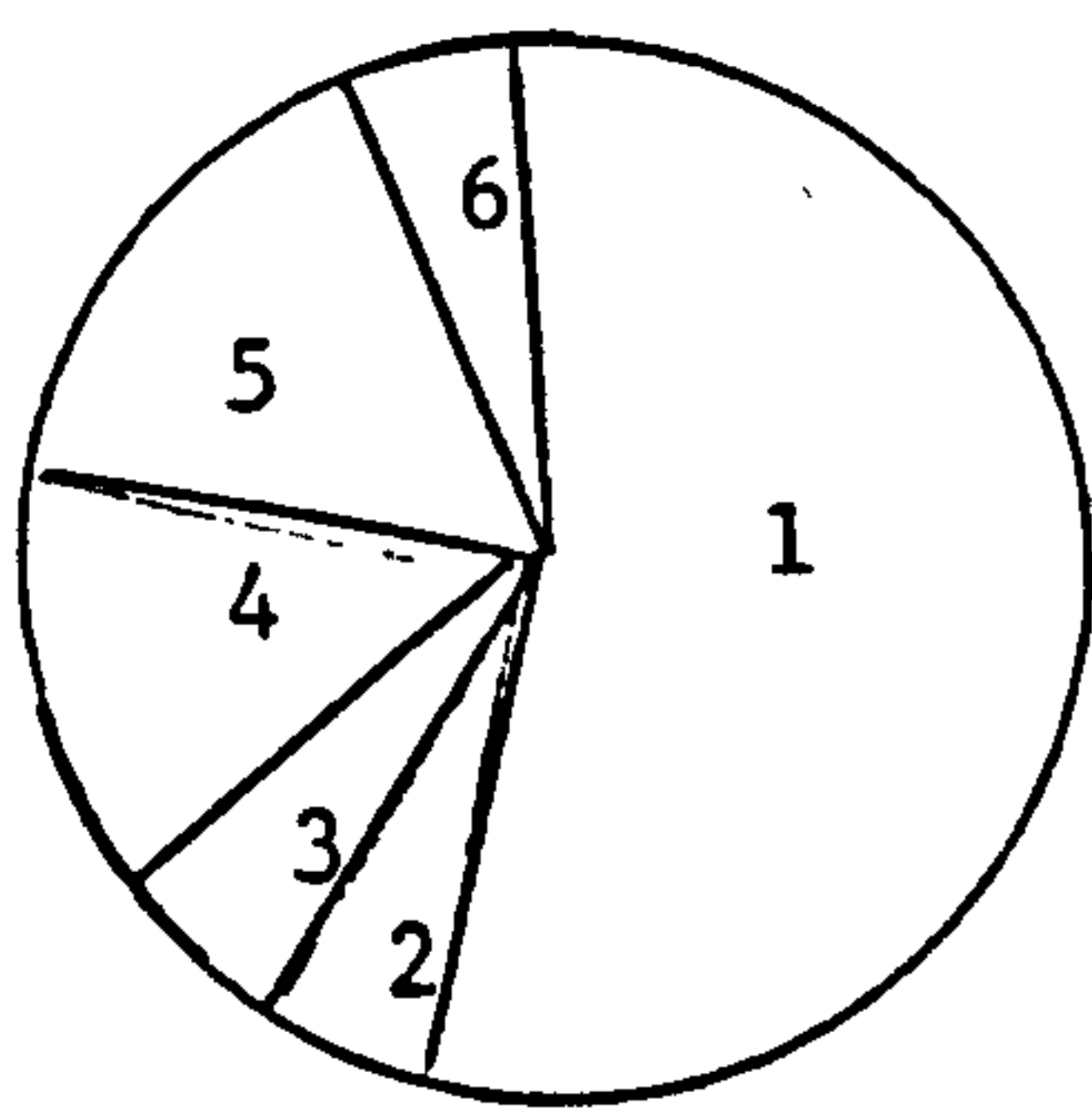
0 = within  $+1\sigma$  (not significant); + = within  $+2\sigma$ ; ++ =  $>+2\sigma$ ; - = within  $-2\sigma$ ; -- =  $<-2\sigma$ .

Figure 49b. Significance of sherds from each area in each composition group.

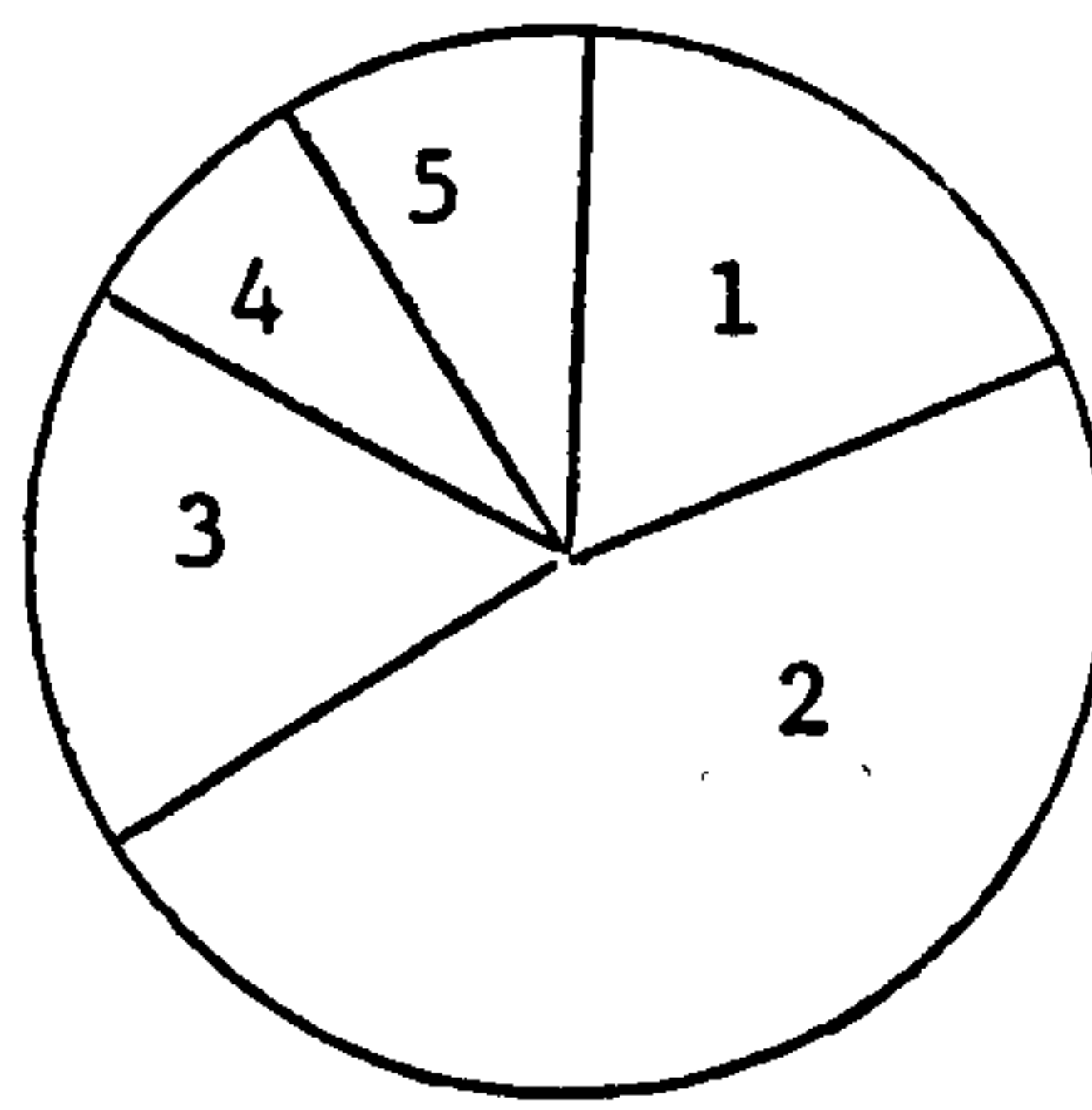
reduced clarity in the results reflects the more varied origins of the material found in Thessaly than of the material found in Euboea and Boeotia.

Since the computer includes the different variables in the discriminant analysis in decreasing order of significance it is interesting to look at their order of inclusion. This is shown for Euboea with Boeotia, for Thessaly and for all the data together in Figure 52. If the first 5 elements included in each case are considered sodium nickel and magnesium are found in each case with calcium included twice and aluminium, titanium and iron included once each. As Figure 52 shows, the high correlation between nickel and chromium leads to the exclusion until nearly last of chromium so that the effect it has on the analysis is negligible. If the correlation were complete then chromium or nickel would have been excluded altogether from the analysis by the computer. That nickel was taken as the more important of the two elements illustrates the fact that it has a greater independent role to play in the discrimination than chromium. Catling et al. (1980) report a correlation coefficient for chromium and nickel of 0.893 and then claim that both elements play a significant part in discriminating between the groups in their analysis. This is strange, particularly since the discriminate analysis should take the correlations into account and therefore ignore the less useful of the correlated pair of elements until such point as its individual contribution is important in the analysis. It would thus appear that if nickel and chromium are indeed two of the most discriminating elements in their analysis, the other elements must have a relatively small contribution to make, indicating that there is perhaps not all that much difference between their groups of samples.

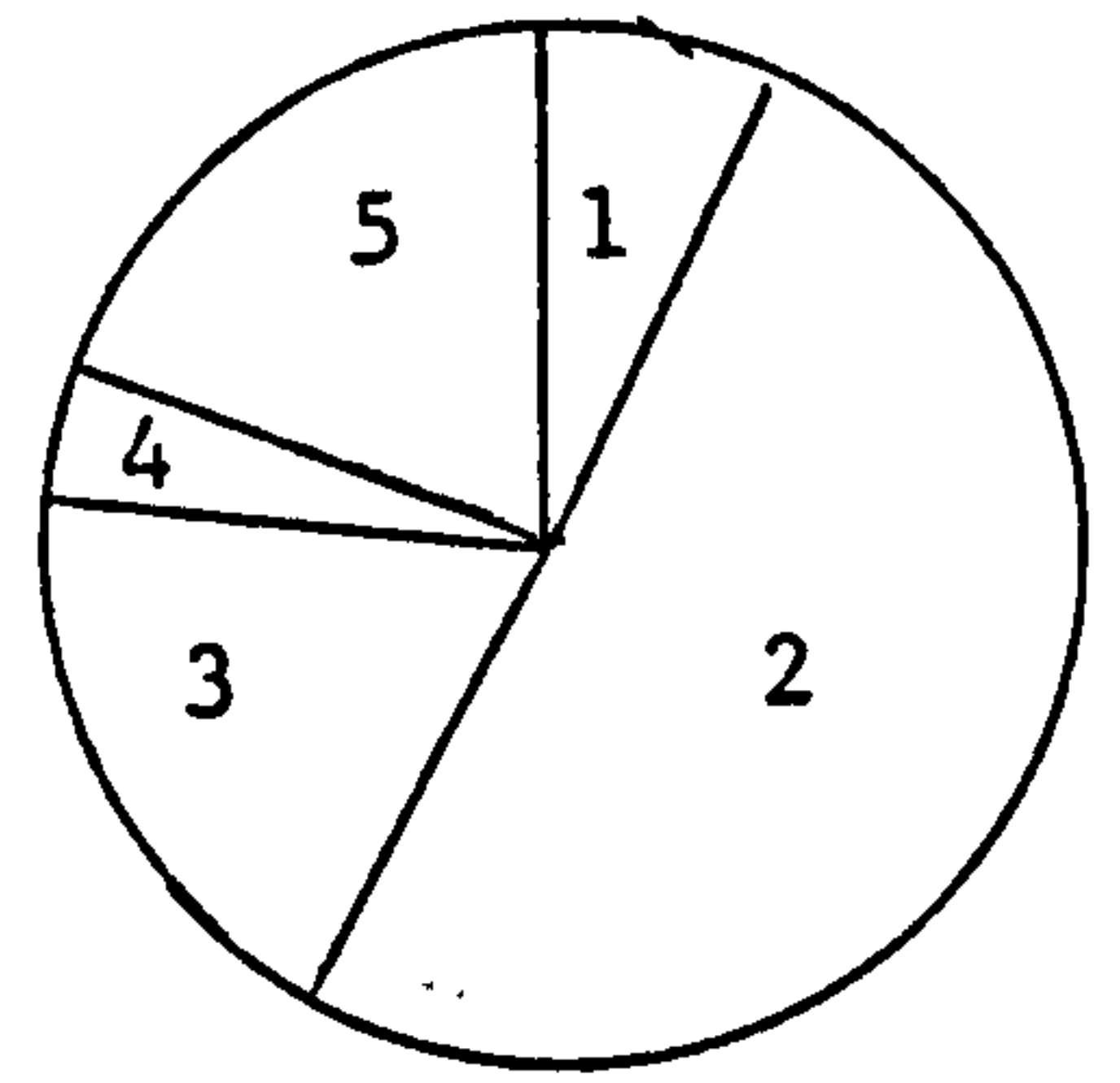




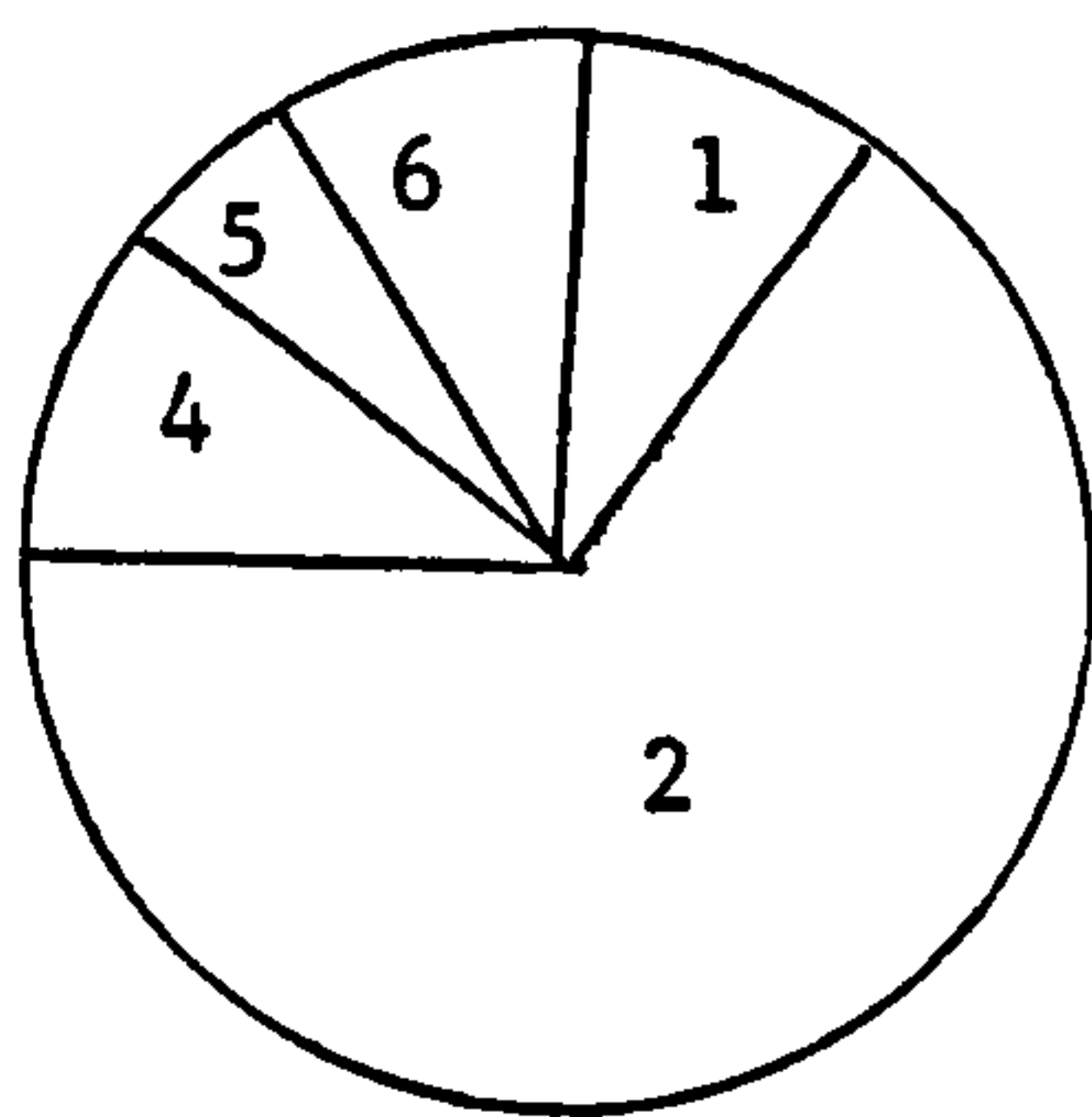
Aliveri



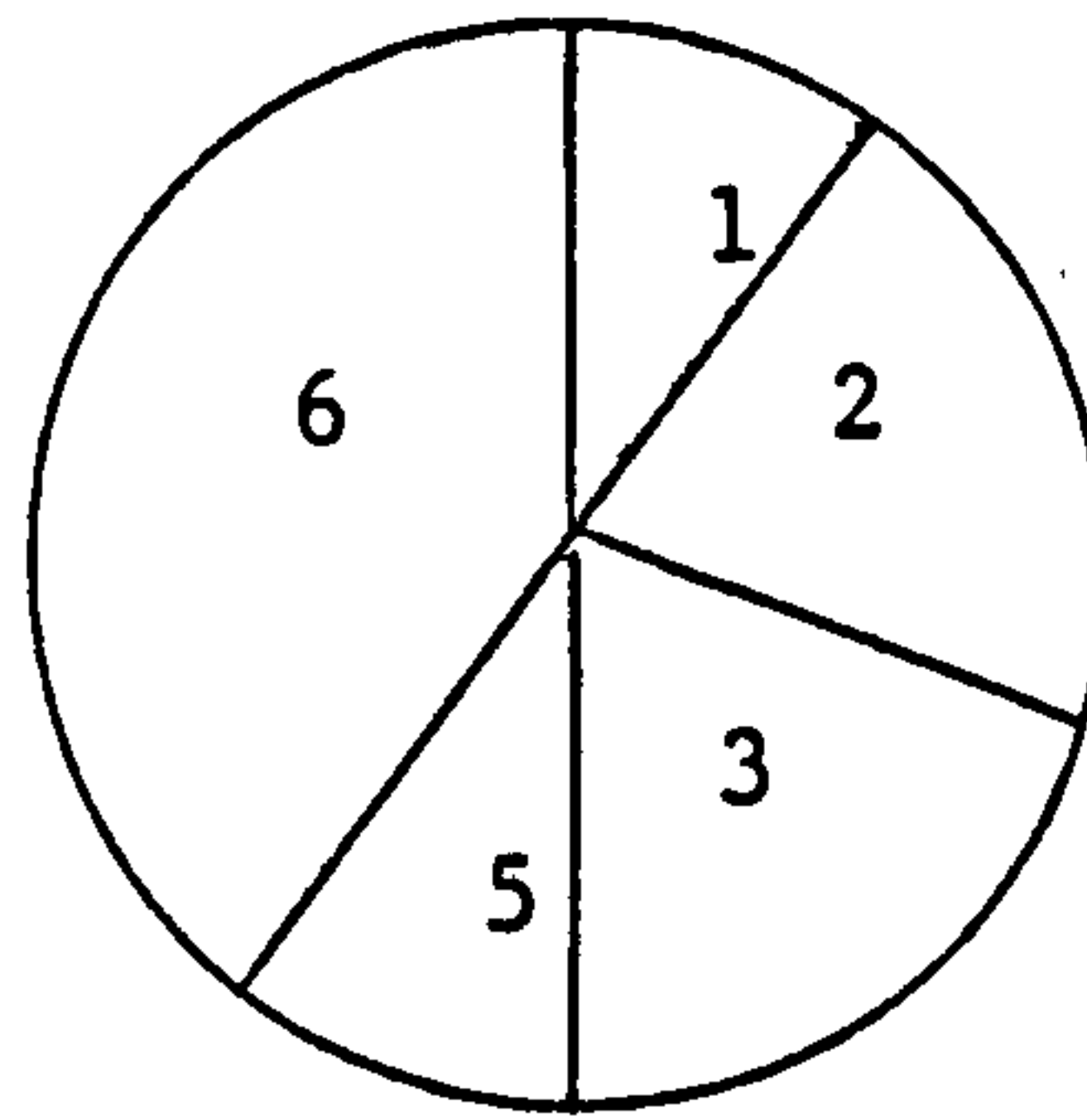
Amarynthos



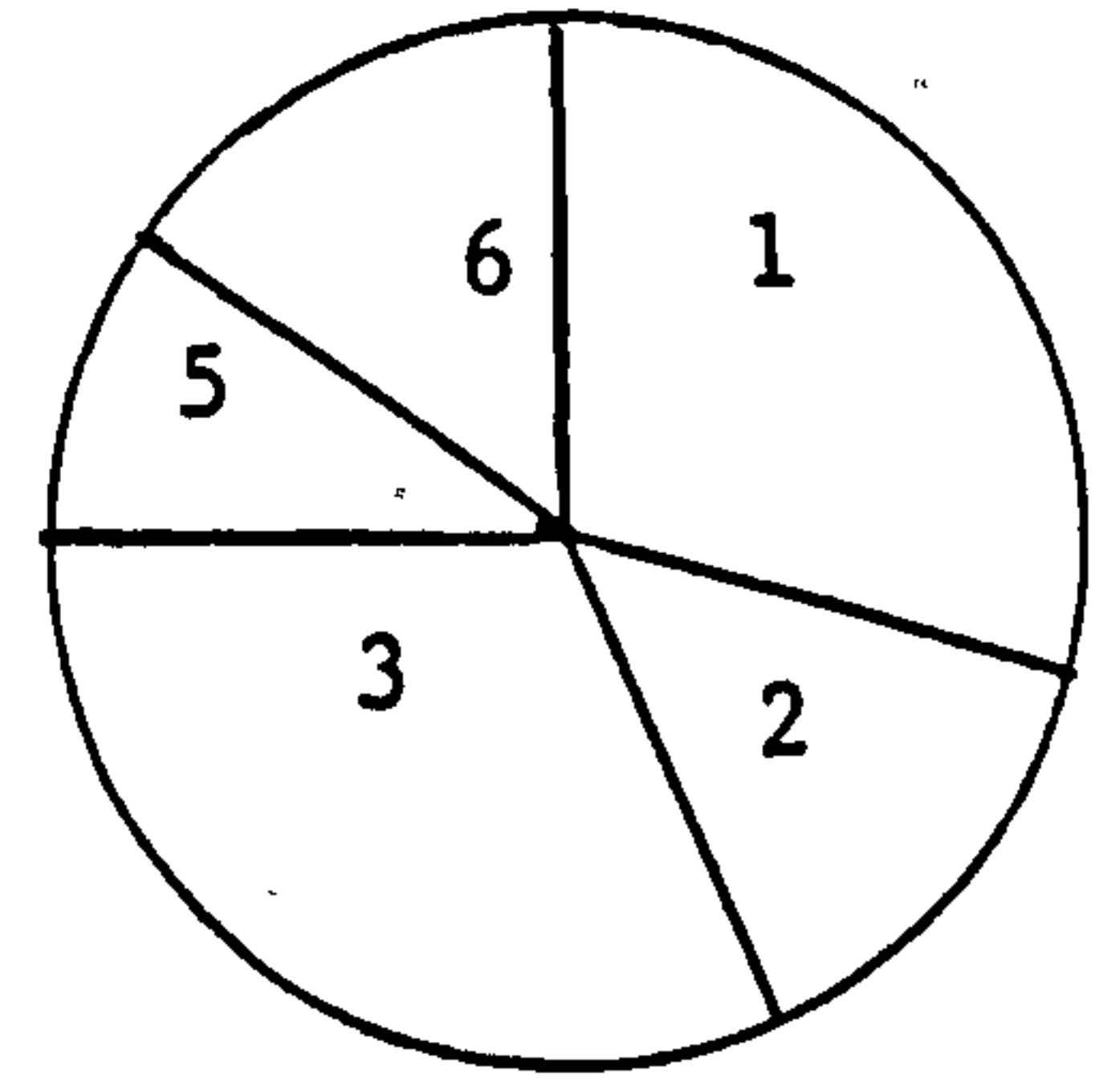
Gialtra



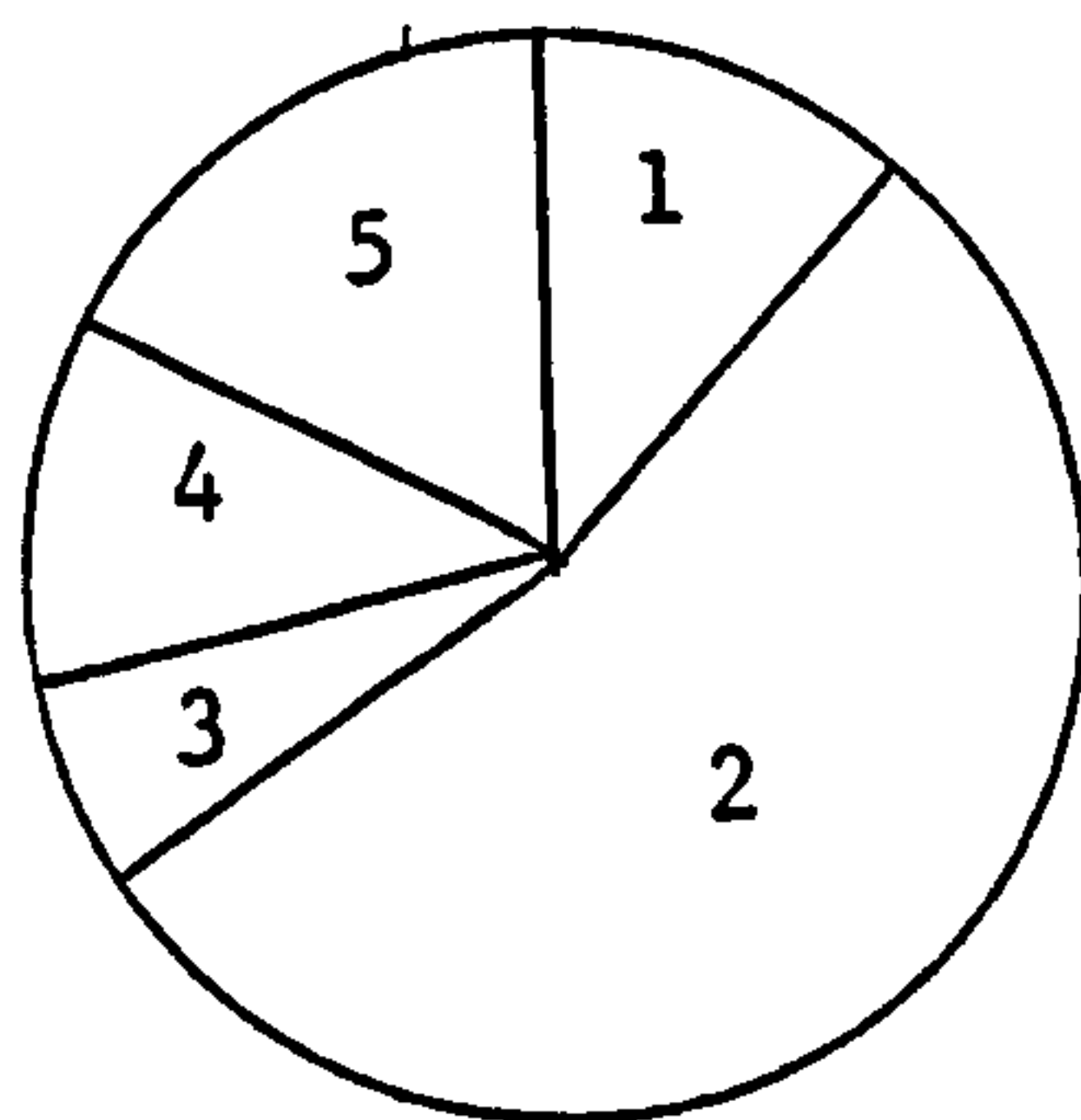
Lefkandi



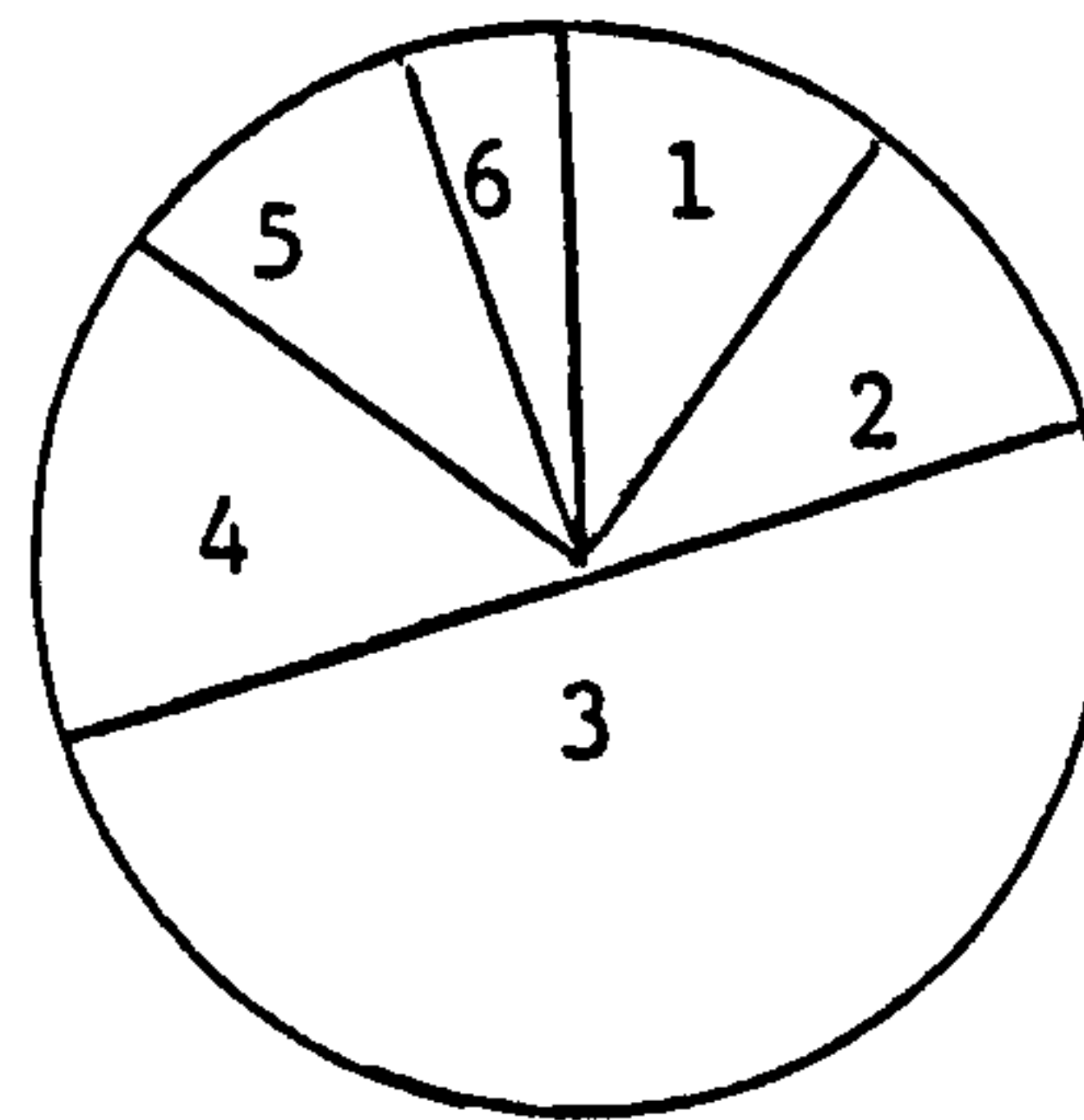
Psakhna



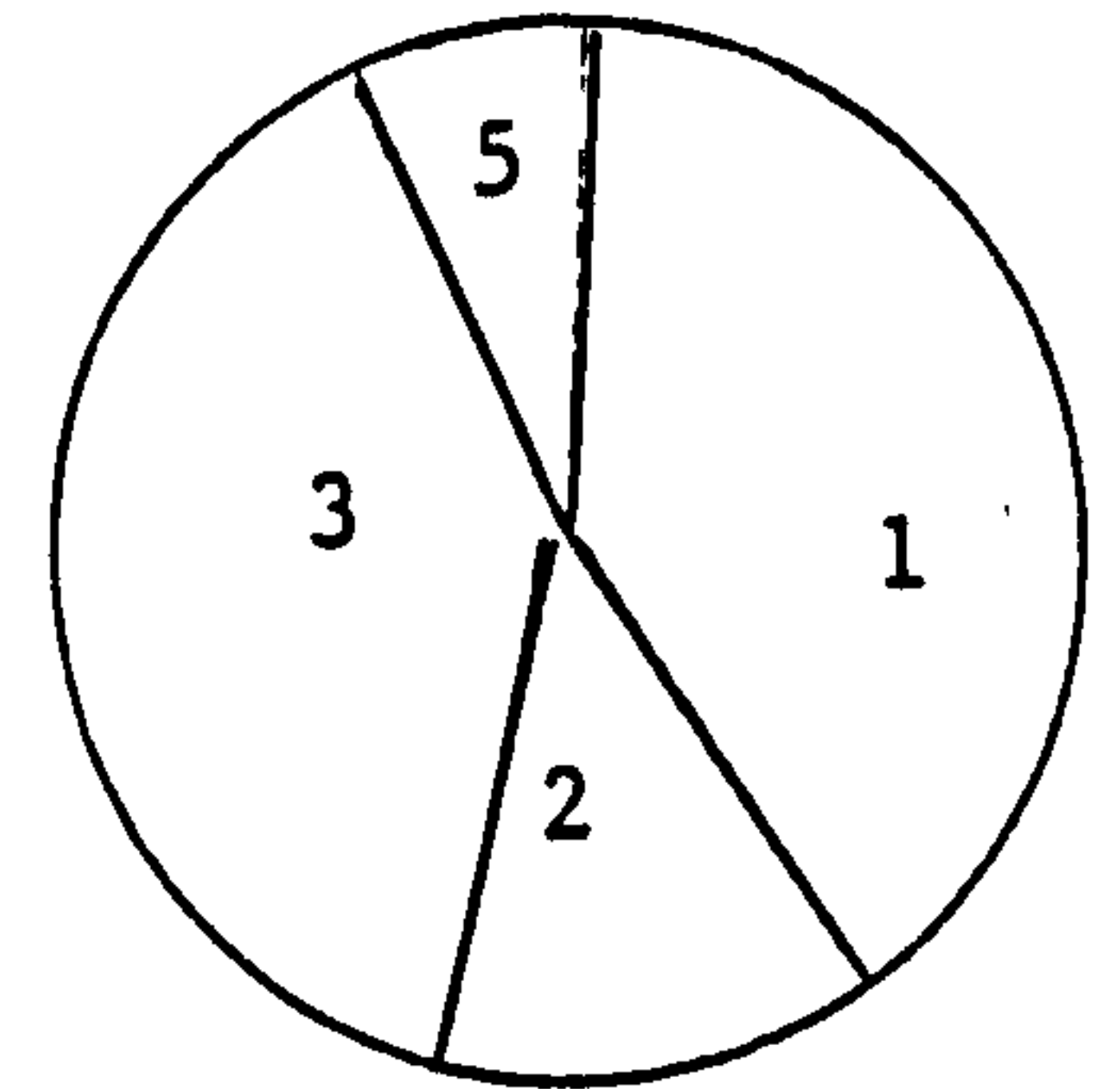
Rovies



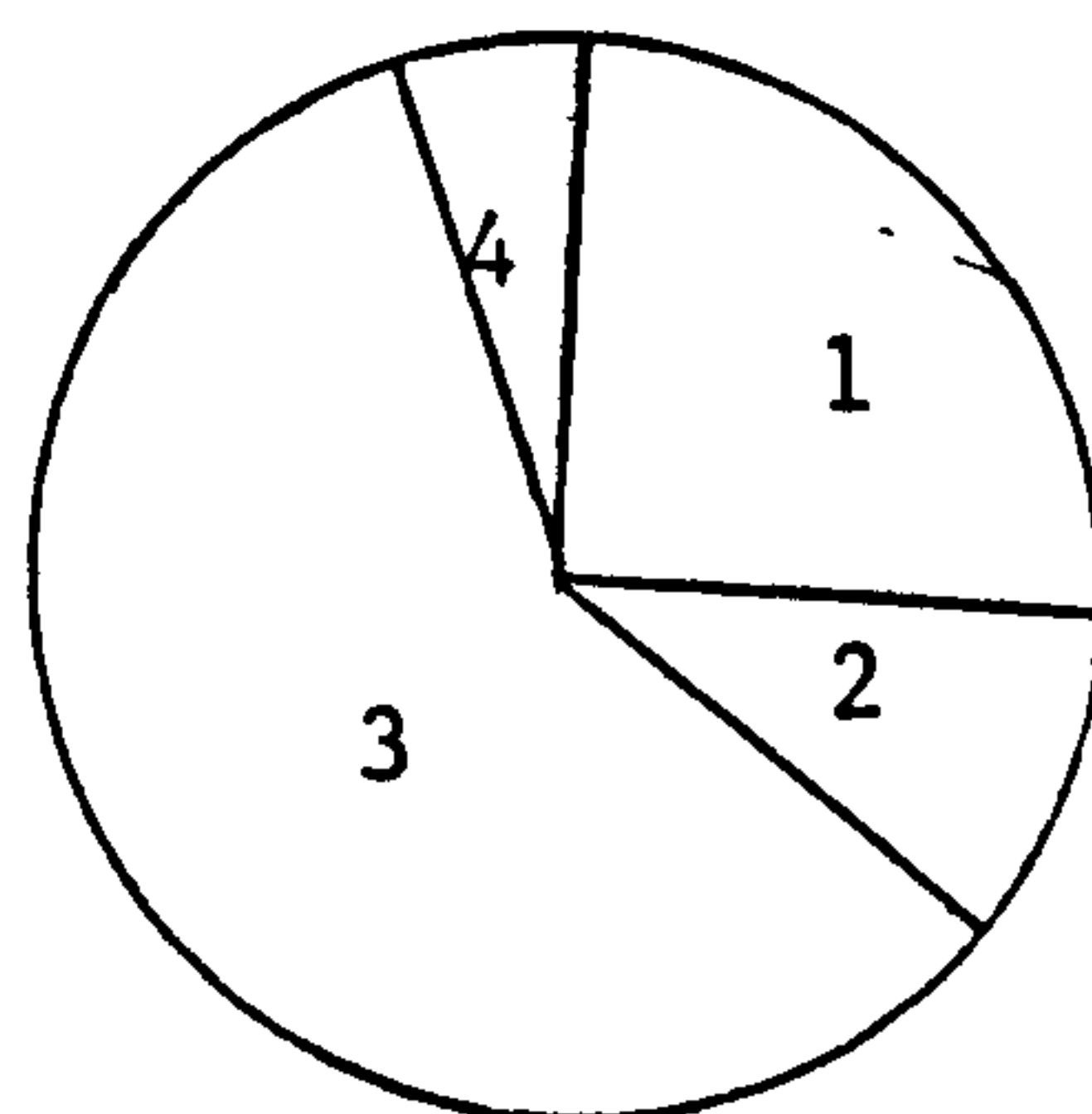
Anthedon



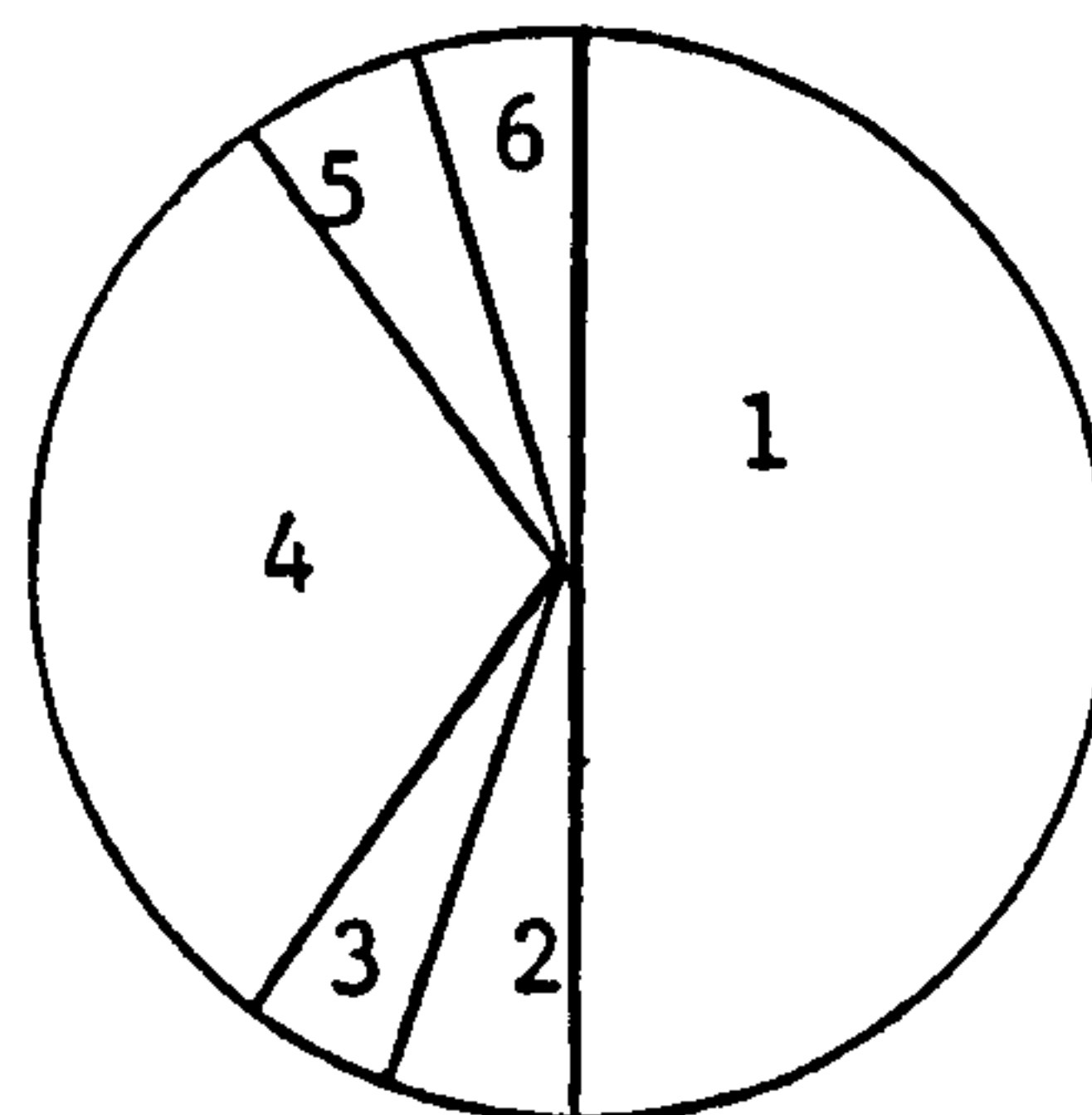
Chalia



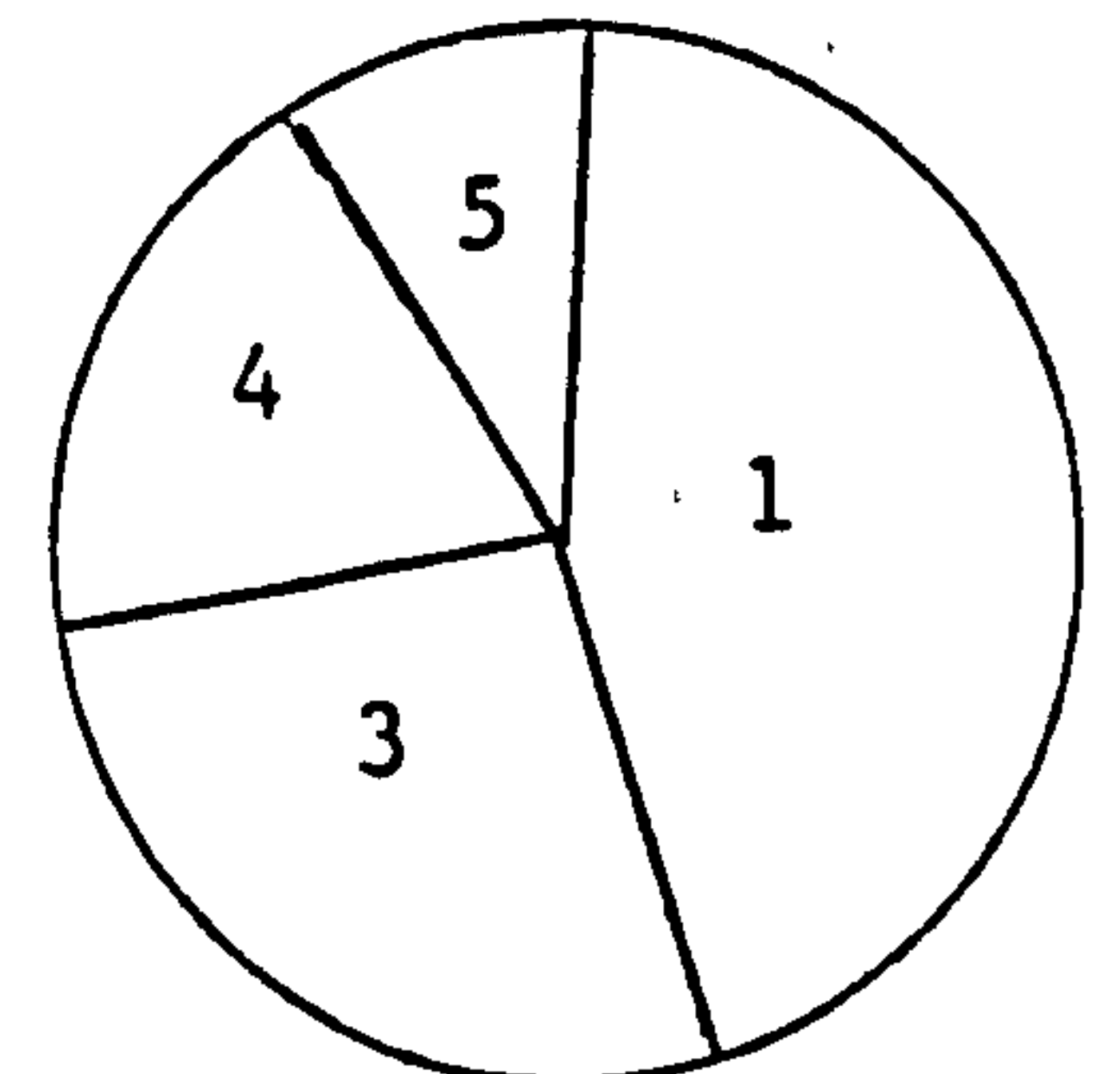
Dramesi



Eleon

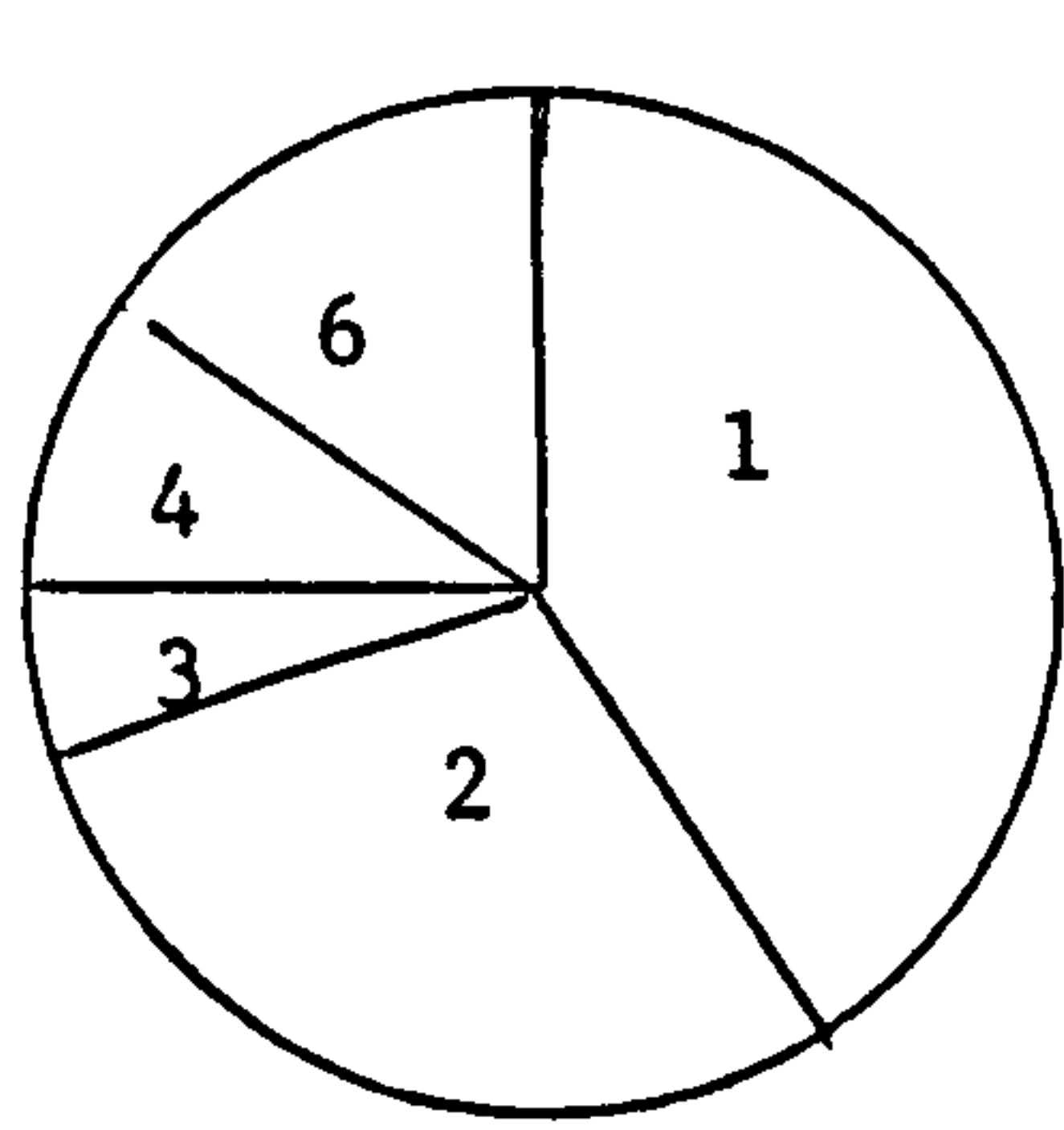


Kynos

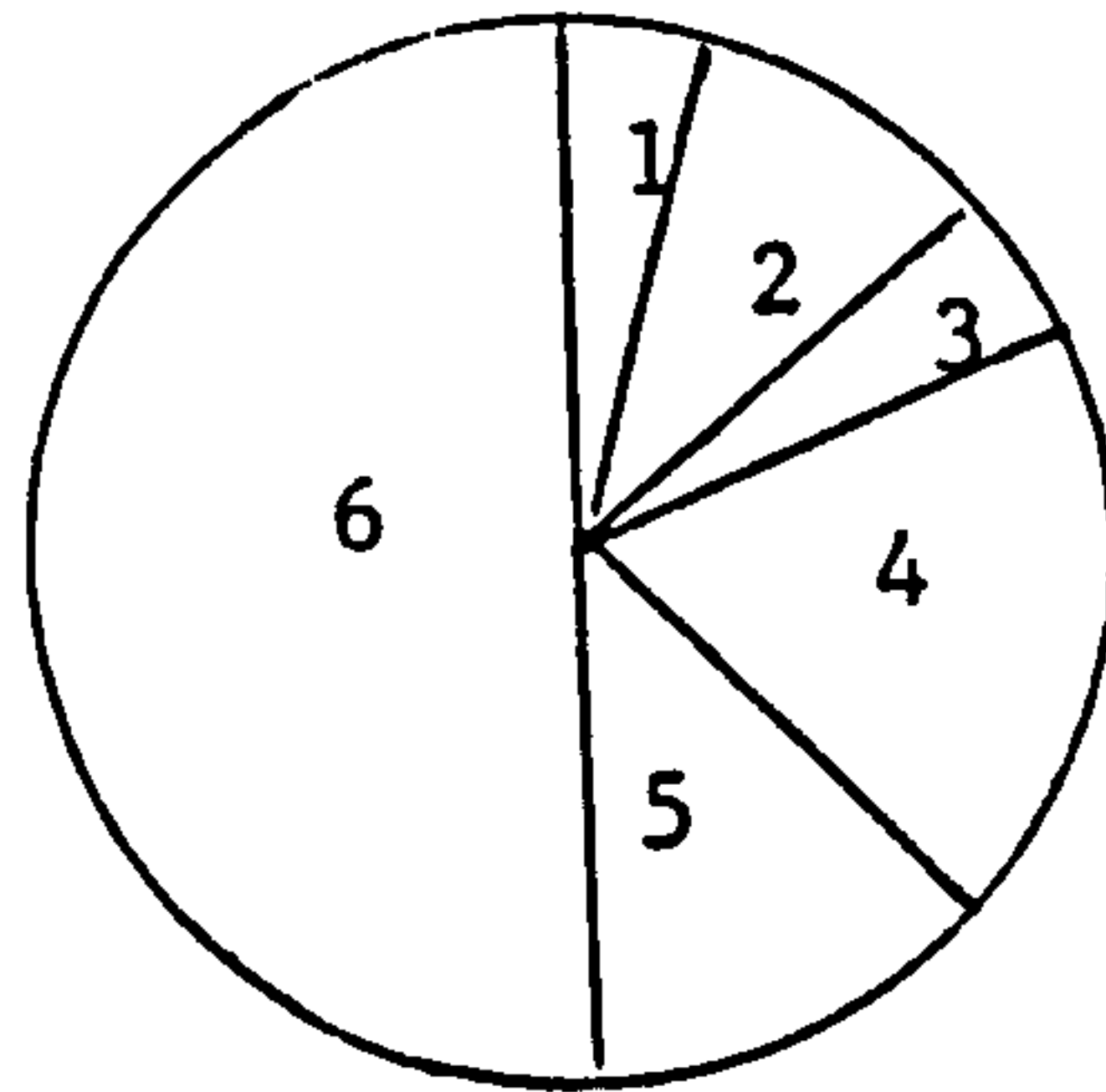


Thebes

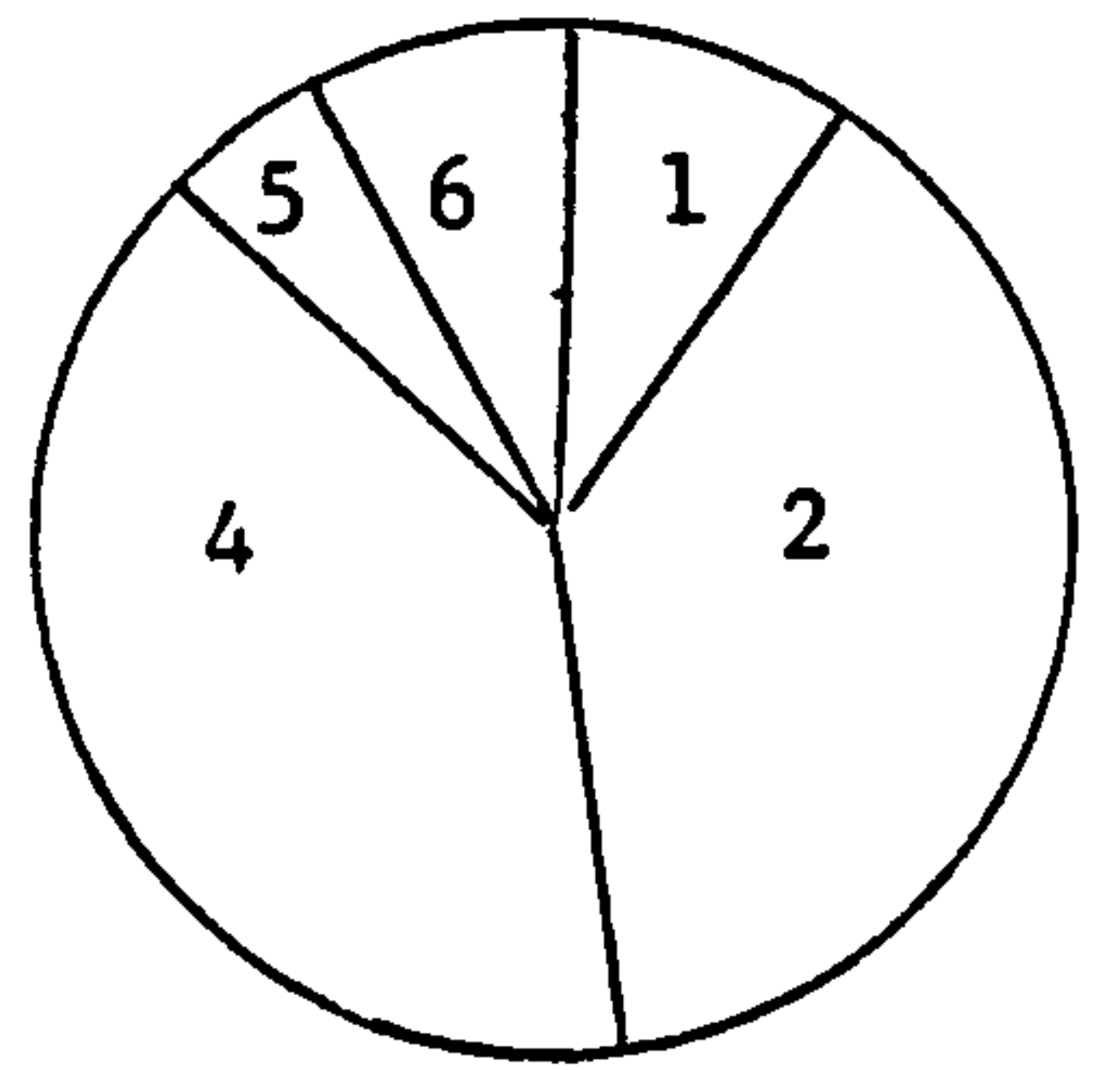
Figure 50. Proportion of sherds from each site in Euboea and Boeotia in each composition group.



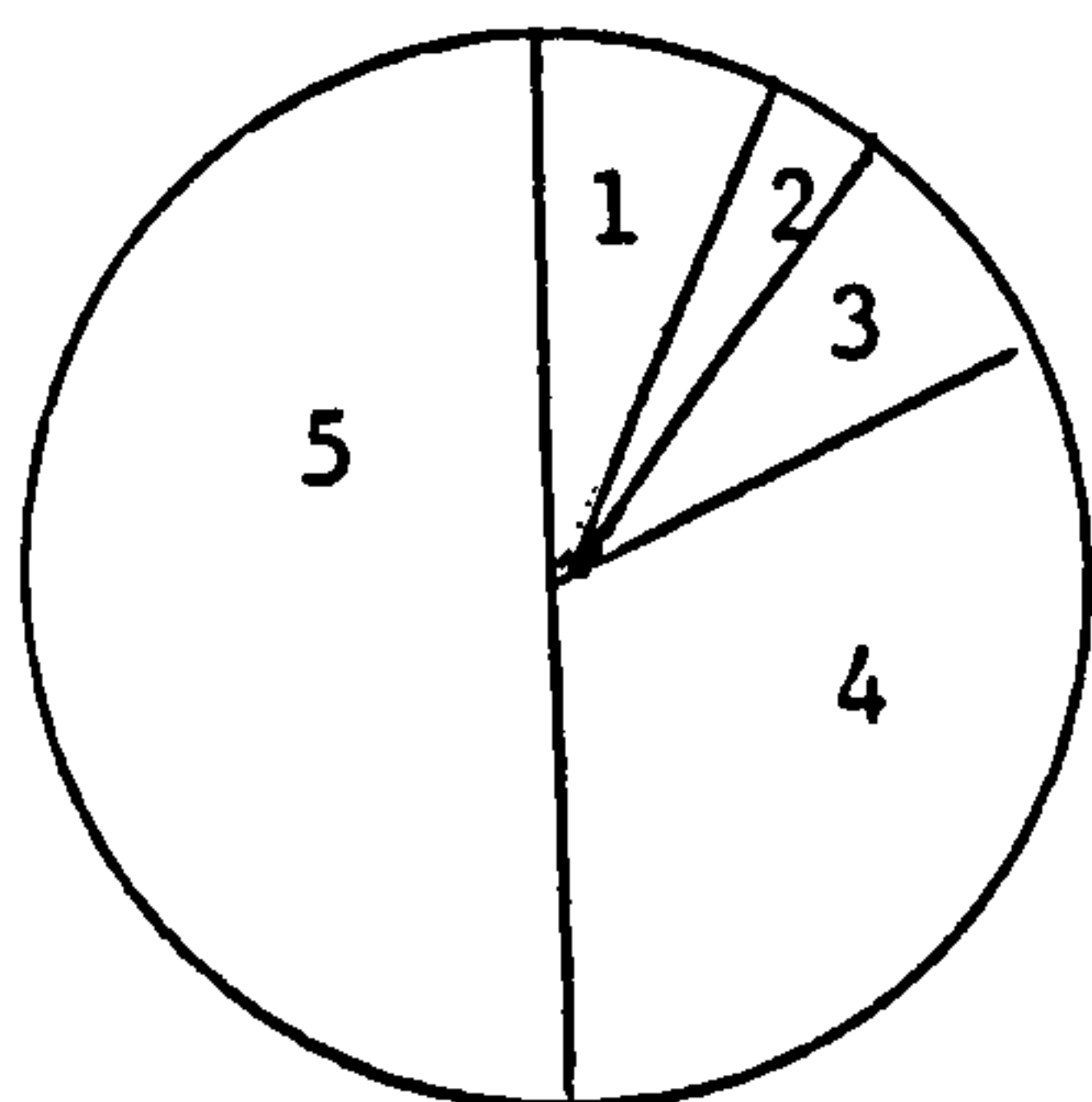
Argissa



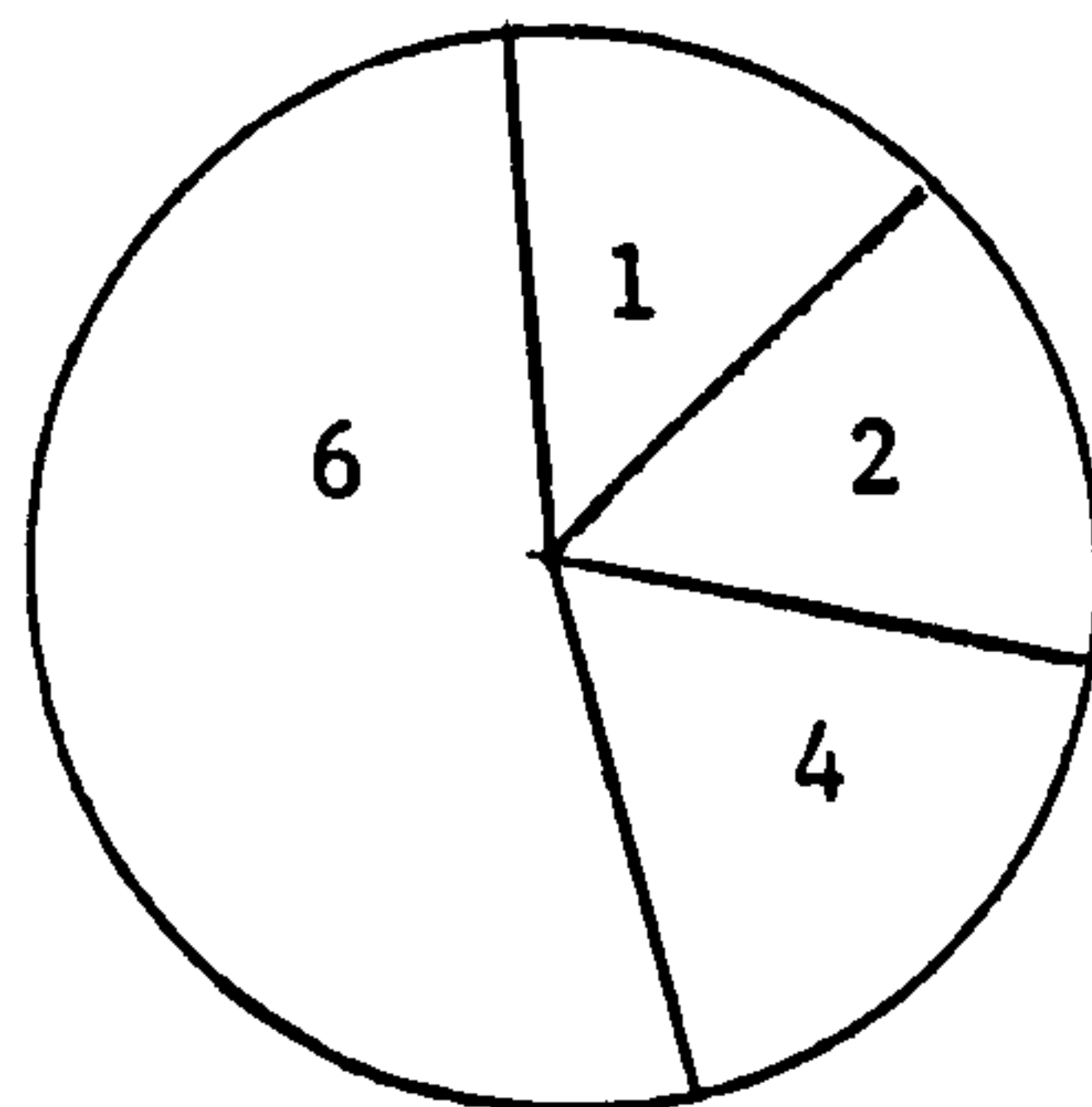
Iolkos



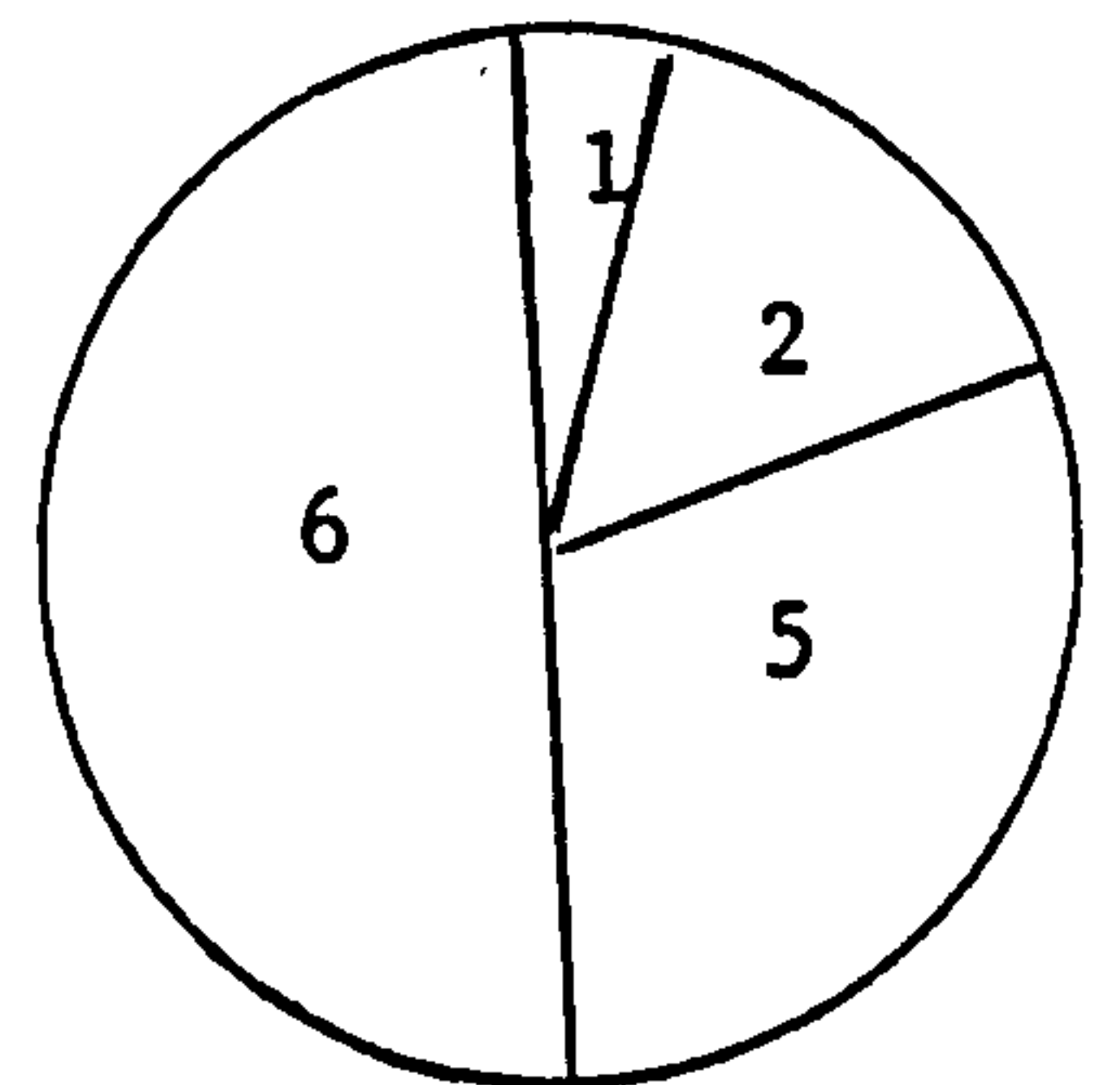
Volos (Iolkos)



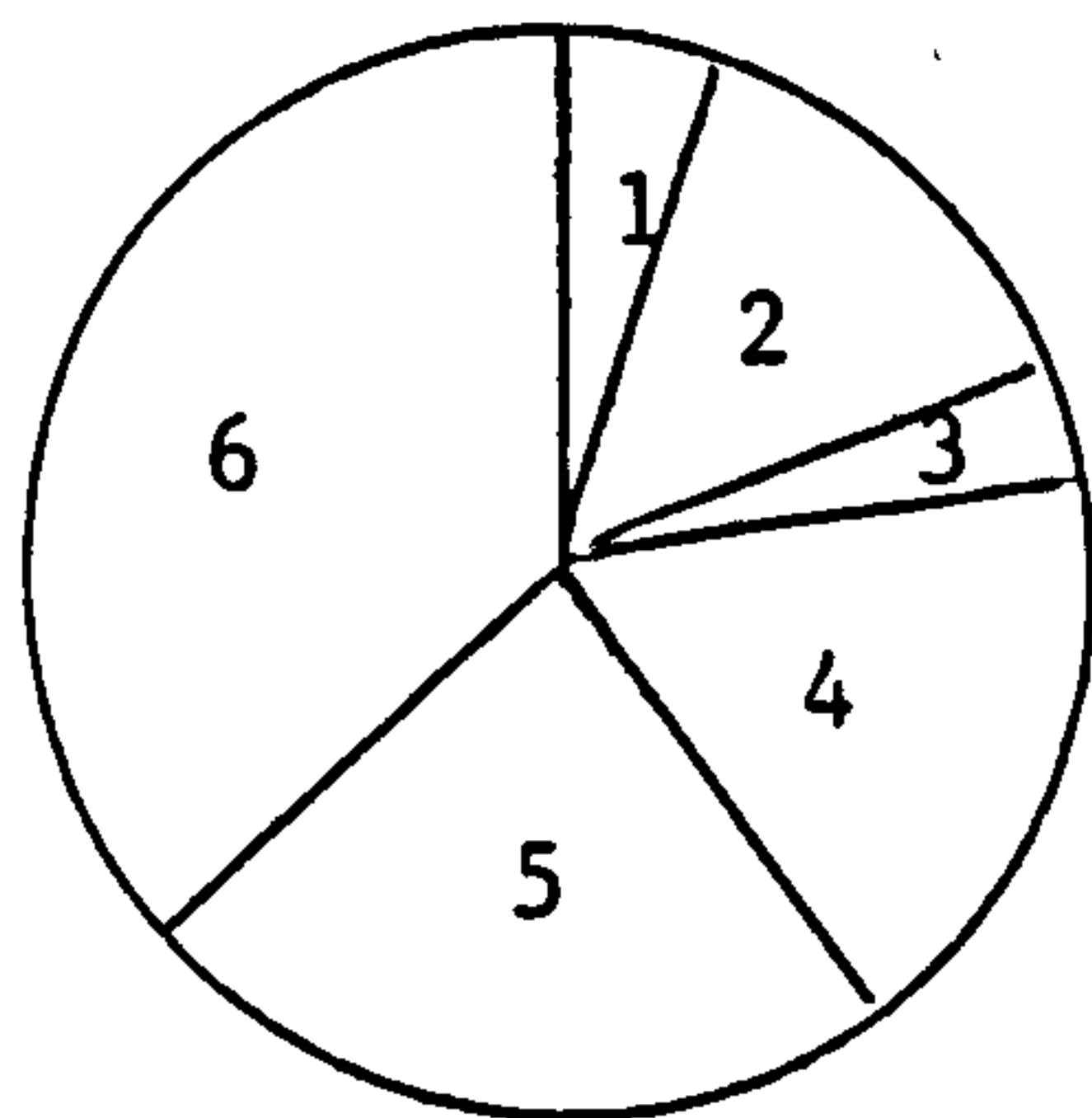
Marmariani



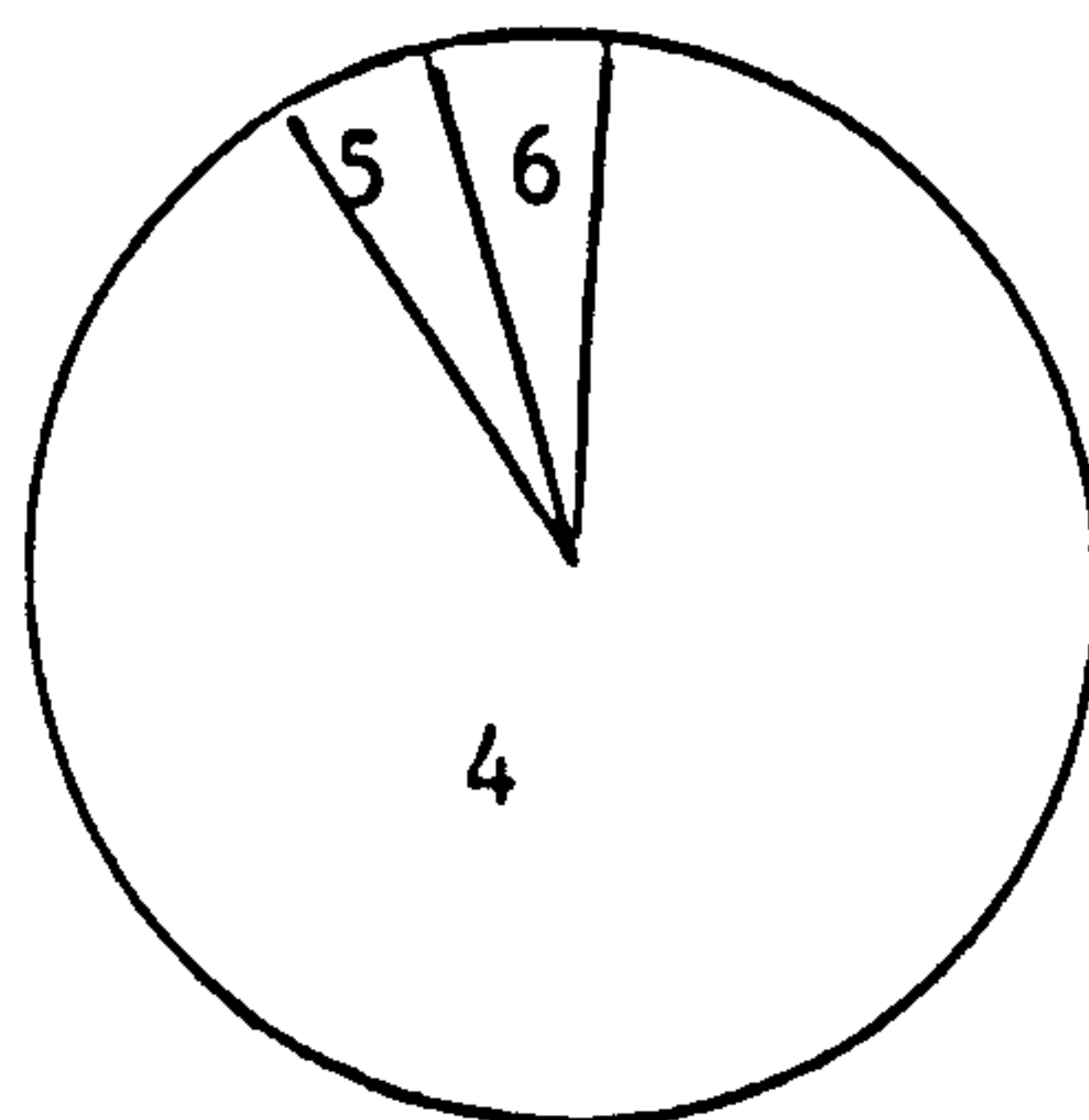
Pevkakia  
Early Bronze Age



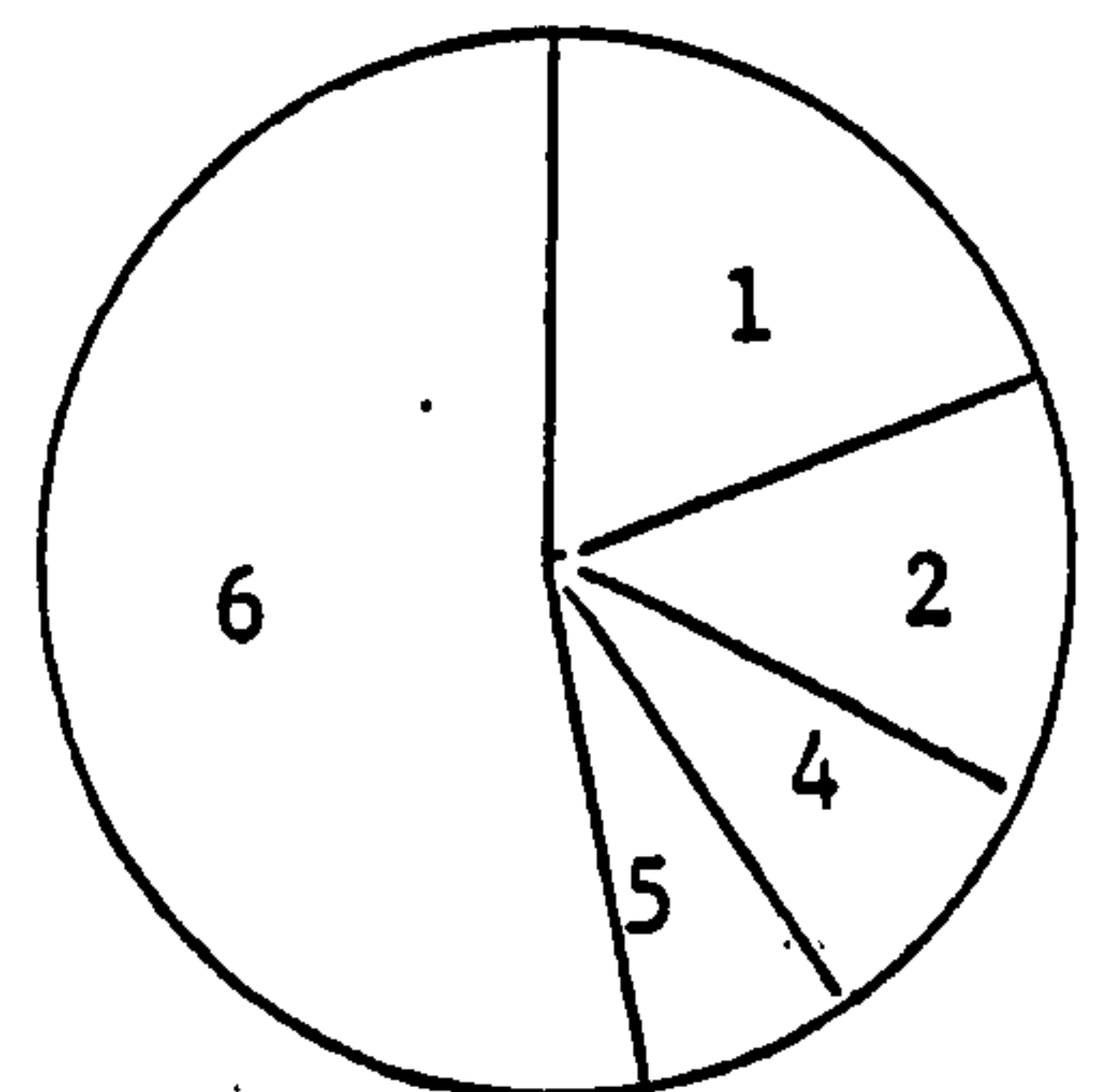
Pevkakia  
Middle Helladic



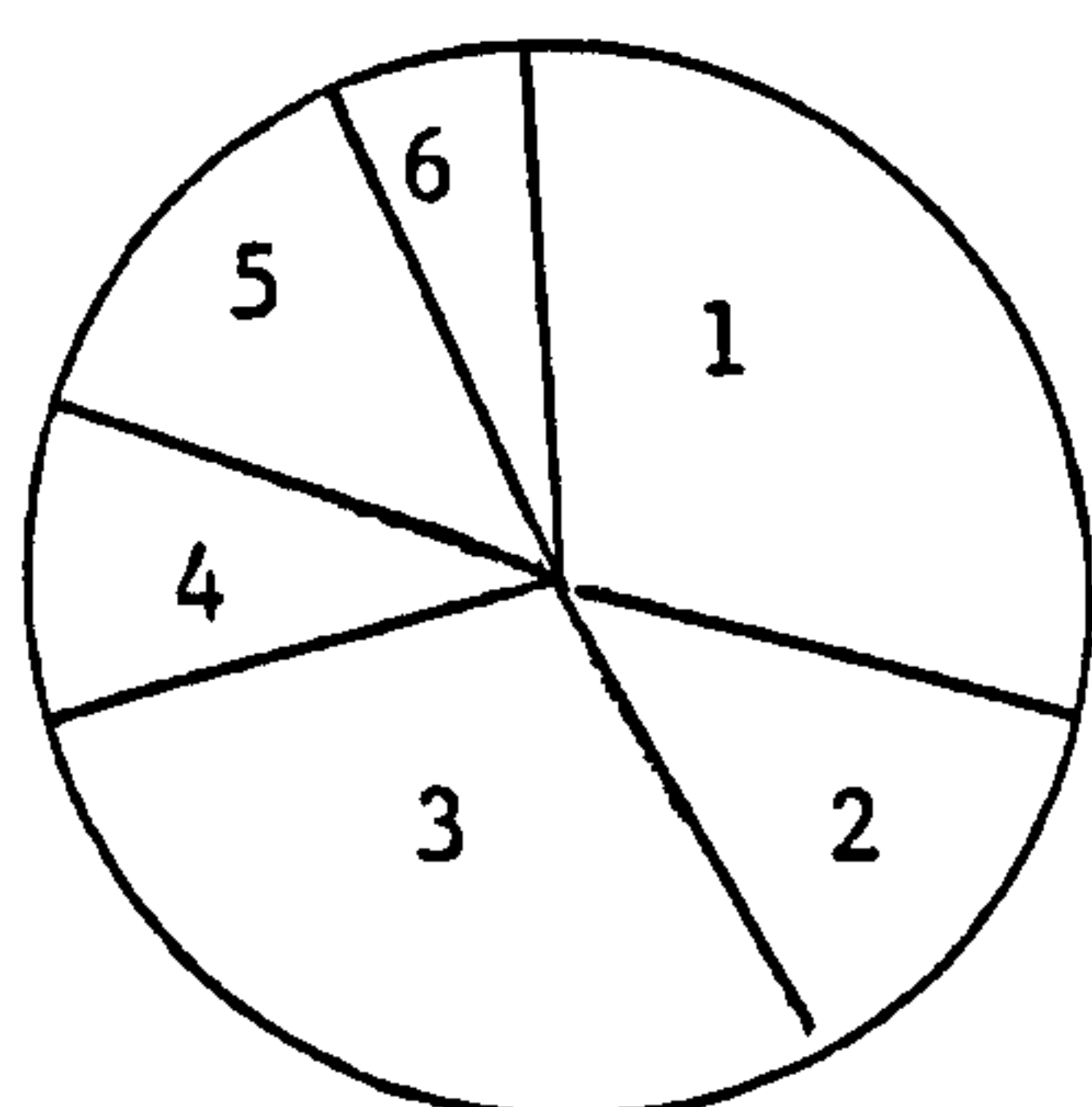
Pevkakia  
Late Helladic



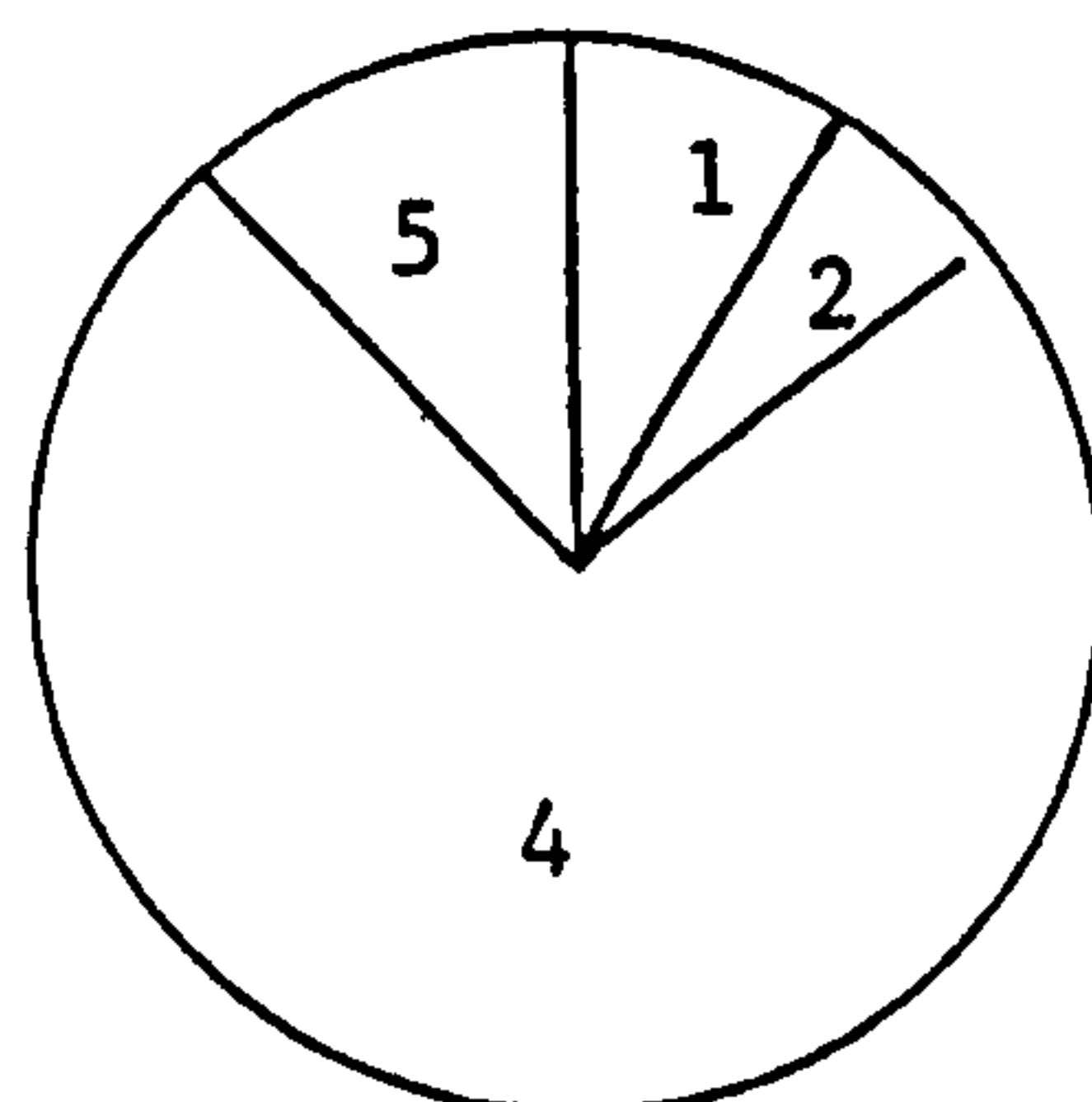
Revmatia



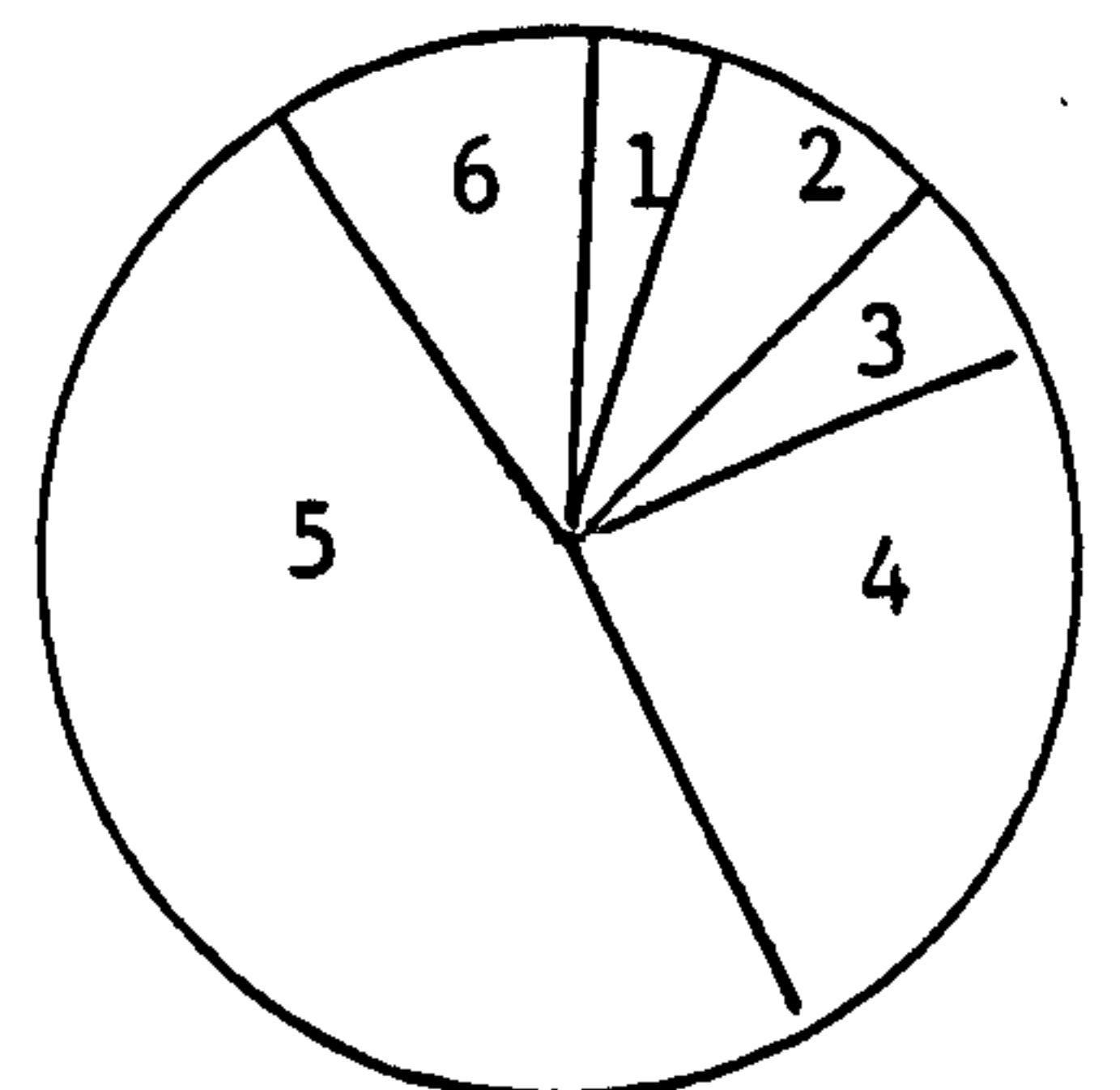
Velestino  
("local" and "Iolkos")



Velestino (Argolid)



Yephyria



Yephyra-Asmakiou

Figure 51. Proportion of sherds from each site in Thessaly in each composition group.

Euboea and Boeotia: Mg, Ni, Na, Al, Ca, Fe, Cr, Mn. Ti not used.

Thessaly: Ni, Ti, Na, Ca, Mg, Al, Fe. Cr and Mn not used.

Euboea, Boeotia and Thessaly: Ni, Mg, Na, Fe, Ca, Al, Ti, Mn, Cr.

Figure 52. The order of inclusion of the elements in the discriminant analysis of the optical emission data.



The first three discriminant functions that were calculated accounted cumulatively for 76.4, 94.1 and 97.8% of the total variance between the groups and so subsequent functions were of relatively little importance.

The means, standard deviations and the composition ranges at an 80% confidence level for the 6 groups are given below (Figure 53).

#### 6.5.4. The clays.

The clays from Euboea, Boeotia and Thessaly were provisionally assigned to the composition group which was most common in the area around where they were found and subjected to discriminant analysis with the archaeological samples. The clays from Amarynthos, Eretria and Lefkandi were provisionally assigned to group 2 (Euboean), the clay from Pyrgos to group 1 (Boeotian) and all the Thessalian clays to group 6. The computer, however, assigned the Amarynthos clay to group 1 with a higher probability than to group 2 (0.974 as opposed to 0.023). The other Euboean and Boeotian clays were not reassigned.

Of the Thessalian clays the Fitch Laboratory's Volos sample was reassigned to group 5 (north Thessalian) with a probability of 0.966 as opposed to a probability of only 0.004 that it could be identified with group 6 and the Dhimini clay was assigned to group 4 (south-west Thessalian) with a probability of 0.957 as opposed to 0.038 that it could belong to group 6. The Sesklo clays were not reassigned.

It was pleasing that the majority of the clays corresponded most closely to the prevalent composition group of the area in which they were found. It is not clear why the Amarynthos clay had a composition which corresponded more closely to that of Boeotia or why the Volos and Dhimini clays were assigned away from group 6. However, it should be

| Group | Al.                 | Ca.      | Mg.     | Fe.      | Ti.       | Na.       | Mn.         | Cr.         | Ni.         |
|-------|---------------------|----------|---------|----------|-----------|-----------|-------------|-------------|-------------|
| 1.    | $\bar{x}$ . 15.8    | 10.4     | 4.0     | 8.4      | 0.81      | 1.19      | 0.088       | 0.058       | 0.039       |
|       | s.d. 2.4            | 3.1      | 1.1     | 1.0      | 0.10      | 0.49      | 0.024       | 0.024       | 0.012       |
|       | 80% range 12.8-18.8 | 6.4-14.4 | 2.6-5.4 | 7.0-9.7  | 0.68-0.94 | 0.56-1.82 | 0.061-0.114 | 0.026-0.089 | 0.024-0.054 |
| 2.    | $\bar{x}$ . 17.6    | 6.2      | 2.3     | 8.0      | 0.77      | 2.19      | 0.086       | 0.030       | 0.020       |
|       | s.d. 3.1            | 3.2      | 1.0     | 1.0      | 0.12      | 0.66      | 0.023       | 0.013       | 0.008       |
|       | 80% range 13.7-21.5 | 2.1-10.3 | 1.1-3.5 | 6.7-9.2  | 0.62-0.92 | 1.35-3.03 | 0.064-0.116 | 0.013-0.047 | 0.010-0.030 |
| 3.    | $\bar{x}$ . 18.6    | 12.6     | 6.3     | 10.0     | 0.95      | 1.29      | 0.107       | 0.075       | 0.054       |
|       | s.d. 3.3            | 3.8      | 1.2     | 1.2      | 0.10      | 0.61      | 0.032       | 0.019       | 0.016       |
|       | 80% range 14.4-22.8 | 7.7-17.5 | 4.8-7.8 | 8.4-11.6 | 0.82-1.08 | 0.51-2.07 | 0.077-0.148 | 0.051-0.099 | 0.034-0.074 |
| 4.    | $\bar{x}$ . 15.3    | 11.8     | 3.1     | 8.0      | 0.71      | 1.52      | 0.109       | 0.047       | 0.030       |
|       | s.d. 3.0            | 6.2      | 1.0     | 1.2      | 0.09      | 0.89      | 0.036       | 0.017       | 0.009       |
|       | 80% range 11.5-19.1 | 3.9-19.7 | 1.9-4.4 | 6.5-9.5  | 0.59-0.83 | 0.38-2.66 | 0.063-0.155 | 0.024-0.069 | 0.019-0.041 |
| 5.    | $\bar{x}$ . 19.3    | 10.3     | 4.6     | 9.9      | 0.89      | 2.14      | 0.139       | 0.056       | 0.038       |
|       | s.d. 3.6            | 6.5      | 1.6     | 1.9      | 0.11      | 1.06      | 0.057       | 0.020       | 0.015       |
|       | 80% range 14.6-24.0 | 2.0-8.6  | 2.6-6.6 | 7.5-12.4 | 0.75-1.03 | 0.78-3.50 | 0.065-0.212 | 0.030-0.081 | 0.022-0.053 |
| 6.    | $\bar{x}$ . 17.3    | 5.1      | 2.1     | 6.8      | 0.71      | 2.78      | 0.090       | 0.035       | 0.016       |
|       | s.d. 3.1            | 2.9      | 0.9     | 1.4      | 0.10      | 1.12      | 0.039       | 0.018       | 0.007       |
|       | 80% range 13.3-21.3 | 1.3-8.9  | 1.0-3.2 | 5.1-8.6  | 0.58-0.84 | 1.35-4.21 | 0.039-0.140 | 0.012-0.058 | 0.007-0.025 |

Figure 53. Compositions of optical emission groups obtained after discriminant analysis (792 sherds).

borne in mind that with the exception of the Lefkandi, Sesklo and Dhimini clays the samples were not collected systematically and the provenance was not always recorded accurately, as in the case of the Volos clay.

While it is important that when pots from a site are analysed clays from the same area are included in the project, it is more than time that a project be carried out which is primarily concerned with clays rather than with pots and which would involve systematic sampling and analysis of raw, levigated and fired clays together with pots from one area and ideally involving a kiln site with wasters in situ.

#### 6.6. Interpretation of the atomic absorption data.

The atomic absorption analyses were performed on about a quarter of the total number of sherds included in this project, and these sherds were selected to represent each of the geographical areas involved in this study, comprised the sherds from Lefkandi and Rovies with half of the sherds from Amarynthos on Euboea; the Thebes, Eleon and Anthedon sherds from Boeotia and the Revmatia, Volos (Iolkos), Pevkakia LH subgroup II sherds and half of the sherds from Marmariani from Thessaly.

When the Euboean and Boeotian sherds were put through cluster analysis together the most satisfactory grouping was at a coefficient of 14.821 with three groups. The next possible fusion would have been at a coefficient of 18.135. Groups 1 and 3 consisted mainly of Boeotian material and was therefore considered to be Boeotian and group 2 which consisted mainly of Euboean material was considered to be Euboean. The Thessalian material divided into 4 groups (groups 4-7) at a coefficient of 13.147 with the next possible fusion at 22.208. These groups were a closer approximation to 'site' groups than any of those identified from



the optical emission analysis. Group 4 contained 21/22 sherds from Revmatia, group 5 contained 19/20 sherds from Marmariani and one from Revmatia, group 6 contained all the sherds from Volos (Iolkos) and group 7 only those from Pevkakia LH sub-group II.

When these groups were tested with discriminant analysis the situation appeared quite complicated. There was good separation between groups 5 and 6 and the others and considerable overlap between all the other groups on a 2-dimensional plot. There was little alteration to the groupings. Figure 54 shows a plot of the group centroids and the space occupied by 90% of the samples in each group on the first two discriminant functions. However, it was felt that the poor precision and the problems associated with the accurate measurement of chromium and nickel might be introducing an untoward bias into the analysis and the discriminant analysis was repeated without chromium and nickel. The resultant plot, shown in Figure 55, is clearer than before with 82.8% of the cases correctly classified and the final groupings are listed in Appendix 5. Their composition ranges are shown in Figure 56. These show that the results of the atomic absorption analysis generally produced tighter clusters than the optical emission analysis even allowing for the smaller volume of data involved. Broadly speaking, the groupings are similar with either technique with 2 Boeotian groups (1 and 3) which are broadly similar but distinct and one Euboean group, group 2. In Thessaly there are 4 groups instead of the 3 found in the optical emission data because Pevkakia LH Group II separated out as a group on its own (Group 7). Group 4 is the western Thessalian group concentrated around Pharsala, group 5 the northern group and group 6 is concentrated on the Volos area. The percentage of the sherds from each area in the different groups is shown in Figure 57a. By the

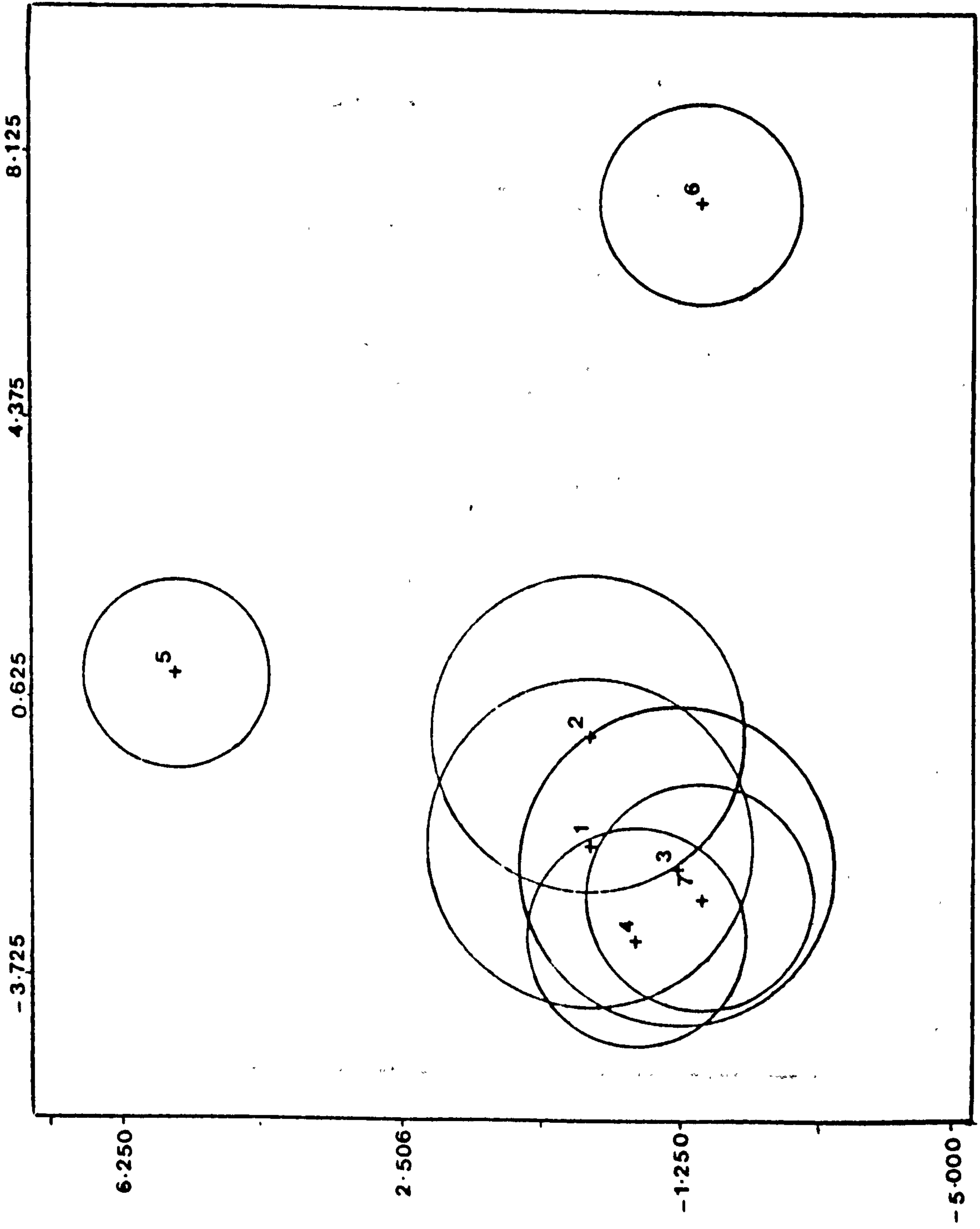


Fig 54 Plot of the area occupied by 90% of the samples in each group of the atomic absorption data on the first 2 discriminant functions

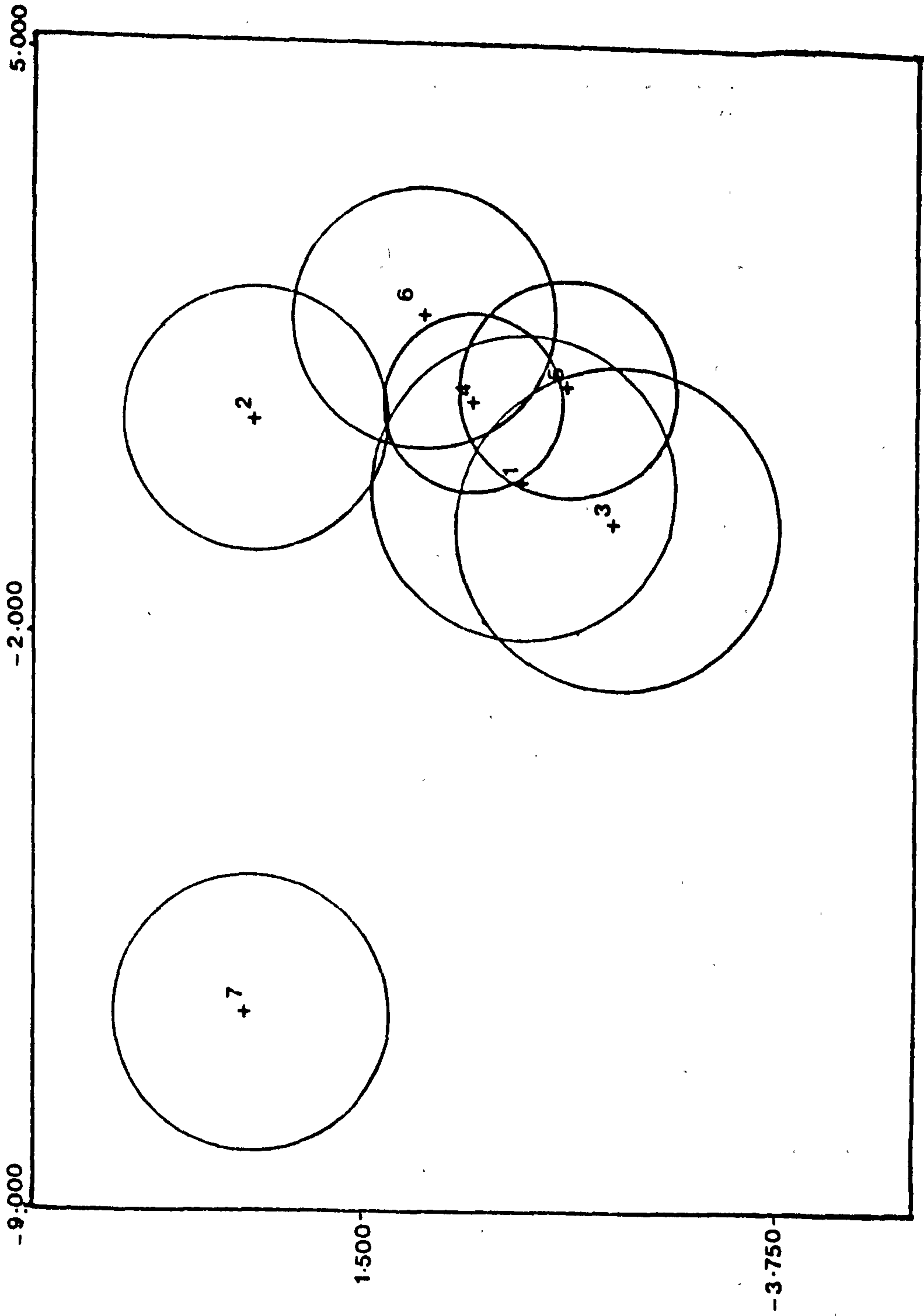


Fig 55 Plot of the area occupied by 90% of the samples in each group of the atomic absorption data (without chromium and nickel) on the first 2 discriminant functions



| Group                               | Al.       | Ca.       | Mg.       | Fe.     | Ti.       | Na.       | Mn.         | K.        |
|-------------------------------------|-----------|-----------|-----------|---------|-----------|-----------|-------------|-----------|
| 1. $\bar{x}$ .<br>s.d.<br>80% range | 14.8      | 11.6      | 4.5       | 7.6     | 1.18      | 0.57      | 0.118       | 2.39      |
|                                     | 2.1       | 4.2       | 1.2       | 0.8     | 0.19      | 0.19      | 0.031       | 0.44      |
|                                     | 12.1-17.5 | 6.2-17.0  | 3.0-6.0   | 6.6-8.6 | 0.94-1.42 | 0.33-0.81 | 0.077-0.158 | 1.83-2.95 |
| 2. $\bar{x}$ .<br>s.d.<br>80% range | 19.5      | 5.2       | 2.6       | 8.0     | 1.34      | 1.46      | 0.122       | 3.42      |
|                                     | 1.8       | 1.2       | 0.5       | 0.7     | 0.17      | 0.31      | 0.022       | 0.65      |
|                                     | 12.0-21.8 | 3.7-6.7   | 1.9-3.3   | 7.1-8.9 | 1.12-1.56 | 1.06-1.86 | 0.093-0.150 | 2.59-4.25 |
| 3. $\bar{x}$ .<br>s.d.<br>80% range | 13.8      | 10.4      | 5.7       | 8.2     | 1.28      | 0.76      | 0.179       | 2.05      |
|                                     | 2.0       | 3.2       | 1.3       | 1.1     | 0.31      | 0.31      | 0.057       | 0.54      |
|                                     | 11.2-16.4 | 6.3-14.5  | 6.8-7.4   | 6.8-9.6 | 0.88-1.68 | 0.36-1.16 | 0.106-0.252 | 1.36-2.74 |
| 4. $\bar{x}$ .<br>s.d.<br>80% range | 15.1      | 16.4      | 2.98      | 7.2     | 0.86      | 0.57      | 0.113       | 1.69      |
|                                     | 1.9       | 3.7       | 0.56      | 0.90    | 0.21      | 0.15      | 0.021       | 0.22      |
|                                     | 12.7-17.6 | 11.7-21.1 | 2.26-3.70 | 6.1-8.4 | 0.59-1.30 | 0.38-0.76 | 0.086-0.140 | 1.41-1.97 |
| 5. $\bar{x}$ .<br>s.d.<br>80% range | 15.4      | 8.5       | 5.4       | 8.0     | 1.09      | 1.30      | 0.202       | 2.32      |
|                                     | 2.4       | 2.9       | 1.2       | 1.3     | 0.23      | 0.35      | 0.043       | 0.43      |
|                                     | 2.3-18.5  | 4.8-12.2  | 3.9-6.9   | 6.4-9.7 | 0.80-1.38 | 0.85-1.75 | 0.147-0.257 | 1.77-2.87 |

continued on page 202

procedure mentioned above (Chapter 6.5.3) the standard deviation for the data from each area was calculated, allowing for the 7 rather than 6 composition groups, and the number of standard deviations by which the percentage of sherds from each area that fell in the groups deviated from the expected value if all probabilities were equal was assessed. Since there were 7 groups in this case 14.3% of the samples from each region might have been expected to fall in each group. Figure 57b shows the significance of the percentage of the sherds that did fall in each group. It shows that there is little indication of pottery having been imported to Euboea and Boeotia from Thessaly although there is evidence to show that there was some trade the other way, especially from Boeotia.

When the discriminant analysis was done omitting nickel and chromium the order in which the elements were selected for their discriminating power was: sodium, magnesium, iron, potassium, calcium and manganese. Titanium and aluminium were not used. As in the optical emission analysis sodium, magnesium, calcium and iron were in the first five elements used with potassium replacing nickel in importance, thus warranting its inclusion in the elements measured.

When all 7 groups were considered in this way the first 4 discriminant functions accounted cumulatively for 34.3, 65.2, 87.6 and 98.2% of the total between-group variance. Since nickel and chromium, one of which at least was of major use as a discriminant in optical emission, were both excluded from the analysis for the reasons mentioned above, it is not surprising that each of the first three discriminant functions is less effective than in the optical emission analysis and that they are more equally weighted. Each of them contributes c 30% of the total between-group variance. The plot shown in Figure 55 is on the first 2

| Group          | Al.       | Ca.      | Mg.     | Fe.       | Ti.       | Na.       | Mn.         | K.        |
|----------------|-----------|----------|---------|-----------|-----------|-----------|-------------|-----------|
| 6. $\bar{x}$ . | 16.6      | 7.5      | 3.6     | 7.2       | 1.16      | 1.51      | 0.127       | 2.60      |
| s.d.           | 2.0       | 3.8      | 1.4     | 1.3       | 0.21      | 0.51      | 0.021       | 0.31      |
| 80% range      | 14.0-19.2 | 2.6-12.4 | 1.8-5.4 | 5.5-8.9   | 0.89-1.43 | 0.86-2.16 | 0.100-0.153 | 2.20-3.00 |
| 7. $\bar{x}$ . | 16.6      | 1.2      | 2.9     | 11.9      | 1.93      | 0.51      | 0.127       | 1.89      |
| s.d.           | 1.3       | 0.1      | 0.9     | 1.2       | 0.13      | 0.18      | 0.026       | 0.35      |
| 80% range      | 14.9-18.3 | 1.1-1.4  | 1.7-4.1 | 10.4-13.4 | 1.8-2.1   | 0.28-0.74 | 0.094-0.160 | 1.44-2.34 |

Figure 56. Compositions of atomic absorption groups obtained after discriminant analysis  
(192 sherds)



discriminant functions but if it were on the first and third a similar picture would be obtained. If it were plotted on the second and third discriminant functions the picture would be a little less clear. A 3 - rather than a 2-dimensional plot would bring out the differences between the groups and since the atomic absorption groups are tighter than the optical emission ones, with smaller concentration ranges, a 3-dimensional plot might well show greater separation between the groups than in optical emission.

|          | 1       | 2      | 3       | 4           | 5           | 6             | 7           |
|----------|---------|--------|---------|-------------|-------------|---------------|-------------|
|          | Boeotia | Euboea | Boeotia | W. Thessaly | N. Thessaly | S.E. Thessaly | Pevkakia II |
| Euboea   | 36.2    | 44.8   | 12.1    | 1.72        | 1.72        | 1.72          | 1.72        |
| Boeotia  | 29.5    | 21.3   | 42.6    | 3.28        | -           | -             | 3.28        |
| Thessaly | 6.8     | 1.4    | 1.4     | 26.0        | 30.1        | 11.0          | 23.3        |

Figure 57a. The percentage of the sherds from each area in each composition group from the atomic absorption analysis (192 sherds).

|          | 1       | 2      | 3       | 4           | 5           | 6             | 7           |
|----------|---------|--------|---------|-------------|-------------|---------------|-------------|
|          | Boeotia | Euboea | Boeotia | W. Thessaly | N. Thessaly | S.E. Thessaly | Pevkakia II |
| Euboea   | >++     | >++    | 0       | <---        | <==         | <---          | <---        |
| Boeotia  | >++     | ++     | >++     | <---        | <---        | <---          | <---        |
| Thessaly | <---    | <---   | <---    | >++         | >++         | 0             | ++          |

0 = within  $\pm 1\sigma$  (not significant); + = over  $> + 2\sigma$ ; ++ = much over  $+ 2\sigma$ ; +++ = between  $-1$  and  $-2\sigma$ ;  
 --- =  $< - 2\sigma$ ; <--- = much  $< -2\sigma$ .

Figure 57b. The significance of the distribution of material shown in Figure 57a.

CHAPTER 7.

DISCUSSION



CHAPTER 7.

DISCUSSION

7.1. Comparison with older data.

Clearly it is desirable to relate the results obtained in this project to earlier analyses done in Oxford and Athens. Unfortunately this is not straightforward. As mentioned above (Chapter 1.1) a recalibration of the technique was effected in 1974 which resulted in the production of a set of 'conversion factors' to be applied to all pre-1971 data (Prag et al., 1974). It now appears that these conversion factors are "inoperable over a wide concentration range" and are valid strictly over a small range of concentrations. Such ranges, for example, include magnesium 3-4%, calcium 10-15% and iron 7-9% (Catling et al., 1980). To make the earlier data comparable with recent analyses a sliding-scale conversion factor is needed which, as was pointed out (*ibid*), would necessitate the use of a computer. Use of older data is also made difficult by the alterations and improvements which have been made in the optical emission technique over the years and which have led to a lack of reproducibility over a period of about ten years. This area has been further complicated by changes in the methods of interpretation of the results. It was only last year that the Fitch laboratory's policy towards the use of this older data was first stated (*ibid*). It is "(1) To treat the data in the first instance as a primary data set. Its principal value rests in the comprehensiveness of its coverage of the Late Bronze Age Aegean... (2) To use the data indirectly in current work.... There is, however, a sufficient measure of agreement between the two sets of data, the former after the application of the conversion factors, for the Fitch laboratory to use individual and group compositions for reliable background information".

The old analytical results produced by the Oxford and Athens laboratories for Euboea, Boeotia and Thessaly, and the more recent Theban control group were compared with the groupings obtained in this project. In the older work (Catling et al., 1965) group B was Boeotian, group D was the 'northern average' which included sherds from Amarynthos in Euboea and Volos and Argyropoulis in Thessaly and group E consisted mainly of material from Marmariani in Thessaly. Apart from the reservations mentioned above it should also be borne in mind that these groups are based on much smaller numbers of samples than the groups in this project. The concentration ranges of groups B, D, E, together with groups 1, 5 and 6 which were defined in Chapter 6, are shown in Figure 58, together with the Theban control group published in Catling et al. (1980). Groups 1, 5 and 6 are included since they might be expected to be the most similar to groups B, E and D respectively. Ideally discriminant analysis would have been performed on these groups to test their similarity or dissimilarity and to test the compositional homogeneity of the older groups. Unfortunately, the individual results for the sherds which make up groups B, D and E have not been published and so this was not possible. Visual comparison of the composition ranges for the groups shows that the ranges for group 1 and the Theban control group correspond quite well and that group B is similar enough to both of them, allowing for the problems of recalibration for them to be considered broadly comparable. The ranges for groups D and 6 overlap for all 8 elements, separating on nickel alone. The composition ranges for group D are broader than for group 6 for most elements. Since it is only on one element that the ranges separate it is still possible to say that the groups are probably comparable. Group E and group 5 can also be equated with each other although there is just

| Group                | Al.   | Ca.   | Mg.  | Fe.  | Ti.   | Na.   | Mn.    | Cr.    | Ni.    |
|----------------------|-------|-------|------|------|-------|-------|--------|--------|--------|
| B                    | 15.5- | 14.3- | 5.6- | 8.4- | 1.01- | 0.78- | 0.099- | 0.042- | 0.026- |
|                      | 22.5  | 20.9  | 7.6  | 12.0 | 1.30  | 1.98  | 0.161  | 0.087  | 0.049  |
|                      | 15.2- | 9.3-  | 3.1- | 7.0- | 0.73- | 0.72- | 0.070- | 0.026- | 0.020- |
| Theban Control Group | 22.2  | 19.3  | 7.7  | 11.0 | 1.03  | 1.90  | 0.132  | 0.090  | 0.086  |
|                      | 12.8- | 6.4-  | 2.6- | 7.1- | 0.68- | 0.56- | 0.061- | 0.026- | 0.024- |
| I                    | 18.8  | 14.4  | 5.4  | 9.7  | 0.94  | 1.82  | 0.114  | 0.089  | 0.054  |
|                      |       |       |      |      |       |       |        |        |        |
| D                    | 17.2- | 4.7-  | 2.0- | 5.6- | 0.73- | 1.49- | 0.087- | 0.011- | 0.026- |
|                      | 28.1  | 7.9   | 4.7  | 10.2 | 1.09  | 2.83  | 0.152  | 0.024  | 0.040  |
| 6                    | 13.3- | 1.3-  | 1.0- | 5.1- | 0.58- | 1.35- | 0.039- | 0.011- | 0.008- |
|                      | 21.3  | 8.9   | 3.2  | 8.6  | 0.84  | 4.21  | 0.140  | 0.058  | 0.024  |
| E                    | 18.5- | 8.5-  | 4.9- | 8.5- | 1.04- | 1.66- | 0.143- | 0.034- | 0.010- |
|                      | 22.8  | 12.3  | 6.1  | 12.4 | 1.33  | 2.42  | 0.195  | 0.051  | 0.031  |
| 5                    | 14.6- | 2.0-  | 2.6- | 7.5- | 0.75- | 0.78- | 0.065  | 0.030- | 0.022- |
|                      | 24.0  | 8.6   | 6.6  | 12.4 | 1.03  | 3.50  | -0.212 | 0.081  | 0.053  |

Figure 58. Composition ranges at an 80% confidence level for groups 1, 5 and 6 with the Oxford laboratory's groups B, D and E and the Fitch laboratory's Theban control group.



separation of the concentration ranges for titanium. The calcium ranges almost separate and it should be remembered that the concentrations are outside the optimum limits for the application of the conversion factors mentioned above. It was especially unfortunate that multivariate analysis could not be performed on the older groupings since they were grouped without the use of a computer and it is possible that some of the sherds would have been re-assigned resulting in better correspondence between the old groups and those identified in this project.

### 7.2. Euboea and Boeotia.

Figure 45 shows that there is no overlap between groups 2 and 3 but that group 1 has some overlap with both group 2 and group 3.

Group 1 consists mainly of sherds from Thebes (9/20) and Kynos (10/20) in Boeotia and Aliveri (11/20) in Euboea. These sites are not particularly close to each other and yet over 40% of the sherds from each of these sites were assigned to this group. However, Thebes, Kynos and Aliveri are on similar geological formations: marls, limestone, sandstone and conglomerates which could account for the similarity if these results represent manufacture at each of these sites. On the other hand, as Dr. O. T. P. K. Dickinson remarked (pers. comm. 1981), it is not unlikely that small sites like Kynos imported pottery, especially fine decorated wares from more important sites like Thebes and therefore that Thebes alone was manufacturing these pots. Forty per cent of the sherds from Dramesi came from each of the mainly Boeotian groups (1 and 3) and most of the remainder from Euboea. This group is therefore thought to come from around Thebes.

Group 3 was the other group which consisted mainly of material from Boeotian sites and it was concentrated in the area on the Boeotian coast opposite Chalkis. It was mainly composed of sherds from Chalia (10/20), Dramesi (8/20), Eleon (12/20) and Thebes (5/20) with 10 sherds from Rovies and a few from the other Euboean sites.

Group 2 was the mainly Euboean group and included a large proportion of the sherds from Amarynthos (20/41), Gialtra (11/21), Lefkandi (13/20) in Euboea and Anthedon in Boeotia (10/18), with a few sherds from Chalia, Dramesi, Eleon and Kynos but none from Thebes.

It is not surprising that there was a considerable amount of movement of pottery within Euboea and Boeotia considering their proximity, the fact that there is no high mountain barrier between the Theban area and the east coast and the narrowness of the Euripos Straits between Euboea and the mainland. Nor is it surprising that in 2 areas of such geological similarity it is not possible to distinguish individual site groups. Boeotia is a large area which was very important in the Late Bronze Age and there are no archaeological reasons for rejecting the hypothesis of 2 areas of pottery manufacture within Boeotia: one around Thebes and the other on the east coast. There is a considerable amount of overlap in the composition ranges of these two groups although they are distinct.

### 7.3. Thessaly.

There appear to have been three areas of pottery production within Bronze Age Thessaly: in the western plain where composition group 4 is predominant, in the north where sherds of group 5 were most common, and around the Gulf of Volos where group 6 was the most common. Of these three areas there is the least evidence for contact between the western

plain and the other areas in terms of the number of pots found there which have compositions which do not conform to group 4. Only two of the sherds from Revmatia were not locally made. One of them was the octopus style sherd mentioned below and the other was assigned to group 5. At Yephyria which was represented by almost twice as many sherds as Revmatia, 75% (30/40) were of the local composition types and half of the remaining sherds came from group 5. Since, as Figure 48 of 90% of the sherds in each composition group on the first two discriminant functions shows, there is considerable overlap between groups 1 and 4 and some between groups 4 and 2 it is possible that the 5 sherds from groups 1 and 2 represent slightly atypical local compositions rather than imports. The probabilities given by the computer for the assignment of these sherds does not allow inferences as to their origins to be made with absolute certainty. From the number of sherds at Yephyria with a group 5 composition it seems likely that there was some trade between the north and west of Thessaly. It can also be inferred that the trade was two-way, since 27% (11/41) of the sherds from Yephyra-Asmakiou and 32.5% (13/40) of the sherds from Marmariani were assigned to group 4. The north and west of Thessaly were more remote from southern Greece than southern Thessaly was and it was much more difficult to travel between the west and the north than between southern Thessaly and either the west or the north, so it is surprising how much pottery was traded between these two areas rather than with the area around Volos. Argissa, although not far geographically from Yephyra-Asmakiou and Marmariani presents a confused picture which is probably largely due to the poor quality and lack of typological homogeneity of the samples which were available for analysis. While 4 of the sherds from Yephyra-Asmakiou were



assigned to group 6 this group was unrepresented at Marmariani. Both sites included 7 sherds assigned to the Euboean and Boeotian groups but these only represent 17% of the total from each site and bearing in mind the overlap between group 5 and the Euboean and Boeotian groups (1-3 on Figure 48) and the distance from north Thessaly to Euboea and Boeotia it is likely that some of these at least represent local variations in composition rather than imports. If the probabilities calculated by the computer for the likelihood of these sherds belonging to certain groups are considered, in only 5 cases from Yephyra-Asmakiou and 4 from Marmariani is the probability much greater that the sherds belong to groups 1, 2 and 3, much greater than that they were locally made.

Group 6 accounts for the majority of the sherds from Iolkos, Pevkakia, the 'local' batch from Velestino and all of the 'Iolkos' batch from Velestino. The sherds from the British School at Athens labelled Volos (Iolkos), samples 689-711, are a mixture, mainly assigned to groups 4 and 2 with little in group 6. Details concerning where they were actually collected were not available and it is possible that they were not all correctly provenanced. However, it should also be remembered that some of the Late Helladic sub-groups from Pevkakia were largely assigned to group 4 (see below), and that groups 2 and 6 have considerable overlap in Figure 48. As was mentioned above (Chapter 6.5.2), the batch of sherds from Velestino which was thought to have been imported from the Argolid was shown by the discriminant analysis with the Fitch laboratory's Argolid control data to have a different origin. The majority of the sherds in this batch were divided between groups 1 and 3 (altogether 58% of the sherds), and the majority of the remainder assigned to group 5.

Sample 658 was a rhyton fragment, a vessel type otherwise virtually unknown in Thessaly and which had a ceremonial function was assigned to the Euboean group. It does appear, therefore, that these sherds, all of which date to LHIIIA-B were indeed imported to Velestino but not from the Argolid. The majority of the rest of the sherds from Velestino which were all LHIIIC in date were locally made. The 5 sherds which Dr. Theochares thought were made in Iolkos all conformed to the group 6 composition and it is unfortunate that more sherds of this type were not available for analysis. Forty-three percent (9/21) of the batch of supposedly locally made sherds from Velestino also fell in group 6. Volos (Iolkos and Pevkakia) and Velestino are not distinguishable from each other by their compositions. Group 1 was represented by 5 sherds but there were none from group 3 and only 3 from group 2 and 2 from each of the other areas of Thessaly. Of the Iolkos sherds 51% (25/49) were local with the greatest number of imports being from western Thessaly (11/49). The Boeotian and Euboean groups were very poorly represented with only 8 sherds between them. The remaining 6 sherds were assigned to the north Thessalian group.

The Pevkakia sherds, which formed the largest set of samples from any one site, provided an insight into how the relative number of imports increased with time from the Early to the Late Bronze Age (see Figure 51). In the Early Bronze Age over half the sherds were locally made and the imports were divided between groups 1, 2 and 4 with none from the other 2 groups. In the Middle Helladic period the local sherds accounted for 50% of the total with the majority of the remainder (30.6%) coming from group 5 with 15% from group 2 and 5.6% from group 1. There were none from groups 4 or 3. By the Late Helladic period only 36% of the sherds



were made in the Volos area. All the other groups were also represented. The majority of the sherds were from Thessaly with 24% from group 5, 18.4% from group 4, 13% from group 2 and only 4% from each of groups 1 and 3. If this is broken down further into the separate sub-groups of Late Helladic material a varied picture emerges. LH sub-group II which Robert Avila (Pers.Comm. 1980) suggested was of north Thessalian or Macedonian origin was predominantly from group 5, the northern group (5/8 sherds), with none from the other two Thessalian groups, 2 from Boeotia and one from Euboea, although it is possible that the Boeotian sherds are really atypical members of group 5. LH sub-groups 1 and 2 contained no sherds which were assigned to the local composition group, 6. LH sub-group 1 was mainly north Thessalian (11/19 sherds) with 6 sherds from western Thessaly and only 2 sherds assigned to Euboea and Boeotia. LH sub-group 2 contained 6/14 sherds from west Thessaly, 3 from the north, 4 from Boeotia and one assigned to the Euboean group. In all of the other Late Helladic sub-groups of pottery the largest proportion of the sherds were assigned to the local group and sub-group 12 was wholly assigned to this group. Four of the Late Helladic sub-groups (3, 8, 9, 10) contained no sherds assigned to a Boeotian origin but only one sub-group (3) had none from Euboea either. Overall, sherds assigned to the Euboean group exceeded those assigned to the two Boeotian groups by over 3:1. Within Thessaly the greatest number of sherds assigned to the groups from the other areas (groups 4 and 5) which were found at Pevkakia were from western Thessaly. Late Helladic sub-groups 2, 3, 4, 8 and 9 show this particularly clearly whereas the sherds in the northern composition group predominate in only sub-groups 1, 6 and 10. Although Volos is closer to the western area than to the north, this distribution



is surprising since the journey from Volos to the area around Marmariani in the north is easier and less hilly than the journey into the western plain.

It is not possible to say categorically exactly how many of these sherds were imported into Thessaly due to the overlap between the groups and especially between groups 2 and 6. However, from the probabilities calculated by the computer it is most likely that the majority of the sherds found in Thessaly and assigned to groups 1-3 do have a Euboean or Boeotian origin. It should also be remembered how similar the fabric and decoration of pots from Lefkandi and Volos are according to Popham and Milburn (1971).

The sub-groups of pottery from Pevkakia which are described as hand-made are amongst those which are predominantly of local manufacture: sub-groups 3, 6, 8, 9, 10 and 12.

These results show that it is not possible to provenance Thessalian pottery with certainty on purely archaeological grounds and that the picture presented by the analytical results is more complicated than might have been expected. Since the only group of pottery which was thought to have been imported from the Argolid was shown to have originated in Euboea and/or Boeotia and that Euboean pots predominate over any other imports, it is clear that the theories mentioned above (Chapter 2.4) of contacts between the Thessaly and the Argolid or Boeotia rather than with Euboea will not hold. The only evidence of much material being exported from Thessaly is the group of sherds from Psakhna in Euboea, 40% of which (8/20) were assigned to group 6, the south Thessalian group, and while some of these could be misclassifications due to the similarity of groups 2 and 6 it is unlikely that they all were. The probabilities

calculated by the computer help with this but in some cases an almost equal probability was given for a sherd belonging to group 2 or group 6. As consideration of the Thessalian data shows, there was more movement of pottery from Euboea and Boeotia to Thessaly than vice versa, which is natural since Mycenaean culture was adopted earlier and more completely in Euboea and Boeotia than in Thessaly.

The Octopus style sherd from Revmatia (615), was associated by the computer with group 6, but this is probably because the computer is obliged to assign the sherds to one of the groups defined for the discriminant analysis. When the composition of this sherd is compared with the group compositions given in Figure 53 it can be seen that the sodium, magnesium and titanium contents for sherd 615 were higher and the chromium and nickel contents were lower than would satisfactorily fit in these groups. The most important thing is that it was clearly distinct from the rest of the sherds from Revmatia. When the composition of this sherd was compared with the ranges for all the composition groups which have been published over the years it did not fit in any one of the quoted ranges of composition. Despite the fact that it is not possible to provenance one sherd alone it is unusual to find a sherd which, instead of fitting within the range for several groups, is distinct from them all. It would be interesting to see the results of more analyses of pottery of this style in an attempt to identify their origin.

#### 7.4. General Points.

The limited and varied amount of information available about the sherds which were sampled made it impossible to assess the proportions of imports to the separate areas which were of different vessel types

and more particularly whether most of the imports consisted of 'closed' vessel types which were likely to have been involved in trade as containers rather than as primary artifacts. From the limited information available about the samples there were no apparent links between vessel types and groups.

It would be advantageous in the future if more projects could be carried out to investigate the chronological variation in the proportions of imported and locally made pottery at particular sites, as was done in this project at Pevkakia.

#### 7.5. Geology.

The relationship between the geology of these areas and the composition of the pottery found there is by no means always obvious, or what it might be expected to be.

From the serpentine and the veins of iron-nickel ores in Euboea, and especially around Psakhna, it seemed possible that the pots from there would be high in magnesium, iron and nickel. However, the Euboean composition group is characterised, among other things, by relatively low magnesium, iron and nickel contents. In this respect it is similar to the pottery from group 6, the south Thessalian group, and it should be remembered that the mountains which run down the eastern coast of Thessaly are continued in Euboea.

Boeotia is relatively rich in dolomitic limestone and indeed, group 3 does have a higher magnesium content than most of the other groups, but the bauxite in the mountains of western Boeotia is not reflected in a higher aluminium content in the pottery. Group 1 is also quite rich in magnesium and both groups 1 and 3 have fairly high chromium contents



and these elements have fairly strong correlations. If any of the sherds from group 1 were made around Kynos rather than being imported from Thebes it would be hoped that this would be shown in higher iron and nickel contents due to the ores near Kynos and Atalandi, but neither of these elements is present in particularly high levels.

In northern Thessaly much of the limestone is dolomitic whereas very little is in the western mountains. In the north Mount Ossa is particularly rich in dolomitic limestone and group 5 has a higher magnesium content than the western group and this may be attributable to the higher magnesium content of this limestone. However, the mica in the northern mountains does not appear to have increased the potassium and aluminium content of pottery from Marmariani on the foothills of Mount Ossa.

There is very little variation in the calcium concentration ranges from group to group, although the concentrations in individual sherds vary considerably within a group. Most of the groups contain an average of over 10% calcium. It is possible that calcium may tend to be levigated out of the clay in coarser, calcite particles before it is used for pottery manufacture.

Without further research into the effects of levigation and firing on clay compositions and without more knowledge of the clays from different areas which might have been combined to achieve a desired effect it is clear that clay compositions cannot simply be forecast by a relatively brief examination of the geology of the area.

7.6. Optical emission and atomic absorption spectroscopy.

Both optical emission and atomic absorption are fairly quick and straightforward to use and both can provide a quantitative analysis for ten or more elements from a 10-15 mg. sample. With both techniques it is possible to analyse about 40 samples for about 9 elements each in five days from taking the sample to the final results.

Theoretically it should have been possible with atomic absorption to extend the range of elements measured, providing the requisite lamps could be made available, whereas the elements measured in optical emission are dependent on the presence of suitable spectral lines on the relevant plate-length. The choice of elements measured by optical emission has remained static for many years and an attempt in this project to establish a calibration for potassium failed due to the lack of a suitable line. As mentioned above, an attempt was made to use atomic absorption to measure zinc, copper, cobalt, lead, silicon and potassium in addition to the 9 elements measured in optical emission. Apart from silicon and potassium they proved to be either too consistent in quantity or present in too small a trace to be measured accurately. Silicon was not used as a discriminating element, but potassium earned its inclusion, and although some authors (Hatcher et al., 1980) measure potassium by flame emission rather than atomic absorption, the results obtained in this project using atomic absorption were satisfactorily reliable (see above, Chapter 5.3.9). In projects involving the analysis of pottery from other areas it would be worth attempting to measure other elements as well as the original 9 since once the samples have been put into solution it is very little extra work to extend the elemental range and in other geographical areas different elements might be useful as discrim-

inants and it is unwise to continue to use only the 9 that proved to be of most use in one area. A flameless atomisation system might increase the potential usefulness of other elements due to its lower limits of detection.

Analysis of the same samples by optical emission and atomic absorption showed that while they reveal broadly similar groupings of sherds the results are not directly comparable, as reference to appendices 2 and 4 shows. Since the results do not differ by any fixed or regular amount it is not possible, as Hatcher et al. (1980) also discovered, to find and apply a correction factor to one set of data to make it comparable with the other.

Atomic absorption produces 'tighter' groups with a smaller concentration range than optical emission. As reference to Chapters 5.2.10 and 5.3.9 shows, the precision and accuracy with atomic absorption was better for most elements than with optical emission, although chromium and nickel proved to be too prone to error for usefulness in the interpretation of the results. Flameless atomisation of the samples might also mean that chromium and nickel could be re-introduced as discriminating elements.

The reproducibility techniques carried out for both techniques and comparison of the results with those obtained in other laboratories served to emphasise how important it is to include an independent standard, like the U.S.G.S. and B.C.S. standards in each batch of analysis or comparison with the results obtained in other laboratories becomes impossible. All too little standardisation of this kind has been done in both optical emission and atomic absorption work so far.



Both techniques have a valid role to play in composition and provenance studies. Although in recent years neutron activation analysis has increased in popularity, it does not wholly duplicate the role played by optical emission since the range of elements that are measured is to a large extent different. The simplicity, range and ease of operation are important factors in favour of optical emission. Atomic absorption is not yet fully established as a technique for pottery analysis, but once putting the sample into solution and overcoming interference effects have been mastered atomic absorption will come into its own as a technique. The main limiting factor in the application of optical emission is that it is less accurate and precise than the other techniques. The most constructive approach, therefore, is to combine optical emission with another technique like atomic absorption or like petrographic analysis.

CHAPTER 8.

CONCLUSIONS

CHAPTER 8.

CONCLUSIONS

1. Six composition groups were identified among the sherds which were analysed in this project. They predominated in, and are therefore assumed to have originated in, the following areas:  
  - Group 1. Boeotian, around Thebes.
  - Group 2. Euboean.
  - Group 3. Boeotian, around the Gulf of Euboea.
  - Group 4. South-west Thessaly around modern Pharsala.
  - Group 5. North Thessaly, around modern Larissa.
  - Group 6. South-east Thessaly, around the Gulf of Volos.
2. The distribution of the pottery groups indicated that there was considerable contact with, and trade between, Euboea and Boeotia in the Late Bronze Age and that there was some movement of pottery within Boeotia in the same period.
3. The largest proportion of imports to Thessaly in the Bronze Age came from Euboea and the next largest from Boeotia.
4. No evidence was found to show that pottery was imported to Thessaly from the Argolid in the Late Bronze Age.
5. The relative proportion of imported to locally produced pottery at Pevkakia increased with time from the Early to the Late Bronze Age. The areas from which the pottery was imported also changed with time. In the Early Bronze Age imports came from Euboea, Boeotia and south-western Thessaly. In the Middle Bronze Age the majority of the imports came from northern Thessaly and in the Late Bronze



Age, although all of the composition groups were represented, the majority of the imported sherds came from the south-west and north of Thessaly.

6. Late Helladic sub-group II from Pevkakia was predominantly northern Thessalian in origin.
7. The Octopus Style sherd from Revmatia did not originate from Thessaly, Boeotia or Euboea and its provenance remains unknown.
8. The optical emission and atomic absorption analyses resulted in the identification of broadly similar groups although the atomic absorption groups have smaller concentration ranges than those obtained from optical emission.
9. Potassium is useful as a tenth element to be included in the analysis.
10. Six out of the nine raw clays which were analysed could be identified with the pots from sites in the same areas.
11. It is not possible simply to predict the composition of pottery and clays from the geological history of the areas surrounding where they were found.

APPENDIX 1.

Sherds which were sampled

The samples are numbered on a running number series and following the order of sites given above (Chapter 4). Also included is the number, if any, given to the sherd by the collection where it is housed, the period of the sherd and whether or not it is decorated. The amount of the available information was not always consistent. Samples which were analysed by both optical emission and atomic absorption spectroscopy are marked with an asterisk.

(1) ALIVERI

In the Euboea Survey (Sackett et al. : 105) the authors commented that: "Certainly the decorated IIIB pottery is for the most part local, and this is nowhere clearer than at Aliveri where the local clay beds must be of an inferior quality."

All the sherds sampled were fine without visible inclusions.

| <u>Number</u> | <u>Period</u> | <u>Plain/Decorated</u> | <u>Comments</u> |
|---------------|---------------|------------------------|-----------------|
| 1             | LHIII         | Monochrome             | Kylix           |
| 2             | "             | Decorated              | Kylix           |
| 3             | "             | Plain                  | Kylix           |
| 4             | "             | Plain                  | Kylix           |
| 5             | "             | Decorated              | Krater          |
| 6             | "             | "                      | Krater          |
| 7             | "             | "                      | Deep bowl       |
| 8             | "             | "                      | "               |
| 9             | "             | "                      | "               |
| 10            | "             | "                      | "               |
| 11            | "             | "                      | "               |
| 12            | "             | "                      | "               |
| 13            | "             | "                      | "               |
| 14            | "             | "                      | "               |
| 15            | P             | "                      | -               |
| 16            | "             | "                      | Deep bowl       |
| 17            | "             | "                      | Krater          |
| 18            | "             | Plain                  | Shallow bowl    |
| 19            | "             | Decorated              | Animal figurine |
| 20            | "             | "                      | Animal figurine |





Plate 2a Aliveri samples I-9



Plate 2b Amarynthos samples 30-40



(2) AMARYNTHOS

Generally fairly soft fabric, but 1-9 harder.

| <u>Number</u> | <u>Period</u> | <u>Plain/Decorated</u> | <u>Comments</u>                       |
|---------------|---------------|------------------------|---------------------------------------|
| *21           | IIIb          | Banded                 | Deep Bowl Quite hard, some inclusions |
| *22           | IIIb          | Monochrome             | Deep Bowl                             |
| *23           | IIIA2-B       | Banded                 | Deep Bowl. A little mica.             |
| *24           | IIIB-C1       | Decorated              | Deep Bowl                             |
| *25           | IIIB-C1       | Decorated              | Deep Bowl                             |
| 26            | IIIB          | Decorated              | Deep Bowl                             |
| 27            | IIIB-C1       | Monochrome             | Deep Bowl                             |
| 28            | IIIB-C1       | Decorated              | Deep Bowl. A little mica              |
| 29            | IIIB-C1       | Decorated              | Deep Bowl. Few inclusions             |
| 30            | IIIA          | Banded                 | Kylix                                 |
| *31           | IIIA          | Monochrome             | Stemmed bowl                          |
| *32           | IIIA          | Monochrome             |                                       |
| *33           | IIIA          | Monochrome             |                                       |
| *34           | IIIA          | Decorated              |                                       |
| *35           | IIIA          | Decorated              | Kylix                                 |
| 36            | IIIA          | Decorated              | Kylix                                 |
| 37            | IIIA          | Monochrome             | Kylix                                 |
| 38            | IIIA          | Monochrome             |                                       |
| 39            | IIIA          | Monochrome             | Kylix                                 |
| 40            | IIIA          | Decorated              |                                       |
| *41           | IIIA          | Plain                  | Kylix                                 |
| *42           | IIIA          | Plain                  | Kylix                                 |
| *43           | IIIA          | Plain                  | Kylix                                 |
| *44           | IIIA          | Decorated              | Kylix                                 |

AMARYNTHOS (Continued)

| <u>Number</u> | <u>Period</u> | <u>Plain/Decorated</u> | <u>Comments</u>          |
|---------------|---------------|------------------------|--------------------------|
| *45           | IIIB-C1       | Decorated              | Deep Bowl                |
| 46            | IIIB-C1       | Decorated              | Deep Bowl                |
| 47            | IIIB-C1       | Decorated              | Deep Bowl                |
| 48            | IIIC1         | Decorated              | Deep Bowl                |
| 49            | IIIC1         | Decorated              | Deep Bowl                |
| 50            | IIIC1         | Decorated              | Deep Bowl                |
| *51           | IIIB2         | Decorated              | Deep Bowl                |
| *52           | IIIB          | Decorated              | Krater                   |
| *53           | IIIB          | Decorated              |                          |
| *54           | IIIB          | Decorated              | Stirrup jar?             |
| *55           | IIIB-C        | Decorated              |                          |
| 56            | III           | Decorated              | Quite hard. Stirrup jar? |
| 57            | IIIC1         | Banded                 | Much coarser. Jar.       |
| 58            | IIIC1         | Decorated              | Krater                   |
| 59            | IIIC1         | Decorated              | Krater                   |
| 60            | IIIB          | Decorated              | Deep Bowl                |
| 61            | IIIC1         | Decorated              |                          |



(3) GIALTRA

| <u>Number</u> | <u>Period</u> | <u>Decoration</u> | <u>Comments</u> |
|---------------|---------------|-------------------|-----------------|
| 62            | LHIIIIB-C     | Decorated         |                 |
| 63            | "             | Decorated         | Hard            |
| 64            | "             | Decorated         | Hard            |
| 65            | "             | Plain             |                 |
| 66            | "             | Decorated         |                 |
| 67            | "             | "                 |                 |
| 68            | "             | "                 | Hard            |
| 69            | "             | "                 |                 |
| 70            | "             | "                 |                 |
| 71            | "             | "                 | Very Hard       |
| 72            | "             | "                 |                 |
| 73            | "             | "                 |                 |
| 74            | "             | "                 | Hard            |
| 75            | "             | "                 |                 |
| 76            | "             | "                 |                 |
| 77            | "             | "                 |                 |
| 78            | "             | "                 | Gritty and hard |
| 79            | "             | "                 |                 |
| 80            | "             | "                 | Very Hard       |
| 81            | "             | "                 | Very Hard       |
| 82            | "             | Monochrome        |                 |

(4) LEFKANDI

The kylix stems were all softer than the bowl fragments. All the sherds were very fine with no inclusions visible.

| <u>Number</u> | <u>Period</u> | <u>Plain/decorated</u> | <u>Comments</u> |
|---------------|---------------|------------------------|-----------------|
| *83           | IIIC          | Decorated              | Deep bowl       |
| *84           | IIIC          | Banded (decoration)    | "               |
| *85           | IIIC          | Decorated              | "               |
| *86           | IIIC          | Plain                  | "               |
| *87           | IIIC          | Decorated              | "               |
| *88           | IIIC          | Banded                 | "               |
| *90           | IIIC          | Monochrome             | "               |
| *91           | IIIC          | Monochrome             | "               |
| *92           | IIIC          | Banded                 | "               |
| *93           | IIIC          | Plain                  | Kylix stem      |
| *93           | IIIB          | Plain                  | "               |
| *95           | IIIB          | Plain                  | "               |
| *96           | IIIC          | Plain                  | "               |
| *97           | IIIB          | Monochrome             | "               |
| *98           | IIIC          | Decorated              | "               |
| *99           | IIIC          | Banded                 | "               |
| *100          | IIIB          | Plain                  | "               |
| *101          | IIIB          | Monochrome             | "               |
| *102          | IIIC          | Plain                  | "               |

(5) PSAKHNA

| <u>Number</u> | <u>Period</u> | <u>Decoration</u> | <u>Comments</u> |
|---------------|---------------|-------------------|-----------------|
| 103           | LHIII B       | Monochrome        |                 |
| 104           | "             | Decorated         |                 |
| 105           | "             | Decorated         |                 |
| 106           | "             | Decorated         |                 |
| 107           | "             | Decorated         |                 |
| 108           | "             | Decorated         |                 |
| 109           | "             | Decorated         |                 |
| 110           | "             | Decorated         |                 |
| 111           | "             | Monochrome        | Very hard       |
| 112           | "             | Decorated         |                 |
| 113           | "             | Decorated         |                 |
| 114           | "             | Decorated         |                 |
| 115           | "             | Decorated         |                 |
| 116           | "             | Decorated         |                 |
| 117           | "             | Decorated         |                 |
| 118           | "             | Plain             |                 |
| 119           | "             | Monochrome        |                 |
| 120           | "             | Decorated         |                 |
| 121           | "             | Decorated         |                 |
| 122           | "             | Decorated         |                 |





Plate 3a. Psakhna samples 103-112



Plate 3b. Eleon samples 202-211



(6) ROVIES

| <u>Number</u> | <u>Period</u> | <u>Decoration</u> | <u>Comments</u> |
|---------------|---------------|-------------------|-----------------|
| *123          | LHIII         | Plain             | Kylix           |
| *124          | LHIIB         | Plain             | Kylix           |
| *125          | LHIII         | Plain             | Kylix           |
| *126          | "             | Decorated         | Kylix           |
| *127          | "             | Decorated         |                 |
| *128          | "             | Decorated         |                 |
| *129          | "             | Decorated         |                 |
| *130          | "             | Decorated         |                 |
| *131          | "             | Decorated         |                 |
| *132          | "             | Decorated         |                 |
| *133          | "             | Decorated         |                 |
| *134          | LHIIB         | Plain             |                 |
| *135          | LHIIB         | Decorated         |                 |
| *136          | LHIII         | Decorated         |                 |
| *137          | LHIIB         | Decorated         |                 |
| *138          | LHIII         | Decorated         |                 |
| *139          | "             | Decorated         |                 |
| *140          | "             | Decorated         |                 |
| *141          | "             | Plain             |                 |
| *142          | "             | Decorated         |                 |
| *143          | "             | Decorated         |                 |

(7) ANTHEDON

| <u>Number</u> | <u>Period</u> | <u>Decoration</u> | <u>Comments</u> |
|---------------|---------------|-------------------|-----------------|
| *144          | LHIII         | Decorated         | Hard            |
| *145          | LHIIIIC       | Decorated         | Hard            |
| *146          | LHIIIIB-C     | Decorated         |                 |
| *147          | LHIIIA-B      | Decorated         |                 |
| *148          | MH            | Plain             | Bowl            |
| *149          | LHIIIIC       | Decorated         | Krater          |
| *150          | LHIIIIB-C     | Decorated         | Deep bowl       |
| *151          | Uncertain     | Decorated         |                 |
| *152          | LHIIIIC       | Decorated         | Deep bowl       |
| *153          | LHIIIIB       | Decorated         |                 |
| *154          | LHIIIIB-C     | Decorated         | Krater          |
| *155          | LHIIIIB       | Decorated         | Kylix           |
| *156          | Uncertain     | Monochrome        |                 |
| *157          | Uncertain     | Decorated         |                 |
| *158          | Uncertain     | Decorated         |                 |
| *159          | LHIIIA-B      | Plain             | Kylix           |
| *160          | Uncertain     | Plain             | Kylix           |
| *161          | Uncertain     | Decorated         |                 |



(8) CHALIA

| <u>Number</u> | <u>Period</u> | <u>Decoration</u> | <u>Comments</u> |
|---------------|---------------|-------------------|-----------------|
| 162           | Uncertain     | Plain             | Kylix           |
| 163           | Uncertain     | Plain             | Kylix           |
| 164           | Uncertain     | Decorated         | Model throne    |
| 165           | LHIIIA        | Decorated         | Stemmed bowl    |
| 166           | LHIIIB-C      | Decorated         | Kylix           |
| 167           | Uncertain     | Decorated         |                 |
| 168           | LHIIIB-C      | Decorated         | Krater          |
| 169           | LHIIIB        | Decorated         | Deep bowl       |
| 170           | LHIIIB-C      | Monochrome        | Deep bowl       |
| 171           | LHIIIB        | Decorated         | Deep bowl       |
| 172           | LHIIIC        | Decorated         | Coarser. Krater |
| 173           | LHIIIB-C      | Decorated         | Krater          |
| 174           | LHIIIB-C      | Plain             | Deep bowl       |
| 175           | LHIIIB-C      | Decorated         | Deep bowl       |
| 176           | LHIIIC        | Decorated         | Bowl            |
| 177           | MH            | Plain             |                 |
| 178           | Uncertain     | Decorated         |                 |
| 179           | LHIIIB-C      | Decorated         | Deep bowl       |
| 180           | LHIIIB        | Decorated         | Deep bowl       |
| 181           | LHIIIC        | Monochrome        | Deep bowl       |

(9) DRAMESI

| <u>Number</u> | <u>Period</u> | <u>Decoration</u> | <u>Comments</u>                 |
|---------------|---------------|-------------------|---------------------------------|
| 182           | Uncertain     | Plain             | Kylix                           |
| 183           | Uncertain     | Plain             | Kylix                           |
| 184           | Uncertain     | Plain             | Kylix                           |
| 185           | Uncertain     | Plain             | Kylix                           |
| 186           | Uncertain     | Plain             | Kylix                           |
| 187           | LHIII B-C     | Decorated         | Deep bowl                       |
| 188           | LHIII B-C     | Decorated         | Deep bowl                       |
| 189           | LHIII C       | Decorated         | Deep bowl                       |
| 190           | Uncertain     | Decorated         | Jar handle                      |
| 191           | LHIII B-C     | Decorated         | Hard. Dark grits.<br>Jar handle |
| 192           | LHIII B-C     | Decorated         | Bowl                            |
| 193           | LHIII B       | Decorated         | Bowl                            |
| 194           | Uncertain     | Decorated         | Hard and gritty                 |
| 195           | LHIII C       | Decorated         | Hard. Krater                    |
| 196           | LHIII A-B     | Decorated         | Stirrup jar                     |
| 197           | LHII?         | Decorated         |                                 |
| 198           | Uncertain     | Decorated         |                                 |
| 199           | LHIII B       | Decorated         |                                 |
| 200           | LHIII A       | Decorated         |                                 |
| 201           | LHIII A       | Decorated         |                                 |

| (10) <u>ELEON</u> |               |                   |                 |
|-------------------|---------------|-------------------|-----------------|
| <u>Number</u>     | <u>Period</u> | <u>Decoration</u> | <u>Comments</u> |
| *202              | LHIIIA-B      | Plain             | Kylix           |
| *203              | LHIIIA-B      | Plain             | Kylix           |
| *204              | LHIIIA        | Plain             | Kylix           |
| *205              | LHIIIB        | Decorated         | Kylix           |
| *206              | Uncertain     | Decorated         |                 |
| *207              | LHIIIC        | Decorated         |                 |
| *208              | LHIIIB-C      | Decorated         | Krater          |
| *209              | LHIIIB-C      | Decorated         | Deep bowl       |
| *210              | Uncertain     | Decorated         | Animal figurine |
| *211              | LHIIIC        | Decorated         | Deep bowl       |
| *212              | LHIIIC        | Decorated         | Deep bowl       |
| *213              | LHIIIA-B      | Decorated         |                 |
| *214              | LHIIIB-C      | Decorated         |                 |
| *215              | LHIIIB        | Decorated         | Deep bowl       |
| *216              | LHIIIB-C      | Plain             | Deep bowl       |
| *217              | LHIIIB-C      | Decorated         | Deep bowl       |
| *218              | LHIIIB-C      | Decorated         | Deep bowl       |
| *219              | LHII?         | Decorated         |                 |
| *220              | LHIIIB-C      | Decorated         | Krater          |
| *221              | LHIIIB-C      | Decorated         | Krater          |



(11) KYNOS

| <u>Number</u> | <u>Period</u> | <u>Decoration</u> | <u>Comments</u> |
|---------------|---------------|-------------------|-----------------|
| 222           | LHIII B-C     | Decorated         | Krater          |
| 223           | LHIII C       | Decorated         |                 |
| 224           | LHIII B       | Decorated         | Deep bowl       |
| 225           | LHIII B-C     | Decorated         | Krater          |
| 226           | LHIII A       | Decorated         | Kylix           |
| 227           | LHIII B-C     | Monochrome        | Deep bowl       |
| 228           | LHIII C       | Decorated         | Deep bowl       |
| 229           | LHIII B       | Decorated         | Kylix           |
| 230           | LHIII C       | Decorated         | Deep bowl       |
| 231           | LHIII C       | Monochrome        | Deep bowl       |
| 232           | LHIII A-B     | Decorated         |                 |
| 233           | LHIII C       | Monochrome        | Deep bowl       |
| 234           | LHIII C       | Decorated         | Deep bowl       |
| 235           | LHIII A-B     | Decorated         | Bowl            |
| 236           | LHIII B-C     | Decorated         |                 |
| 237           | LHIII C       | Decorated         | Deep bowl       |
| 238           | LHIII B-C     | Monochrome        | Deep bowl       |
| 239           | LHIII B-C     | Decorated         |                 |
| 240           | LHIII B-C     | Monochrome        |                 |
| 241           | LHIII B-C     | Decorated         |                 |



Plate 4a. Kynos samples 222-231



Plate 4b. Volos (Iolkos) samples 689-697



(12) THEBES

These sherds are amongst those selected for analysis in 1972 by Perlman and Asaro. Although the results of the analyses remain unpublished, some comments were made about them in Asaro and Perlman (1972:219). The sherds are housed in the Swedish Institute in Athens.

| <u>Number</u> | <u>Swedish Institute No.</u> | <u>Period</u> | <u>Decoration</u> |
|---------------|------------------------------|---------------|-------------------|
| *242          | GPI 4                        | LHIIIB        | Decorated         |
| *243          | GPI 1                        | LHIIIB        | Decorated         |
| *244          | GPII 1                       | LHIIIB        | Plain             |
| *245          | GPII 3                       | LHIIIB        | Decorated         |
| *246          | GPIII 4                      | LHIIIB        | Decorated         |
| *247          | GPIII 5                      | LHIIIB        | Decorated         |
| *248          | GPIV 2                       | LHIIIB        | Decorated         |
| *249          | GPIV 3                       | LHIIIB        | Decorated         |
| *250          | GPV 1                        | LHIIIB        | Decorated         |
| *251          | GPV 3                        | LHIIIB        | Decorated         |
| *252          | GPVI 2                       | LHIIIB        | Decorated         |
| *253          | GPVI 4                       | LHIIIB        | Decorated         |
| *254          | GPVII 2                      | LHIIIB        | Decorated         |
| *255          | GPVII 3                      | LHIIIB        | Decorated         |
| *256          | GPVIII 3                     | LHIIIB        | Decorated         |
| *257          | GPVIII 4                     | LHIIIB        | Decorated         |
| *258          | GPIX 3                       | LHIIIB        | Decorated         |
| *259          | GPIX 4                       | LHIIIB        | Decorated         |
| *260          | GPX 1                        | LHIIIB        | Decorated         |
| *261          | GPX 4                        | LHIIIB        | Decorated         |



(13) ARGISSA

| <u>Number</u> | <u>Larissa<br/>Museum No.</u> | <u>Period</u> | <u>Decoration</u> |
|---------------|-------------------------------|---------------|-------------------|
| 262           | ARG A2 11                     | LHIIIA-B      | Decorated         |
| 263           | ARG A15 VIII                  | "             | Plain             |
| 264           | ARG A15 V                     | "             | Decorated         |
| 265           | ARG B5 IIIa                   | "             | Plain             |
| 266           | ARG AB13-15 II                | "             | Plain             |
| 267           | ARG A13 II                    | "             | Decorated         |
| 268           | ARG B14 II                    | "             | Decorated         |
| 269           | ARG A15 IIb                   | "             | Plain             |
| 270           | ARG A15 IIb                   | "             | Decorated         |
| 271           | ARG A6 IIIc                   | "             | Decorated         |
| 272           | ARG A4 II                     | "             | Decorated         |
| 273           | ARG A10 II                    | "             | Decorated         |
| 274           | ARG B12 III                   | "             | Decorated         |
| 275           | ARG A14 IIb                   | "             | Plain             |
| 276           | ARG P                         | "             | Plain             |
| 277           | ARG Pb                        | "             | Decorated         |
| 278           | ARG P                         | "             | Decorated         |
| 279           | ARG P                         | "             | Plain             |
| 280           | ARG P b-c                     | "             | Decorated         |
| 281           | ARG PII                       | "             | Plain             |

(14) IOLKOS (Volos) (Sampled by R. Avila).

| <u>Number</u> | <u>Volos Museum<br/>Label</u> | <u>Period</u> | <u>Decoration</u>         |
|---------------|-------------------------------|---------------|---------------------------|
| 282           | 3.85m                         | LHIII         | Linear Decoration         |
| 283           | 4.10m                         | "             | Monochrome                |
| 284           | 4.20m                         | "             | Monochrome                |
| 285           | 4.20m                         | "             | Monochrome                |
| 286           | 4.20m                         | "             | Decorated                 |
| 287           | 4.35m                         | "             | Decorated                 |
| 288           | 4.35m                         | "             | Decorated                 |
| 289           | 4.35m                         | "             | Linear decoration         |
| 290           | 4.35m                         | "             | Monochrome                |
| 291           | 4.5m 1973                     | "             | Plain                     |
| 292           | 5.0m                          | "             | Linear decoration         |
| 293           | 5.0m                          | "             | Decorated                 |
| 294           | 5.4m                          | "             | Monochrome                |
| 295           | 5.4m                          | "             | Decorated                 |
| 296           | 5.4m                          | "             | Decorated                 |
| 297           | 5.4m                          | "             | Decorated                 |
| 298           | 5.4m                          | "             | Decorated                 |
| 299           | 5.4m                          | "             | Linear decoration         |
| 300           | 5.4m                          | "             | Linear decoration         |
| 301           | 5.4m                          | "             | Decorated                 |
| 302           | 4.7m                          | "             | Decorated                 |
| 303           | 4.7m                          | "             | White slip and decoration |
| 304           | 4.7m                          | "             | Decorated                 |
| 305           | 4.7m                          | "             | Decorated                 |
| 306           | 5.15m                         | "             | Linear decoration         |

(14) IOLKOS (Volos) (Continued)

| <u>Number</u> | <u>Volos Museum<br/>Label</u> | <u>Period:</u> | <u>Decoration</u>                   |
|---------------|-------------------------------|----------------|-------------------------------------|
| 307           | 5.15m                         | LHIII          | Monochrome                          |
| 308           | 5.15m                         | "              | Linear decoration                   |
| 309           | 5.15m                         | "              | Decorated                           |
| 310           | 5.15m                         | "              | Decorated                           |
| 311           | 5.15m                         | "              | Decorated                           |
| 312           | 5.85m                         | "              | White slip and linear<br>decoration |
| 313           | 5.85m                         | "              | Decorated                           |
| 314           | 5.85m                         | "              | White slip and decoration           |
| 315           | 5.85m                         | "              | Decorated                           |
| 316           | 5.85m                         | "              | Decorated                           |
| 317           | 5.85m                         | "              | White slip and decoration           |
| 318           | 5.85m                         | "              | Decorated                           |
| 319           | 5.85m                         | "              | Decorated                           |
| 320           | 5.90m '73.Lot Karag           | "              | Plain                               |
| 321           | 5.9m '73.Lot Karag            | "              | Plain                               |
| 322           | 5.9m '73.Lot Karag            | "              | Plain                               |
| 323           | 5.9m '73.Lot Karag            | "              | Plain                               |
| 324           | 5.9m '73.Lot Karag            | "              | Plain                               |
| 325           | 5.9m '73.Lot Karag            | "              | Plain                               |
| 326           | 5.9m '73.Lot Karag            | "              | Plain                               |
| 327           | 5.9m '73.Lot Karag            | "              | Plain                               |
| 328           | 5.9m '73.Lot Karag            | "              | Plain                               |
| 329           | 5.9m '73.Lot Karag            | "              | Plain                               |
| 330           | 5.9m '73.Lot Karag            | "              | Plain                               |



Samples labelled "Volos, Iolkos" in the British School at Athens.

| <u>Number</u> | <u>Number in<br/>Hunter (1954)</u> | <u>Period</u> | <u>Decoration</u> |
|---------------|------------------------------------|---------------|-------------------|
| *689          | 243                                | LHIIIA        | Decorated         |
| *690          | 118                                | LHIIIC        | Decorated         |
| *691          | 244                                | LHIIIA-B      | Decorated         |
| *692          | 228                                | LHIIIB-C      | Decorated         |
| *693          | 134                                | LHI-II        | Decorated         |
| *694          | 184                                | LHIIIA        | Decorated         |
| *695          | 154                                | LHIIIA        | Plain             |
| *696          | 153                                | LHIIIA        | Plain             |
| *697          | 152                                | LHIIIA        | Plain             |
| *698          |                                    | LHIII         | Plain             |
| *699          |                                    | LHIII         | Plain             |
| *700          |                                    | LHIII         | Decorated         |
| *701          |                                    | LHIII         | Decorated         |
| *702          |                                    | LHIII         | Banded decoration |
| *703          |                                    | LHIII         | Monochrome        |
| *704          |                                    | LHIII         | Decorated         |
| *705          |                                    | LHIII         | Decorated         |
| *706          |                                    | LHIII         | Decorated         |
| *707          |                                    | LHIII         | Monochrome        |
| *708          |                                    | LHIII         | Banded decoration |
| *709          |                                    | LHIII         | Decorated         |
| *710          |                                    | LHIII         | Banded decoration |
| *711          |                                    | LHIII         | Banded decoration |

(15) MARMARIANI Generally quite micaceous.

| <u>Number</u> | <u>Number in<br/>Hunter</u> | <u>Period</u> | <u>Decoration</u> |
|---------------|-----------------------------|---------------|-------------------|
| *331          | 116                         | LHIIIB        | Decorated         |
| *332          | 125                         | LHIIIC        | Decorated         |
| *333          | 156                         | LHIIIA        | Monochrome        |
| *334          | 155                         | LHIIIA        | Monochrome        |
| *335          | 157                         | LHIIIA-B      | Monochrome        |
| *336          | 160                         | LHIIIA-B      | Murex decoration  |
| *337          | 162                         | LHIIIB        | Decorated         |
| *338          | 165                         | LHIII         | Plain             |
| *339          | 166                         | LHIIIB-C      | Plain             |
| *340          | 186                         | LHIIIB-C      | Decorated         |
| *341          | 183                         | LHIIIA        | Decorated         |
| *342          | 188                         | LHIIIA-B      | Decorated         |
| *343          | 185                         | LHIIIA-B      | Decorated         |
| *344          | 187                         | LHIIIB-C      | Decorated         |
| *345          | 124                         | LHIIIB-C      | Decorated         |
| *346          | 126                         | LHIIIC        | Decorated         |
| *347          | 117                         | LHIIIC        | Decorated         |
| *348          | 114                         | LHIIIA        | Decorated         |
| *349          | 245                         | LHIII         | Decorated         |
| *350          |                             | LHIII         | Plain             |
| 351           |                             | LHIII         | Plain             |
| 352           |                             | LHIII         | Banded decoration |
| 353           |                             | LHIII         | Plain             |
| 354           |                             | LHIII         | Banded decoration |
| 355           |                             | LHIII         | Plain             |

(15) MARMARIANI (Continued)

| <u>Number</u> | <u>Number in<br/>Hunter</u> | <u>Period</u> | <u>Decoration</u> |
|---------------|-----------------------------|---------------|-------------------|
| 356           |                             | LHIII         | Monochrome        |
| 357           |                             | LHIII         | Plain             |
| 358           |                             | LHIII         | Monochrome        |
| 359           |                             | LHIII         | Plain             |
| 360           |                             | LHIII         | Monochrome        |
| 361           |                             | LHIII         | Monochrome        |
| 362           |                             | LHIII         | Monochrome        |
| 363           |                             | LHIII         | Decorated         |
| 364           |                             | LHIII         | Banded decoration |
| 365           |                             | LHIII         | Banded decoration |
| 366           |                             | LHIII         | Decorated         |
| 367           |                             | LHIII         | Decorated         |
| 368           |                             | LHIII         | Decorated         |
| 369           |                             | LHIII         | Decorated         |
| 370           |                             | LHIII         | Decorated         |



(16) PEVKAKIA

The number in brackets for each sample is that given to the sherd by the archaeologists from Germany (Elmar Christman, Joseph Maran and Robert Avila) who are working on the material and who provided the samples for analysis. Their studies of the material are not yet complete. Firm dates have not yet, therefore, been assigned to all of the groups of pottery.

Early Bronze Age

| <u>Number</u> | <u>Volos Museum<br/>Number</u> | <u>Decoration</u> |
|---------------|--------------------------------|-------------------|
| 371           | (24) πY FVIII 13 XIX4          | Decorated         |
| 372           | (25) πY FVIII 47 XXXI MR328    | Banded decoration |
| 373           | (26) πY FVIII 46 XXXX2         | Decorated         |
| 374           | (27) πY FVIII 34 XXVI4         | Monochrome        |
| 375           | (28) πY FVIII 27 Gel 8 XXIX3   | Monochrome        |
| 376           | (29) πY EVIII 57 XXXI 3        | Decorated         |
| 377           | (30) πY 1976 HV39 IVC          | Decorated         |
| 378           | (31) πY EVIII 47 XXVI MR328    | Decorated         |
| 379           | (32) πY EVIII 50 Grau XXVII6   | Decorated         |
| 380           | (33) πY FVIII 45 XXXV13        | Monochrome        |
| 381           | (34) πY EVIII 40 XXXI          | Decorated         |
| 382           | (35) πY FVIII 42 XX4           | Monochrome        |
| 383           | (36) πY EVIII 37 XXVII         | Decorated         |
| 384           | (38) πY EVIII 37 Grau XXXII3   | Monochrome        |
| 385           | (39) πY EVIII 39 XXVII6        | Monochrome        |
| 386           | (40) πY FVIII 47 XXVL3         | Monochrome        |
| 387           | (42) πY FVIII 23 XXII5         | Monochrome        |
| 388           | (43) πY EVIII 37 XXXIV3        | Decorated         |

(16) PEVKAKIA

Early Bronze Age (Continued)

| <u>Number</u>          | <u>Volos Museum Number</u>         | <u>Decoration</u>              |
|------------------------|------------------------------------|--------------------------------|
| 389                    | (44) πY FVIII 21 Schwarz XXVIII    | Monochrome                     |
| 390                    | (45) -                             | Monochrome                     |
| 391                    | (49) πY FVIII 26 XXII7 484         | Decorated                      |
| 392                    | (57) πY FVIII 31 XXX12 R395        | Monochrome                     |
| 393                    | (58) πY EVIII 50 XXX3 R323         | Decorated                      |
| 394                    | (60) πY 1976 HV50 u,m.6(0.765-775) | Plain                          |
| 395                    | (69) πY FVIII 17 XIX7              | Plain                          |
| 396                    | (70) πY FVIII 36 XXII2             | Plain                          |
| 397                    | (71) πY FVIII 46 XXII2             | Decorated (incised)            |
| 398                    | (76) πY FVIII 45-37 m376           | Plain                          |
| 399                    | (77) πY FVIII 21 XXIII             | Monochrome                     |
| <u>Middle Helladic</u> |                                    |                                |
| 400                    | (4) πY FVIII 54 XXVII3             | Decorated                      |
| 401                    | (5) πY EVIII 575 XXVII3            | Decorated                      |
| 402                    | (6) πY EVIII 49 (8) XIX6           | Decorated                      |
| 403                    | (7) FVIII 54 XIX2 NR433            | Decorated                      |
| 404                    | (8) πY FVIII 27 XVIII3             | White slip with red decoration |
| 405                    | (9) πY FVIII 47 XV2 G405           | Decorated                      |
| 406                    | (10) πY EVIII 28 XXXI              | Banded decoration              |
| 407                    | (II) πY EVII 80 X2                 | Plain                          |
| 408                    | (12) πY EVII 89 XI                 | Incised decoration             |
| 409                    | (13) πY EVII 16 XI                 | Decorated                      |
| 410                    | (18) πY 1977 IX 83.1. VIII6        | Incised decoration             |
| 411                    | (19) πY EVII 87 XI3                | Monochrome                     |

(16) PEVKAKIA Middle Helladic (Continued)

| <u>Number</u> | <u>Volos Museum Number</u>    | <u>Decoration</u>         |
|---------------|-------------------------------|---------------------------|
| 412           | (20) πY AVS M319              | Decorated                 |
| 413           | (21) πY EVII 26 XI            | Banded decoration         |
| 414           | (46) no number                | White slip and decoration |
| 415           | (47) πY EVIII 29 IX           | Pale slip and decoration  |
| 416           | (48) πY EVIII 27 XIII/2       | Pale slip and decoration  |
| 417           | (49) πY FVIII 91 XVII         | Banded decoration         |
| 418           | (50) πY EVIII 37W XXI H 3II   | Decorated                 |
| 419           | (51) πY FVIII 60 XIX6         | Decorated                 |
| 420           | (52) πY FVIII 23 XIV          | Pale slip and decoration  |
| 421           | (53) πY EVIII 30 XVIII3       | Pale slip and decoration  |
| 422           | (54) πY FVIII 31 VIII2        | Banded decoration         |
| 423           | (56) πY EVIII 48 G413 XVIII3  | Decorated                 |
| 424           | (55) πY EVIII 47 XXII2 H.3II  | Decorated                 |
| 425           | (57) πY 1976 V 62-83 I        | Decorated                 |
| 426           | (68) πY FVIII 37 XVII2 G418   | Decorated                 |
| 427           | (72) πY EVIII 34 XX3 e) 990   | Plain                     |
| 428           | (73) πY EVIII 27 XIV          | Burnished?                |
| 429           | (62) πY FVIII 47 VXIII2       | Plain                     |
| 430           | (63) πY EVIII 49 XVIII        | Burnished?                |
| 431           | (64) πY EVIII 40 XX H317 Gelb | Plain                     |
| 432           | (65) πY EVIII 50 XXXI3        | Burnished?                |
| 433           | (66) πY EVIII 94W XXII2 H311  | Burnished?                |
| 434           | (67) πY EVIII 37W XXII2 H3II  | Burnished?                |
| 435           | (74) πY FVIII 37 XVIII2       | Plain                     |



(16) PEVKAKIA

Late Helladic

Group 1. Fine, mostly wheel-made decorated Mycenaean sherds.

| <u>Number.</u> | <u>Volos Museum Number</u>   | <u>Decoration</u>         |
|----------------|------------------------------|---------------------------|
| 436            | (1) πY EVIII 27 XII          | Decorated                 |
| 437            | (2) πY EVIII 38 XII          | Decorated                 |
| 438            | (3) πY EVIII 38 XIII         | Decorated                 |
| 439            | (4) πY EVIII 39 XIII2        | Decorated                 |
| 440            | (5) πY EVIII 26 XII2         | Decorated                 |
| 441            | (6) πY EVIII 20 VI Gr 340    | Decorated                 |
| 442            | (7) πY FXIII 47 XIV ½G405    | Decorated                 |
| 443            | (8) πY EVIII 37 XIII/2       | Decorated                 |
| 444            | (9) πY EVIII 20 VIII Gr345   | Monochrome                |
| 445            | (10) πY LVIII 38 X12         | Decorated                 |
| 446            | (11) πY EVII 66XI Gr254      | Decorated                 |
| 447            | (12) πY EVIII 38 XII         | Decorated                 |
| 448            | (13) πY EVIII 38 XII         | Decorated                 |
| 449            | (14) πY EVIII 38 X12         | Decorated                 |
| 450            | (15) πY EVIII 16/17 XV Gr403 | Decorated                 |
| 451            | (16) πY EVIII 16 XII         | Pale slip with decoration |
| 452            | (17) πY EVIII 38 XIII        | Decorated                 |
| 453            | (18) πY EVIII 39 X12         | Decorated                 |
| 454            | (19) πY 62 392 XIV           | Decorated                 |

Group 2. Mycenaean with linear decoration. Mostly buff, wheel-made.

Mostly LHII - LHIIIA

|     |                           |
|-----|---------------------------|
| 455 | (20) πY EVIII 27 X12      |
| 456 | (21) πY EVIII 16 XII      |
| 457 | (22) πY EVIII 20 VI Gr340 |

(16) PEVKAKIA Late Helladic, Group 2 (Continued).

| <u>Number</u> | <u>Volos Museum Number</u>   |
|---------------|------------------------------|
| 458           | (23) πY EVIII 30 IV Gr340    |
| 459           | (24) πY FVIII 37XIV          |
| 460           | (25) πY EVIII 47 XVIII       |
| 461           | (26) πY EVIII 30VI Gr 340    |
| 462           | (27) πY EVIII 39 X12         |
| 463           | (28) πY EVIII 26 XII2        |
| 464           | (29) πY EVIII 26 XVII2       |
| 465           | (30) πY EVIII 40 XVIII2 G423 |
| 466           | (31) πY EVIII 26 XLL2        |
| 467           | (32) πY FVIII 32 XII         |
| 468           | (33) πY EVIII 20 XI Gr 340   |

Group 3. Mycenaean, handmade fine ware. Monochrome. Mostly LHII-LHIIIA.

|     |                               |
|-----|-------------------------------|
| 469 | (34) πY EVIII 38 XIII         |
| 470 | (35) πY Grube 372 XIII        |
| 471 | (36) πY Gr 382 FVIII 33 XIV   |
| 472 | (37) πY FVIII 23 XII Gr 371   |
| 473 | (38) πY EVIII 28 X12          |
| 474 | (39) πY Gr 372 XIII           |
| 475 | (40) πY EVIII 37-39 Gr 392 XV |
| 476 | (41) πY EVII67/77 X12 Gr 611  |
| 477 | (42) πY EVII 67/77 X12 Gr 611 |
| 478 | (43) πY XIV Gr 382            |
| 479 | (44) πY FVIII 43 XIV          |
| 480 | (45) πY Gr 372 XIII           |
| 481 | (46) πY FVIII 32 XII Gr 372   |

(16) PEVKAKIA Group 3 (Continued).

| <u>Number</u> | <u>Volos Museum Number</u>   |
|---------------|------------------------------|
| 482           | (47) πY EVIII 37-39 XIV2 392 |
| 483           | (48) πY EVIII 15 XIV 2       |

Group 4. Mycenaean fine ware, mostly rather soft. Good quality.

Generally wheel-made. Unpainted. LHII-LHIIIA.

|     |                                 |
|-----|---------------------------------|
| 484 | (49) πY EVIII 20 VI Gr 340      |
| 485 | (50) πY EVIII 26 X12            |
| 486 | (51) πY EVIII 37 XV12 Gr 392    |
| 487 | (52) πY XIV Gr 382              |
| 488 | (53) πY FVIII 33 XII Gr 372     |
| 489 | (54) πY Gr 372 XIII FVIII 23/33 |
| 490 | (55) πY Gr 392 XIV              |
| 491 | (56) πY EVIII 40 XIII           |
| 492 | (57) πY Gr 372 XIII2            |
| 493 | (58) πY EVIII 20 VIII Gr 345    |
| 494 | (59) πY EVIII 16 XII            |
| 495 | (60) πY F8/7 323 22             |
| 496 | (61) πY FVIII 33 XII Gr 372     |
| 497 | (62) πY EVIII 27 XV             |
| 498 | (63) πY FVII 23 XII Gr 371      |
| 499 | (64) πY XIV Gr 382              |
| 500 | (65) πY EVIII XIV Gr 382        |
| 501 | (66) πY EVIII 16 XIV            |
| 502 | (67) πY FVIII 33 XII Gr 372     |



(16) PEVKAKIA Late Helladic, Group 6.

Burnished fine ware all very hard and clearly handmade. Unpainted.

LHII-LHIIIA.

| <u>Number.</u> | <u>Volos Museum Number.</u>    |
|----------------|--------------------------------|
| 503            | (80) πY FVIII 33 XII Gr 372    |
| 504            | (81) πY EVIII 48 XVIII3 Gr 372 |
| 505            | (82) πY EVIII XV12/G392        |
| 506            | (83) πY Gr372 XIII/2           |
| 507            | (84) πY XIV Gr 382             |
| 508            | (85) πY EVIII 37 XV12 G 392    |
| 509            | (86) πY Gr 392 XIV             |
| 510            | (87) πY XIII Gr 372            |
| 511            | (88) πY Gr 372 XIII            |
| 512            | (89) πY EVIII 37 XVI G 392     |
| 513            | (90) πY EVIII 38 XVIII 639     |
| 514            | (91) πY EVIII 40 XIII/2        |
| 515            | (92) πY EVIII 38-40 XV Gr 392  |
| 516            | (93) πY EVIII 38-40 XV Gr 392  |
| 517            | (94) πY EVIII 38-40 XIV Gr 392 |
| 518            | (95) πY FVIII 33 XII Gr 372    |
| 519            | (96) πY FVIII 32 XII Gr 372    |
| 520            | (97) πY FVIII 32 XII Gr 372    |
| 521            | (98) πY EVII 40 XVII G 392     |
| 522            | (99) πY Gr 372 XIII/2          |
| 523            | (100) πY EVIII 37 XVIII Gr 397 |
| 524            | (101) πY EVIII 38 XVI G 392    |
| 525            | (103) πY FVIII 33 XII Gr 372   |
| 526            | (104) πY Gr 372 XIII/2         |

(16) PEVKAKIA Late Helladic, Group 6 (Continued).

| <u>Number</u>   | <u>Volos Museum Number</u>                                                                    |
|-----------------|-----------------------------------------------------------------------------------------------|
| 527             | (105) πY XIV Gr 382                                                                           |
| 528             | (106) πY G 372 XIII/2                                                                         |
| 529             | (107) πY EVIII 37-39 XV2 G392                                                                 |
| 530             | (108) πY EVIII 38 XVI G392                                                                    |
| <u>Group 8.</u> | Fine ware, fairly hard, clearly handmade with polished outer-surface. Mostly LHII and LHIIIA. |
| 531             | (112) πY EVIII 37-39 XV3 G392                                                                 |
| 532             | (113) πY Gr 372 XIII/2                                                                        |
| 533             | (114) πY FVIII 23XII Gr 372                                                                   |
| 534             | (115) πY EVII 38 XVII                                                                         |
| 535             | (116) πY EVIII 77 X3 G211                                                                     |
| 536             | (117) πY EVIII 29 XV                                                                          |
| 537             | (118) πY FVIII 37 XIV                                                                         |
| 538             | (119) No number                                                                               |
| 539             | (120) πY FVIII 47 XIII2 G382                                                                  |
| 540             | (121) πGr 372 XIII/2                                                                          |
| 541             | (122) πY FVIII 23XII G372                                                                     |
| 542             | (123) πY XIV Gr 382                                                                           |
| 543             | (124) πY EVIII 39 XVI Gr 392                                                                  |
| 544             | (125) πY EVIII 33 XII G372                                                                    |
| 545             | (126) πY EVIII 40 XVII G392                                                                   |
| 546             | (127) πY EVIII 37-39 XIV2 G392                                                                |
| 547             | (128) πY Gr 372 XIII/2                                                                        |
| 548             | (129) πY EVIII 37-39 XV3 Gr 392                                                               |
| 549             | (130) πY Gr 392 XIV                                                                           |

(16) PEVKAKIA Late Helladic, Group 8 (Continued).

| <u>Number</u>   | <u>Volos Museum Number</u>                                      |
|-----------------|-----------------------------------------------------------------|
| 550             | (131) πY XIV Gr 382                                             |
| 551             | (133) πY Gr 372 XIII/2                                          |
| 552             | (134) πY Gr 372 XIII                                            |
| 553             | (135) πY Gr 372 XIII                                            |
| 554             | (136) πY FVIII 32XII Gr 372                                     |
| <u>Group 9.</u> | Fine ware with hard polished coat. Mostly handmade. Mostly LHII |
| 555             | (145) πY EVIII 39 XVII Gr 392                                   |
| 556             | (146) πY EVIII 39/44 XV12                                       |
| 557             | (147) πY EVIII 39-49 XV12 G392                                  |
| 558             | (148) πY FVIII 32 XII Gr 372                                    |
| 559             | (149) πY EVIII 38-40 XV Gr 392                                  |
| 560             | (150) πY EVIII 39 XVII                                          |
| 561             | (151) πY Gr 372 XIII                                            |
| 562             | (152) πY EVIII 38 XVIII Gr 392                                  |
| 563             | (153) πY EVIII 59/69 XV12 G 392                                 |
| 564             | (154) πY EVIII 49 XVIII3 G392                                   |
| 565             | (155) πY G372 XIII/2                                            |
| 566             | (156) πY EVIII 39 XVII G392                                     |
| 567             | (157) πY EVIII 37-39 XV2 G392                                   |
| 568             | (158) πY Grub 372 XIII                                          |
| 569             | (159) πY G372 XIII                                              |
| 570             | (160) πY FVIII 33 XII G372                                      |
| 571             | (161) πY Gr 392 XIV                                             |
| 572             | (162) πY Gr 372 XIII/2                                          |
| 573             | (163) πY G392 XIV                                               |
| 574             | (164) πY EVIII 38-40 XV Gr 392                                  |
| 575             | (165) πY EVIII 30 VI Gr 340                                     |



(16) PEVKAKIA Late Helladic (Continued)

Group 10. Unpainted good quality, fine ware but hard. Handmade.

Polished surface. Mostly LHII.

| <u>Number.</u> | <u>Volos Museum Number</u>       |
|----------------|----------------------------------|
| 576            | (174) πY EVIII 37-39 XIV2 Gr 392 |
| 577            | (175) πY Gr372 XIII/2            |
| 578            | (176) πY FVIII 32 XII Gr372      |
| 579            | (177) πY FVIII 33 XII Gr372      |
| 580            | (178) πY Gr372 XIII/2            |
| 581            | (179) πY FVIII 32 XII Gr372      |
| 582            | (180) πY EVIII 38 XV12 Gr392     |
| 583            | (181) πY Gr372 XIII/2            |
| 584            | (182) πY Gr392 XIV               |
| 585            | (183) πY EVIII 37-39 XV2 Gr392   |
| 586            | (184) πY Gr312 XIII              |
| 587            | (185) πY XIV Gr382               |
| 588            | (186) πY EVIII 37 XVI Gr392      |
| 589            | (187) πY EVIII 37-39 XV3 Gr392   |
| 590            | (189) πY Gr392 XIV               |
| 591            | (190) πY Graube 372 XIII         |
| 592            | (191) πY Gr 392 19 XIV           |

(16) PEVKAKIA Late Helladic (Continued)

Group 11. Northern Greek matt-painted ware and one similar sherd. LHI-II.

Possibly North Thessalian or Macedonian.

| <u>Number</u> | <u>Volos Museum Number</u> |
|---------------|----------------------------|
| *593          | (269) πY FVIII 14 XI2      |
| *594          | (270) πY FVIII 14 X12      |
| *595          | (271) πY FVIII 14 X12      |
| *596          | (272) πY FVIII 14 X12      |
| *597          | (273) πY FVIII 14 X12      |
| *598          | (274) πY FVIII 14 X12      |
| *599          | (275) πY FVIII 14 X12      |
| *600          | (280) πY EVIII 29 X1       |

Group 12. Fine ware with matt coating. Handmade. LHII-IIIA.

|     |                              |
|-----|------------------------------|
| 601 | (166) πY EVIII 18 X12        |
| 602 | (167) πY FVIII 31 XIV2       |
| 603 | (168) πY EVIII 38 XVIII G392 |
| 604 | (169) πY FVIII 33 XII Gr372  |
| 605 | (170) πY FVIII 32 XII Gr 372 |
| 606 | (171) πY XIV Gr382           |
| 607 | (172) πY EVI X12 G611        |
| 608 | (173) πY EVIII 40 XVII G392  |
| 609 | (173a) πY EVIII 38 XVI 392   |





Plate 5a Marmariani samples 33I-340



Plate 5b Revmatia samples 6I0-6I5, 6I8



(17) REVMATIA PALIAMBELA

| <u>Number</u> | <u>Dr. French<br/>Number</u> | <u>Period</u> | <u>Decoration</u>         |
|---------------|------------------------------|---------------|---------------------------|
| *610          | 10                           | LHIIIA-B      | Monochrome                |
| *611          | 16                           | "             | Plain                     |
| *612          | 17                           | "             | Monochrome                |
| *613          | 18                           | "             | Banded decoration         |
| *614          | 19                           | "             | Monochrome                |
| *615          | 20                           | LHIIIC        | Octopus Style stirrup jar |
| *616          | 21                           | LHIIIA-B      | Decorated                 |
| *617          | 22                           | "             | Decorated                 |
| *618          | 23                           | "             | Decorated                 |
| *619          | 24                           | "             | Decorated                 |
| *620          | 25                           | "             | Decorated                 |
| *621          | 26                           | "             | Decorated                 |
| *622          | 5                            | "             | Decorated                 |
| *623          | 7                            | "             | Decorated                 |
| *624          | 8                            | "             | Decorated                 |
| *625          | 6                            | "             | Decorated                 |
| *626          | 9                            | "             | Decorated                 |
| *627          | 11                           | "             | Monochrome                |
| *628          | 12                           | "             | Decorated                 |
| *629          | 13                           | "             | Monochrome                |
| *630          | 14                           | "             | Decorated                 |
| *631          | 15                           | "             | Decorated                 |

(18) VELESTINO (PHERAE)

(a) Group said by Dr. Theochares to have been made in Iolkos.

All fine with a red fabric coated in a white slip.

Janakopoulos Plot. Inside level 10 in Ancient pit. Bags 19/20.

| <u>Number</u> | <u>Period</u> | <u>Decoration</u>       |
|---------------|---------------|-------------------------|
| 632           | LHIIIC        | Red linear decoration   |
| 633           | LHIIIC        | Black linear decoration |
| 634           | LHIIIC        | Plain                   |
| 635           | LHIIIC        | Red linear decoration   |
| 636           | LHIIIC        | Black linear decoration |

(b) Hard, fine sherds thought to be of local manufacture.

From Ath. Sarantis plot, level 6 bags 12, 13, 14 in Volos Museum.

|     |        |                                   |
|-----|--------|-----------------------------------|
| 637 | LHIIIC | Decorated                         |
| 638 | LHIIIC | Banded outside, painted inside    |
| 639 | LHIIIC | Banded decoration                 |
| 640 | LHIIIC | Banded decoration                 |
| 641 | LHIIIC | Decorated                         |
| 642 | LHIIIC | Decorated outside, painted inside |
| 643 | LHIIIC | Monochrome                        |
| 644 | LHIIIC | Banded decoration                 |
| 645 | LHIIIC | Banded decoration                 |
| 646 | LHIIIC | Banded decoration                 |
| 647 | LHIIIC | Band on rim. Painted inside.      |
| 648 | LHIIIC | Plain                             |
| 649 | LHIIIC | Banded decoration                 |
| 650 | LHIIIC | Decorated outside, painted inside |
| 651 | LHIIIC | Monochrome                        |

(18) VELESTINO (PHERAE), Group B (Continued)

| <u>Number</u>                                                                                   | <u>Period</u> | <u>Decoration</u>                  |
|-------------------------------------------------------------------------------------------------|---------------|------------------------------------|
| 652                                                                                             | LHIIIIC       | Banded decoration                  |
| 653                                                                                             | LHIIIIC       | Banded decoration                  |
| 654                                                                                             | LHIIIIC       | Banded decoration                  |
| 655                                                                                             | LHIIIIC       | Banded decoration                  |
| 656                                                                                             | LHIIIIC       | Banded decoration                  |
| 657                                                                                             | LHIIIIC       | Banded decoration                  |
| <p>(c) All fine with a soft yellow fabric. Thought to be possible imports from the Argolid.</p> |               |                                    |
| <p>From several plots, bags labelled VAφ</p>                                                    |               |                                    |
| 658                                                                                             | LHIIIB        | Banded decoration. Rhyton fragment |
| 659                                                                                             | LHIIIB        | Banded decoration                  |
| 660                                                                                             | LHIIIB        | Decorated inside and out           |
| 661                                                                                             | LHIIIB        | Decorated and rim band             |
| 662                                                                                             | LHIIIB        | Decorated outside, painted inside  |
| 663                                                                                             | LHIIIB?       | Monochrome                         |
| 664                                                                                             | LHIIIB        | Banded decoration                  |
| 665                                                                                             | LHIIIB        | Decorated                          |
| 666                                                                                             | LHIIIB        | Banded decoration inside and out   |
| 667                                                                                             | LHIIIB        | Monochrome on inside only          |
| 668                                                                                             | LHIIIB        | Painted inside, banded outside     |
| 669                                                                                             | LHIIIB        | Decorated                          |
| 670                                                                                             | LHIIIB        | Painted inside, banded outside     |
| 671                                                                                             | LHIIIA        | Painted inside, decorated outside  |
| 672                                                                                             | LHIIIA        | Banded decoration                  |
| 673                                                                                             | LHIIIA        | Decorated outside                  |



(18) VELESTINE (PHERAE), Group C (Continued)

| <u>Number</u> | <u>Period</u> | <u>Decoration</u>              |
|---------------|---------------|--------------------------------|
| 674           | LHIII B       | Painted inside and out         |
| 675           | LHIII B       | Banded decoration              |
| 676           | LHIII B       | Banded decoration              |
| 677           | LHIII B       | Painted inside, banded outside |
| 678           | LHIII B       | Banded decoration              |
| 679           | LHIII B       | Painted inside, banded outside |
| 680           | LHIII B       | Decorated                      |
| 681           | LHIII B       | Diagonal band                  |
| 682           | LHIII B       | Banded decoration              |
| 683           | LHIII B       | Banded decoration              |
| 684           | LHIII B       | Band over rim                  |
| 685           | LHIII B       | Monochrome                     |
| 686           | LHIII B       | Banded decoration              |
| 687           | LHIII B       | Decorated                      |
| 689           | LHIII B       | Some remains of paint          |

(19) YEPHYRIA

| <u>Number</u> | <u>Dr. French<br/>Number</u> | <u>Period</u> | <u>Decoration</u>                    |
|---------------|------------------------------|---------------|--------------------------------------|
| 712           | 81                           | LHIII         | Plain                                |
| 713           | 77a                          | LHIII         | Banded decoration )                  |
| 714           | 77b                          | LHIII         | Banded decoration )                  |
| 715           | 44                           | LHIII         | Painted inside, banded<br>outside    |
| 716           | 79                           | LHIII         | Banded decoration                    |
| 717           | 86                           | LHIII         | Painted inside, decorated<br>outside |
| 718           | 62                           | LHIII         | Painted inside. banded<br>outside    |
| 719           | 59                           | LHIII         | Painted inside, decorated<br>outside |
| 720           | 43                           | LHIII         | Banded decoration                    |
| 721           | 48                           | LHIII         | Monochrome                           |
| 722           | 45                           | LHIII         | Banded decoration                    |
| 723           | 84                           | LHIII         | Decorated                            |
| 724           | 66                           | LHIII         | Painted inside and rim band          |
| 725           | 64                           | LHIII         | Painted inside and rim band          |
| 726           | 50                           | LHIII         | Monochrome                           |
| 727           | 53                           | LHIII         | Monochrome                           |
| 728           | 38                           | LHIII         | Painted inside, decorated<br>outside |
| 729           | 56                           | LHIII         | Painted inside, decorated<br>outside |
| 730           | 39                           | LHIII         | Painted inside, banded outside       |
| 731           | 41                           | LHIII         | Banded decoration                    |
| 732           | 52                           | LHIII         | Monochrome                           |

(19) YEPHYRIA (Continued)

| <u>Number</u> | <u>Dr. French<br/>Number</u> | <u>Period</u> | <u>Decoration</u>                 |
|---------------|------------------------------|---------------|-----------------------------------|
| 733           | 42                           | LHIII         | Banded decoration                 |
| 734           | 68                           | LHIII         | Painted inside, decorated outside |
| 735           | 57                           | LHIII         | Painted inside, banded outside    |
| 736           | 55                           | LHIII         | Painted inside, banded outside    |
| 737           | 70                           | LHIII         | Painted inside, banded outside    |
| 738           | 69                           | LHIII         | Painted inside, plain outside     |
| 739           | 82                           | LHIII         | Plain                             |
| 740           | 47                           | LHIII         | Banded outside                    |
| 741           | 73                           | LHIII         | Painted inside, banded outside    |
| 742           | 37                           | LHIII         | Painted inside, decorated outside |
| 743           | 67                           | LHIII         | Band                              |
| 744           | 49                           | LHIII         | Monochrome                        |
| 745           | 79                           | LHIII         | Banded outside                    |
| 746           | 58                           | LHIII         | Painted inside, banded outside    |
| 747           | 36                           | LHIII         | Painted inside, decorated outside |
| 748           | 40                           | LHIII         | Banded decoration                 |
| 749           | 61                           | LHIII         | Banded inside and out             |
| 750           | 75                           | LHIII         | Painted inside, banded outside    |
| 751           | 76                           | LHIII         | Painted inside, banded outside    |



(20) YEPHYRA-ASMAKIOU

Generally quite micaceous.

| <u>Number</u> | <u>Dr. French<br/>Number</u> | <u>Period</u> | <u>Decoration</u>                 |
|---------------|------------------------------|---------------|-----------------------------------|
| 752           | 22                           | LHIII         | Painted inside and partly outside |
| 753           | 23                           | LHIII         | Banded decoration                 |
| 754           | 26                           | LHIII         | Banded decoration                 |
| 755           | 27                           | LHIII         | Banded decoration                 |
| 756           | 36                           | LHIII         | Monochrome                        |
| 757           | 42                           | LHIII         | Plain                             |
| 758           | 24                           | LHIII         | Painted inside, banded outside    |
| 759           | 6                            | LHIII         | Banded decoration                 |
| 760           | 20                           | LHIII         | Banded decoration                 |
| 761           | 21                           | LHIII         | Banded decoration                 |
| 762           | 35                           | LHIII         | Monochrome                        |
| 763           | 4                            | LHIII         | Painted inside, banded outside    |
| 764           | 5                            | LHIII         | Rim band and decoration           |
| 765           | 12                           | LHIII         | Painted inside, banded outside    |
| 766           | 13                           | LHIII         | Banded inside and out             |
| 767           | 17                           | LHIII         | Painted inside, banded outside    |
| 768           | 18                           | LHIII         | Painted inside and rim band       |
| 769           | 19                           | LHIII         | Painted inside, banded outside    |
| 770           | 28                           | LHIII         | Monochrome                        |
| 771           | 29                           | LHIII         | Painted inside, banded outside    |
| 772           | 30                           | LHIII         | Monochrome                        |
| 773           | 31                           | LHIII         | Monochrome                        |
| 774           | 32                           | LHIII         | Painted inside and out            |
| 775           | 33                           | LHIII         | Painted inside and out            |

(20) YEPHYRA-ASMAKIOU (Continued)

| <u>Number</u> | <u>Dr. French<br/>Number</u> | <u>Period</u> | <u>Decoration</u>                         |
|---------------|------------------------------|---------------|-------------------------------------------|
| 776           | 34                           | LHIII         | Painted inside and out                    |
| 777           | 40                           | LHIII         | Monochrome                                |
| 778           | 41                           | LHIII         | Plain                                     |
| 779           | 3                            | LHIII         | Painted inside, band outside              |
| 780           | 7                            | LHIII         | Painted inside, banded outside            |
| 781           | 8                            | LHIII         | Painted inside, banded outside            |
| 782           | 9                            | LHIII         | Painted inside, banded outside            |
| 783           | 10                           | LHIII         | Painted inside, bands on white<br>outside |
| 784           | 11                           | LHIII         | Painted inside, decorated outside         |
| 785           | 14                           | LHIII         | Painted inside, decorated outside         |
| 786           | 15                           | LHIII         | Painted inside, decorated outside         |
| 787           | 16                           | LHIII         | Painted inside, decorated outside         |
| 788           | 25                           | LHIII         | Banded decoration                         |
| 789           | 38                           | LHIII         | Monochrome                                |
| 790           | 38                           | LHIII         | Monochrome                                |
| 791           | 39                           | LHIII         | Monochrome                                |
| 792           | 43                           | LHIII         | Plain                                     |

CLAYS

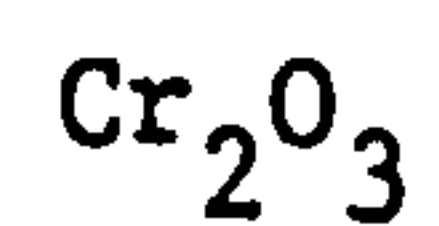
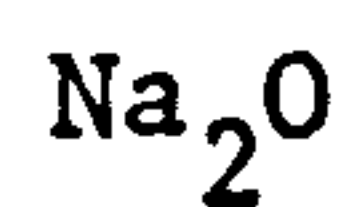
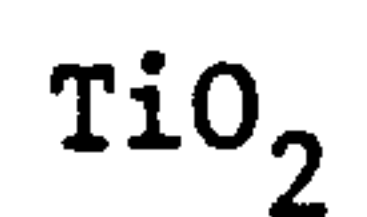
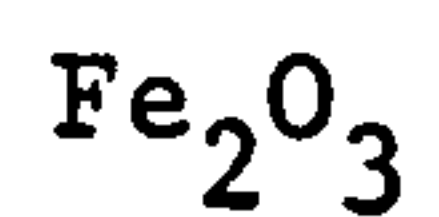
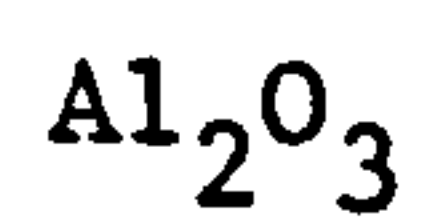
| <u>Source</u> | <u>BSA No.</u> | <u>Colour</u>   |
|---------------|----------------|-----------------|
| Lefkandi      | 22a            | Dark red        |
| Amarynthos    | 12a            | Pink            |
| Eretria       | 41             | Grey            |
| Pyrghos       | 17a            | Grey            |
| Volos         |                | Yellowish brown |
| Sesklo (1)    |                | Red             |
| Sesklo (2)    |                | White           |
| Sesklo (3)    |                | Orange          |
| Dhimini       |                | Yellowish brown |



APPENDIX 2

Results obtained by optical emission analysis

The results are expressed in oxides (see below) following the practice set down in Oxford and Athens.



The results are given site by site in the order given in Chapter 4.

(1) ALIVERI

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 1          | 16.0 | 9.0  | 5.1 | 10.0 | 0.75 | 2.30 | 0.092 | 0.075 | 0.039 |
| 2          | 16.2 | 9.2  | 3.0 | 6.7  | 0.77 | 0.35 | 0.052 | 0.063 | 0.030 |
| 3          | 17.5 | 9.4  | 2.7 | 8.0  | 0.82 | 0.87 | 0.052 | 0.062 | 0.027 |
| 4          | 12.7 | 8.9  | 5.8 | 8.0  | 0.71 | 1.07 | 0.093 | 0.081 | 0.042 |
| 5          | 15.1 | 11.4 | 5.2 | 8.6  | 0.88 | 0.94 | 0.078 | 0.070 | 0.032 |
| 6          | 14.0 | 12.5 | 2.0 | 6.7  | 0.66 | 0.47 | 0.056 | 0.057 | 0.032 |
| 7          | 17.0 | 7.8  | 2.6 | 8.4  | 0.74 | 2.60 | 0.081 | 0.059 | 0.029 |
| 8          | 14.4 | 11.3 | 4.9 | 8.6  | 0.80 | 1.20 | 0.099 | 0.086 | 0.039 |
| 9          | 19.8 | 9.2  | 3.6 | 10.0 | 0.90 | 1.60 | 0.090 | 0.046 | 0.028 |
| 10         | 13.7 | 5.9  | 2.3 | 8.8  | 0.78 | 2.15 | 0.073 | 0.056 | 0.028 |
| 11         | 15.1 | 4.4  | 1.5 | 6.5  | 0.56 | 3.20 | 0.085 | 0.032 | 0.009 |
| 12         | 17.0 | 7.2  | 2.5 | 9.5  | 0.88 | 2.30 | 0.067 | 0.065 | 0.031 |
| 13         | 16.2 | 9.0  | 4.4 | 8.6  | 0.75 | 0.88 | 0.078 | 0.100 | 0.039 |
| 14         | 15.0 | 10.9 | 3.0 | 9.0  | 0.84 | 1.60 | 0.073 | 0.039 | 0.021 |
| 15         | 13.7 | 8.7  | 4.7 | 7.5  | 0.70 | 0.95 | 0.078 | 0.056 | 0.029 |
| 16         | 17.1 | 9.7  | 3.1 | 8.8  | 0.83 | 1.30 | 0.071 | 0.041 | 0.024 |
| 17         | 19.7 | 7.3  | 1.8 | 8.8  | 0.75 | 2.10 | 0.110 | 0.096 | 0.016 |
| 18         | 17.2 | 13.4 | 2.6 | 8.0  | 0.83 | 0.42 | 0.077 | 0.067 | 0.035 |
| 19         | 25.0 | 18.5 | 3.7 | 9.0  | 0.82 | 0.38 | 0.125 | 0.081 | 0.034 |
| 20         | 16.7 | 9.0  | 5.8 | 8.4  | 0.96 | 0.92 | 0.085 | 0.060 | 0.046 |

(2) AMARYNTHOS

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|------------|------|------|-----|------|------|------|-------|---------|-------|
| 21         | 17.5 | 10.5 | 3.1 | 7.4  | 0.83 | 3.00 | 0.098 | 0.018   | 0.005 |
| 22         | 18.5 | 7.2  | 3.1 | 7.4  | 1.07 | 1.35 | 0.053 | 0.043   | 0.027 |
| 23         | 15.4 | 14.5 | 5.2 | 9.5  | 0.76 | 0.86 | 0.096 | 0.031   | 0.072 |
| 24         | 19.5 | 11.7 | 7.0 | 9.7  | 1.25 | 1.14 | 0.087 | 0.066   | 0.056 |
| 25         | 17.5 | 10.2 | 3.1 | 8.2  | 0.99 | 0.55 | 0.061 | 0.050   | 0.038 |
| 26         | 20.0 | 10.1 | 2.9 | 7.8  | 0.96 | 1.56 | 0.059 | 0.036   | 0.021 |
| 27         | 19.5 | 9.0  | 1.9 | 8.2  | 1.03 | 1.90 | 0.100 | 0.027   | 0.018 |
| 28         | 17.4 | 10.2 | 3.3 | 7.4  | 0.80 | 1.60 | 0.115 | Too low | 0.004 |
| 29         | 18.5 | 9.4  | 2.3 | 7.0  | 0.85 | 1.99 | 0.074 | 0.008   | 0.005 |
| 30         | 20.0 | 11.7 | 3.3 | 8.1  | 0.96 | 2.65 | 0.095 | 0.034   | 0.025 |
| 31         | 19.5 | 7.2  | 2.0 | 8.2  | 0.91 | 2.20 | 0.096 | 0.027   | 0.018 |
| 32         | 15.0 | 6.4  | 1.4 | 7.8  | 0.75 | 2.00 | 0.092 | 0.021   | 0.014 |
| 33         | 17.4 | 6.2  | 1.6 | 8.4  | 0.81 | 2.25 | 0.090 | 0.026   | 0.015 |
| 34         | 19.0 | 10.6 | 3.5 | 9.2  | 1.02 | 1.30 | 0.100 | 0.039   | 0.029 |
| 35         | 16.5 | 10.5 | 3.2 | 9.4  | 0.91 | 1.25 | 0.108 | 0.031   | 0.027 |
| 36         | 20.5 | 10.4 | 4.8 | 9.0  | 1.04 | 0.68 | 0.112 | 0.057   | 0.045 |
| 37         | 23.5 | 25.0 | 3.6 | 8.1  | 1.10 | 0.40 | 0.074 | 0.065   | 0.045 |
| 38         | 19.0 | 6.3  | 1.7 | 9.5  | 0.90 | 2.20 | 0.102 | 0.030   | 0.017 |
| 39         | 17.4 | 6.7  | 1.4 | 8.6  | 0.79 | 1.78 | 0.098 | 0.020   | 0.012 |
| 40         | 17.6 | 13.5 | 5.5 | 10.0 | 0.84 | 1.20 | 0.090 | 0.067   | 0.038 |
| 41         | 19.5 | 10.6 | 3.3 | 8.1  | 0.88 | 1.80 | 0.111 | 0.017   | 0.006 |



AMARYNTHOS (Continued)

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|------------|------|------|-----|------|------|------|-------|---------|-------|
| 42         | 14.0 | 3.2  | 1.3 | 7.5  | 0.71 | 2.00 | 0.106 | 0.021   | 0.013 |
| 43         | 13.8 | 16.5 | 6.4 | 10.1 | 0.96 | 1.30 | 0.095 | 0.057   | 0.042 |
| 44         | 13.7 | 14.1 | 3.7 | 8.6  | 0.82 | 1.70 | 0.126 | 0.030   | 0.020 |
| 45         | 13.9 | 12.0 | 3.5 | 8.5  | 0.73 | 2.00 | 0.123 | 0.020   | 0.023 |
| 46         | 16.7 | 10.5 | 4.1 | 9.6  | 0.82 | 1.10 | 0.109 | 0.035   | 0.023 |
| 47         | 17.6 | 8.0  | 3.2 | 10.0 | 0.75 | 2.90 | 0.130 | 0.021   | 0.009 |
| 48         | 13.5 | 13.6 | 4.3 | 7.6  | 0.74 | 1.90 | 0.106 | 0.018   | 0.005 |
| 49         | 20.2 | 15.6 | 2.5 | 6.8  | 0.74 | 1.90 | 0.122 | Too low | 0.005 |
| 50         | 15.2 | 9.7  | 3.2 | 10.0 | 0.84 | 1.80 | 0.103 | 0.056   | 0.039 |
| 51         | 16.1 | 5.0  | 4.9 | 9.2  | 0.79 | 2.10 | 0.116 | 0.024   | 0.015 |
| 52         | 20.6 | 16.2 | 7.2 | 10.4 | 1.02 | 1.30 | 0.106 | 0.056   | 0.035 |
| 53         | 26.0 | 14.9 | 4.9 | 11.5 | 1.04 | 0.48 | 0.081 | 0.074   | 0.045 |
| 54         | 17.4 | 10.0 | 4.8 | 10.7 | 0.84 | 1.20 | 0.150 | 0.035   | 0.023 |
| 55         | 13.9 | 18.0 | 8.4 | 10.9 | 0.93 | 1.30 | 0.255 | 0.076   | 0.055 |
| 56         | 13.7 | 4.9  | 2.4 | 8.6  | 0.87 | 2.10 | 0.110 | 0.023   | 0.011 |
| 57         | 18.0 | 7.0  | 2.8 | 9.2  | 0.85 | 1.60 | 0.135 | Too low | 0.009 |
| 58         | 20.0 | 3.3  | 2.3 | 10.5 | 0.86 | 2.20 | 0.112 | 0.070   | 0.015 |
| 59         | 17.7 | 3.3  | 2.5 | 8.9  | 0.77 | 2.30 | 0.103 | 0.022   | 0.012 |
| 60         | 17.6 | 11.4 | 2.7 | 7.7  | 0.76 | 0.68 | 0.097 | 0.033   | 0.018 |
| 61         | 24.2 | 15.2 | 3.4 | 6.5  | 0.70 | 1.60 | 0.105 | Too low | 0.004 |

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 62         | 18.6 | 6.7  | 3.0 | 7.0  | 0.85 | 2.26 | 0.072 | 0.038 | 0.019 |
| 63         | 19.2 | 11.4 | 3.9 | 8.0  | 0.86 | 1.30 | 0.086 | 0.032 | 0.022 |
| 64         | 17.0 | 7.0  | 2.6 | 6.4  | 0.80 | 1.90 | 0.052 | 0.024 | 0.014 |
| 65         | 18.5 | 8.2  | 4.4 | 8.4  | 0.92 | 2.90 | 0.074 | 0.035 | 0.021 |
| 66         | 20.0 | 5.6  | 4.0 | 9.0  | 0.98 | 2.20 | 0.066 | 0.038 | 0.027 |
| 67         | 19.2 | 9.3  | 4.1 | 8.7  | 1.00 | 2.80 | 0.082 | 0.039 | 0.023 |
| 68         | 15.1 | 15.2 | 3.3 | 9.5  | 0.85 | 0.80 | 0.105 | 0.036 | 0.024 |
| 69         | 21.5 | 7.2  | 6.0 | 10.7 | 1.10 | 2.40 | 0.113 | 0.040 | 0.027 |
| 70         | 17.0 | 2.5  | 2.0 | 8.3  | 1.00 | 1.80 | 0.106 | 0.026 | 0.013 |
| 71         | 21.4 | 5.5  | 4.0 | 8.5  | 0.74 | 2.00 | 0.087 | 0.039 | 0.018 |
| 72         | 16.0 | 6.0  | 2.8 | 7.0  | 0.76 | 1.75 | 0.060 | 0.032 | 0.013 |
| 73         | 19.8 | 9.6  | 3.4 | 7.4  | 0.92 | 2.30 | 0.060 | 0.031 | 0.018 |
| 74         | 18.6 | 10.6 | 4.2 | 8.0  | 0.96 | 2.30 | 0.075 | 0.038 | 0.020 |
| 75         | 15.6 | 1.8  | 3.2 | 9.5  | 0.97 | 2.75 | 0.077 | 0.045 | 0.027 |
| 76         | 19.4 | 6.9  | 4.2 | 8.4  | 0.90 | 2.50 | 0.063 | 0.037 | 0.021 |
| 77         | 19.5 | 12.2 | 6.3 | 9.5  | 0.91 | 1.60 | 0.076 | 0.067 | 0.043 |
| 78         | 16.8 | 10.4 | 4.0 | 8.2  | 0.90 | 2.70 | 0.078 | 0.038 | 0.021 |
| 79         | 17.9 | 10.4 | 6.0 | 9.7  | 0.85 | 2.40 | 0.120 | 0.058 | 0.052 |
| 80         | 18.5 | 15.5 | 5.4 | 9.2  | 0.98 | 1.10 | 0.069 | 0.060 | 0.042 |
| 81         | 20.5 | 7.2  | 3.7 | 9.6  | 1.14 | 2.40 | 0.075 | 0.044 | 0.028 |
| 82         | 19.9 | 3.5  | 6.8 | 9.8  | 0.91 | 0.86 | 0.132 | 0.078 | 0.053 |

(4) LEFKANDI

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|------------|------|------|-----|------|------|------|-------|---------|-------|
| 83         | 15.3 | 0.5  | 1.6 | 7.0  | 0.65 | 2.40 | 0.081 | 0.022   | 0.036 |
| 84         | 14.1 | 7.7  | 3.5 | 7.7  | 0.84 | 2.20 | 0.111 | 0.043   | 0.043 |
| 85         | 16.5 | 8.2  | 4.0 | 10.5 | 0.89 | 1.80 | 0.138 | 0.056   | 0.027 |
| 86         | 18.2 | 3.9  | 1.7 | 8.1  | 0.77 | 1.80 | 0.081 | 0.023   | 0.025 |
| 87         | 13.2 | 2.9  | 1.2 | 7.7  | 0.56 | 1.70 | 0.086 | 0.026   | 0.020 |
| 88         | 16.2 | 3.2  | 1.6 | 7.8  | 0.73 | 2.20 | 0.085 | 0.022   | 0.018 |
| 89         | 16.5 | 8.9  | 2.0 | 8.2  | 0.75 | 2.20 | 0.096 | 0.025   | 0.013 |
| 90         | 15.9 | 6.0  | 1.4 | 7.4  | 0.67 | 2.00 | 0.100 | 0.021   | 0.036 |
| 91         | 14.3 | 4.5  | 1.4 | 7.1  | 0.70 | 1.90 | 0.083 | 0.021   | 0.028 |
| 92         | 15.0 | 13.0 | 1.8 | 6.7  | 0.69 | 1.60 | 0.081 | 0.021   | 0.021 |
| 93         | 14.0 | 5.1  | 2.8 | 8.3  | 0.85 | 1.60 | 0.071 | 0.045   | 0.053 |
| 94         | 23.9 | 7.6  | 2.1 | 9.6  | 0.84 | 1.90 | 0.115 | 0.028   | 0.025 |
| 95         | 10.7 | 1.7  | 0.8 | 7.2  | 0.52 | 2.50 | 0.080 | 0.023   | 0.022 |
| 96         | 13.0 | 2.9  | 1.3 | 6.8  | 0.71 | 2.20 | 0.078 | 0.024   | 0.018 |
| 97         | 18.5 | 4.2  | 1.6 | 8.2  | 0.72 | 1.80 | 0.092 | 0.026   | 0.023 |
| 98         | 18.6 | 4.4  | 1.4 | 7.8  | 0.81 | 1.40 | 0.082 | 0.027   | 0.020 |
| 99         | 14.1 | 1.9  | 1.2 | 7.2  | 0.65 | 1.90 | 0.074 | 0.027   | 0.025 |
| 100        | 18.4 | 5.4  | 1.7 | 9.0  | 0.70 | 2.60 | 0.102 | Too low | 0.012 |
| 101        | 15.3 | 2.1  | 1.5 | 7.5  | 0.66 | 2.10 | 0.081 | 0.027   | 0.019 |
| 102        | 12.8 | 3.8  | 1.9 | 8.8  | 0.75 | 2.50 | 0.080 | 0.040   | 0.022 |



(5) PSAKHNA

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 103        | 22.5 | 9.8  | 3.3 | 9.2  | 0.88 | 1.70 | 0.090 | 0.057 | 0.035 |
| 104        | 18.0 | 12.0 | 3.9 | 8.8  | 0.85 | 1.36 | 0.100 | 0.037 | 0.026 |
| 105        | 18.2 | 10.4 | 4.4 | 8.5  | 0.85 | 2.00 | 0.125 | 0.054 | 0.031 |
| 106        | 25.0 | 5.1  | 2.0 | 6.8  | 0.83 | 2.64 | 0.072 | 0.022 | 0.014 |
| 107        | 21.4 | 11.0 | 7.5 | 10.0 | 0.92 | 1.20 | 0.087 | 0.075 | 0.046 |
| 108        | 17.6 | 3.6  | 4.1 | 8.5  | 0.90 | 1.02 | 0.054 | 0.059 | 0.031 |
| 109        | 14.2 | 2.1  | 1.2 | 6.6  | 0.58 | 3.31 | 0.061 | 0.018 | 0.010 |
| 110        | 20.0 | 5.4  | 1.5 | 7.4  | 0.77 | 2.30 | 0.072 | 0.025 | 0.014 |
| 111        | 14.4 | 3.4  | 1.0 | 8.4  | 0.47 | 1.96 | 0.037 | 0.015 | 0.014 |
| 112        | 19.2 | 3.4  | 1.8 | 8.7  | 0.72 | 2.14 | 0.090 | 0.023 | 0.012 |
| 113        | 21.5 | 5.7  | 2.0 | 6.5  | 0.83 | 2.64 | 0.056 | 0.024 | 0.011 |
| 114        | 21.6 | 2.8  | 1.9 | 7.8  | 0.91 | 2.34 | 0.063 | 0.030 | 0.011 |
| 115        | 22.3 | 5.5  | 2.0 | 7.4  | 0.79 | 2.34 | 0.080 | 0.022 | 0.012 |
| 116        | 21.5 | 10.8 | 6.3 | 9.0  | 1.00 | 1.35 | 0.090 | 0.055 | 0.040 |
| 117        | 15.2 | 12.0 | 7.3 | 9.9  | 0.80 | 2.75 | 0.055 | 0.155 | 0.086 |
| 118        | 19.6 | 15.2 | 8.3 | 9.4  | 0.98 | 0.81 | 0.099 | 0.076 | 0.051 |
| 119        | 18.2 | 3.0  | 1.7 | 7.4  | 0.74 | 2.75 | 0.071 | 0.024 | 0.011 |
| 120        | 19.2 | 3.2  | 1.8 | 8.0  | 0.78 | 2.90 | 0.079 | 0.031 | 0.013 |
| 121        | 24.1 | 5.6  | 1.9 | 7.4  | 0.82 | 1.50 | 0.059 | 0.024 | 0.007 |
| 122        | 17.7 | 7.6  | 1.8 | 10.4 | 0.76 | 2.20 | 0.100 | 0.035 | 0.021 |

(6) ROVIES

| Sample No. | Al.  | Ca.     | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|---------|-----|------|------|------|-------|-------|-------|
| 123        | 13.2 | 7.8     | 5.1 | 10.5 | 0.96 | 1.00 | 0.089 | 0.086 | 0.068 |
| 124        | 14.0 | 3.2     | 1.4 | 8.0  | 0.65 | 2.50 | 0.084 | 0.024 | 0.016 |
| 125        | 12.5 | 10.7    | 5.1 | 7.6  | 0.75 | 1.00 | 0.093 | 0.054 | 0.047 |
| 126        | 15.0 | 10.1    | 6.9 | 8.8  | 0.85 | 0.88 | 0.100 | 0.079 | 0.049 |
| 127        | 13.5 | 10.1    | 5.7 | 10.0 | 0.86 | 2.40 | 0.090 | 0.126 | 0.065 |
| 128        | 19.5 | 10.4    | 5.3 | 10.9 | 0.94 | 2.10 | 0.114 | 0.028 | 0.066 |
| 129        | 12.5 | 10.2    | 6.5 | 8.4  | 0.82 | 0.79 | 0.106 | 0.085 | 0.060 |
| 130        | 16.0 | 10.9    | 6.8 | 9.4  | 0.94 | 1.10 | 0.108 | 0.092 | 0.060 |
| 131        | 15.0 | 7.7     | 4.2 | 7.8  | 0.78 | 1.20 | 0.072 | 0.049 | 0.038 |
| 132        | 21.2 | 11.7    | 6.3 | 10.0 | 0.92 | 0.85 | 0.106 | 0.071 | 0.057 |
| 133        | 12.2 | 10.0    | 5.2 | 8.2  | 0.92 | 1.14 | 0.096 | 0.056 | 0.054 |
| 134        | 19.9 | Too low | 1.3 | 7.8  | 0.57 | 3.40 | 0.072 | 0.018 | 0.006 |
| 135        | 18.6 | 3.6     | 1.7 | 8.0  | 0.72 | 1.80 | 0.070 | 0.022 | 0.014 |
| 136        | 18.5 | 8.4     | 3.8 | 7.7  | 0.84 | 0.88 | 0.050 | 0.054 | 0.038 |
| 137        | 14.2 | 2.6     | 1.2 | 7.9  | 0.63 | 2.10 | 0.091 | 0.021 | 0.014 |
| 138        | 13.5 | 10.3    | 5.3 | 8.9  | 0.75 | 1.20 | 0.093 | 0.086 | 0.056 |
| 139        | 14.7 | 10.1    | 5.0 | 8.0  | 0.94 | 1.80 | 0.092 | 0.074 | 0.048 |
| 140        | 19.5 | 10.7    | 7.7 | 10.9 | 0.98 | 1.20 | 0.092 | 0.074 | 0.061 |
| 141        | 15.5 | 10.4    | 6.8 | 8.6  | 0.90 | 1.40 | 0.086 | 0.094 | 0.050 |
| 142        | 21.0 | 11.0    | 7.5 | 13.1 | 0.95 | 1.40 | 0.150 | 0.054 | 0.052 |
| 143        | 19.9 | 10.3    | 6.2 | 12.5 | 1.00 | 1.10 | 0.150 | 0.057 | 0.048 |

(7) ANTHEDON

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 144        | 17.0 | 4.1  | 3.3 | 7.8  | 0.85 | 2.10 | 0.094 | 0.032 | 0.023 |
| 145        | 16.0 | 2.9  | 1.3 | 8.5  | 0.66 | 2.30 | 0.086 | 0.024 | 0.015 |
| 146        | 13.0 | 3.0  | 2.6 | 7.2  | 0.76 | 2.10 | 0.086 | 0.030 | 0.024 |
| 147        | 17.8 | 13.3 | 5.7 | 7.6  | 0.80 | 1.00 | 0.096 | 0.056 | 0.053 |
| 148        | 16.5 | 12.3 | 3.7 | 9.9  | 0.66 | 1.00 | 0.121 | 0.047 | 0.063 |
| 149        | 21.6 | 22.0 | 3.8 | 11.6 | 0.89 | 1.10 | 0.200 | 0.059 | 0.064 |
| 150        | 18.6 | 2.9  | 1.7 | 8.7  | 0.81 | 2.00 | 0.103 | 0.026 | 0.014 |
| 151        | 15.5 | 7.5  | 3.2 | 7.3  | 0.87 | 1.90 | 0.098 | 0.029 | 0.019 |
| 152        | 17.0 | 6.6  | 3.9 | 7.4  | 0.83 | 1.70 | 0.096 | 0.028 | 0.020 |
| 153        | 16.5 | 10.5 | 5.3 | 8.6  | 0.88 | 1.40 | 0.099 | 0.047 | 0.046 |
| 154        | 21.5 | 7.7  | 4.4 | 10.3 | 1.20 | 2.20 | 0.108 | 0.040 | 0.030 |
| 155        | 21.4 | 20.0 | 7.0 | 9.2  | 1.10 | 1.10 | 0.085 | 0.069 | 0.053 |
| 156        | 15.0 | 4.4  | 3.4 | 10.2 | 0.87 | 2.10 | 0.103 | 0.045 | 0.040 |
| 157        | 22.6 | 6.9  | 2.3 | 8.3  | 0.83 | 1.70 | 0.105 | 0.026 | 0.007 |
| 158        | 20.5 | 6.8  | 1.8 | 10.4 | 0.76 | 2.20 | 0.120 | 0.033 | 0.021 |
| 159        | 15.2 | 4.2  | 1.8 | 10.2 | 0.86 | 1.80 | 0.140 | 0.101 | 0.045 |
| 160        | 20.6 | 3.6  | 1.7 | 10.6 | 0.63 | 2.80 | 0.145 | 0.031 | 0.015 |
| 161        | 13.4 | 3.4  | 1.1 | 7.5  | 0.54 | 2.20 | 0.087 | 0.023 | 0.012 |



(8) CHALIA

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|------------|------|------|-----|------|------|------|-------|---------|-------|
| 162        | 17.6 | 9.2  | 2.5 | 7.3  | 0.70 | 1.70 | 0.096 | 0.032   | 0.022 |
| 163        | 21.3 | 10.0 | 5.4 | 10.0 | 0.95 | 1.60 | 0.116 | 0.060   | 0.062 |
| 164        | 17.0 | 12.2 | 5.6 | 8.1  | 0.87 | 1.30 | 0.105 | 0.063   | 0.042 |
| 165        | 15.7 | 10.7 | 6.0 | 8.4  | 0.92 | 0.94 | 0.960 | Too low | 0.047 |
| 166        | 12.7 | 14.5 | 6.2 | 9.1  | 0.75 | 0.64 | 0.120 | 0.068   | 0.035 |
| 167        | 19.6 | 12.5 | 8.3 | 10.0 | 1.00 | 0.79 | 0.142 | 0.066   | 0.062 |
| 168        | 16.0 | 8.6  | 3.2 | 8.9  | 0.71 | 1.60 | 0.125 | 0.064   | 0.058 |
| 169        | 19.0 | 11.8 | 6.0 | 9.8  | 0.89 | 1.00 | 0.107 | 0.068   | 0.058 |
| 170        | 16.0 | 12.4 | 5.8 | 10.0 | 0.87 | 1.80 | 0.116 | 0.091   | 0.059 |
| 171        | 16.6 | 10.6 | 5.8 | 9.0  | 0.96 | 1.90 | 0.097 | 0.069   | 0.047 |
| 172        | 18.0 | 6.0  | 1.5 | 6.8  | 0.78 | 2.60 | 0.082 | 0.023   | 0.011 |
| 173        | 17.2 | 10.6 | 6.6 | 8.6  | 0.91 | 1.40 | 0.100 | 0.067   | 0.037 |
| 174        | 18.3 | 6.9  | 1.6 | 8.4  | 0.67 | 2.40 | 0.097 | 0.031   | 0.016 |
| 175        | 15.0 | 13.0 | 2.4 | 9.6  | 0.65 | 1.40 | 0.085 | 0.085   | 0.047 |
| 176        | 20.8 | 7.2  | 2.0 | 9.8  | 0.72 | 4.10 | 0.105 | 0.032   | 0.110 |
| 177        | 15.5 | 6.8  | 3.9 | 8.5  | 0.80 | 1.20 | 0.073 | 0.052   | 0.029 |
| 178        | 20.9 | 8.3  | 3.6 | 8.8  | 0.80 | 2.20 | 0.096 | 0.066   | 0.048 |
| 179        | 16.5 | 8.3  | 9.5 | 11.3 | 1.00 | 1.20 | 0.132 | 0.107   | 0.048 |
| 180        | 14.0 | 11.3 | 5.5 | 9.6  | 0.85 | 1.30 | 0.142 | 0.067   | 0.070 |
| 181        | 24.4 | 5.8  | 2.3 | 8.5  | 0.88 | 2.60 | 0.102 | 0.028   | 0.015 |

(9) DRAMESI

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 182        | 22.5 | 16.7 | 7.6 | 9.1  | 0.92 | 0.71 | 0.095 | 0.071 | 0.045 |
| 183        | 16.5 | 17.7 | 6.9 | 7.5  | 0.82 | 0.55 | 0.127 | 0.056 | 0.049 |
| 184        | 15.2 | 15.0 | 7.2 | 8.4  | 0.97 | 1.45 | 0.108 | 0.139 | 0.053 |
| 185        | 16.6 | 10.7 | 4.8 | 7.7  | 0.77 | 1.25 | 0.096 | 0.014 | 0.041 |
| 186        | 18.2 | 9.0  | 3.1 | 6.6  | 0.79 | 1.02 | 0.044 | 0.045 | 0.023 |
| 187        | 21.0 | 12.9 | 5.3 | 7.8  | 0.92 | 0.63 | 0.070 | 0.041 | 0.028 |
| 188        | 17.0 | 13.5 | 5.8 | 8.9  | 0.88 | 0.92 | 0.095 | 0.067 | 0.042 |
| 189        | 19.5 | 7.3  | 1.9 | 7.7  | 0.80 | 1.65 | 0.106 | 0.024 | 0.013 |
| 190        | 13.8 | 13.4 | 8.0 | 10.8 | 0.92 | 1.60 | 0.145 | 0.090 | 0.060 |
| 191        | 13.5 | 10.8 | 5.1 | 9.0  | 0.81 | 1.00 | 0.090 | 0.086 | 0.049 |
| 192        | 15.5 | 17.6 | 6.4 | 8.8  | 0.94 | 2.05 | 0.100 | 0.068 | 0.040 |
| 193        | 16.4 | 6.0  | 1.9 | 7.3  | 0.70 | 1.75 | 0.107 | 0.024 | 0.012 |
| 194        | 16.2 | 7.6  | 5.4 | 9.4  | 0.93 | 2.30 | 0.094 | 0.064 | 0.038 |
| 195        | 19.5 | 6.5  | 2.0 | 8.2  | 0.81 | 1.80 | 0.100 | 0.025 | 0.014 |
| 196        | 18.5 | 16.5 | 3.8 | 9.4  | 0.86 | 1.05 | 0.076 | 0.038 | 0.024 |
| 197        | 16.6 | 9.8  | 6.5 | 10.0 | 0.88 | 1.65 | 0.093 | 0.092 | 0.046 |
| 198        | 12.4 | 11.5 | 7.8 | 12.0 | 1.00 | 1.57 | 0.135 | 0.102 | 0.071 |
| 199        | 12.6 | 9.9  | 5.3 | 8.8  | 0.77 | 0.97 | 0.084 | 0.070 | 0.048 |
| 200        | 13.4 | 11.4 | 5.3 | 9.1  | 0.85 | 1.40 | 0.087 | 0.073 | 0.051 |
| 201        | 13.6 | 8.6  | 4.7 | 8.3  | 0.74 | 1.80 | 0.092 | 0.062 | 0.037 |

(10) ELEON

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 202        | 15.6 | 8.2  | 2.4 | 5.8  | 0.60 | 0.40 | 0.086 | 0.008 | 0.016 |
| 203        | 18.0 | 15.4 | 6.6 | 9.4  | 0.80 | 0.79 | 0.103 | 0.052 | 0.060 |
| 204        | 20.6 | 11.6 | 6.3 | 10.5 | 0.94 | 0.87 | 0.094 | 0.063 | 0.055 |
| 205        | 14.7 | 14.5 | 4.2 | 7.4  | 0.67 | 0.53 | 0.070 | 0.006 | 0.039 |
| 206        | 20.0 | 5.7  | 1.7 | 7.1  | 0.78 | 0.50 | 0.075 | 0.019 | 0.019 |
| 207        | 14.4 | 12.0 | 4.4 | 7.4  | 0.87 | 0.55 | 0.072 | 0.050 | 0.032 |
| 208        | 16.0 | 6.7  | 3.5 | 6.5  | 0.80 | 0.46 | 0.065 | 0.030 | 0.026 |
| 209        | 18.0 | 17.5 | 5.8 | 8.0  | 0.88 | 0.59 | 0.078 | 0.049 | 0.043 |
| 210        | 23.5 | 10.8 | 7.5 | 12.6 | 1.20 | 1.17 | 0.103 | 0.069 | 0.060 |
| 211        | 27.5 | 12.6 | 6.4 | 13.4 | 1.10 | 1.30 | 0.118 | 0.080 | 0.052 |
| 212        | 14.7 | 10.4 | 5.6 | 8.6  | 0.84 | 0.62 | 0.079 | 0.053 | 0.039 |
| 213        | 17.0 | 20.5 | 3.3 | 6.9  | 0.86 | 0.61 | 0.124 | 0.033 | 0.037 |
| 214        | 17.0 | 13.0 | 4.4 | 6.8  | 0.71 | 0.49 | 0.074 | 0.040 | 0.035 |
| 215        | 17.5 | 10.9 | 5.8 | 8.6  | 0.98 | 0.77 | 0.095 | 0.055 | 0.045 |
| 216        | 20.6 | 13.4 | 6.1 | 10.0 | 1.00 | 0.94 | 0.087 | 0.048 | 0.044 |
| 217        | 18.8 | 9.8  | 5.3 | 9.0  | 0.98 | 0.74 | 0.091 | 0.042 | 0.037 |
| 218        | 18.0 | 13.5 | 7.0 | 9.4  | 1.00 | 0.95 | 0.123 | 0.061 | 0.056 |
| 219        | 16.6 | 11.6 | 6.9 | 9.6  | 0.88 | 0.83 | 0.101 | 0.065 | 0.060 |
| 220        | 21.4 | 12.5 | 6.9 | 9.9  | 1.00 | 0.95 | 0.146 | 0.057 | 0.057 |
| 221        | 17.9 | 13.7 | 7.2 | 9.5  | 0.92 | 1.50 | 0.104 | 0.085 | 0.049 |



(11) KYNOS

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 222        | 14.7 | 10.1 | 3.8 | 8.6  | 0.98 | 1.70 | 0.069 | 0.066 | 0.035 |
| 223        | 15.5 | 10.0 | 3.5 | 8.5  | 0.93 | 1.60 | 0.069 | 0.056 | 0.034 |
| 224        | 17.2 | 14.9 | 1.4 | 7.7  | 0.84 | 1.50 | 0.084 | 0.026 | 0.021 |
| 225        | 17.6 | 11.4 | 3.6 | 7.7  | 1.00 | 2.10 | 0.070 | 0.053 | 0.031 |
| 226        | 15.5 | 11.7 | 4.4 | 8.6  | 0.78 | 1.10 | 0.092 | 0.054 | 0.042 |
| 227        | 14.3 | 14.2 | 3.2 | 8.0  | 0.86 | 1.20 | 0.080 | 0.036 | 0.031 |
| 228        | 15.2 | 8.9  | 4.9 | 9.5  | 0.81 | 1.10 | 0.089 | 0.063 | 0.040 |
| 229        | 11.0 | 5.8  | 3.0 | 6.0  | 0.68 | 1.50 | 0.097 | 0.072 | 0.033 |
| 230        | 14.6 | 8.2  | 5.0 | 7.0  | 0.89 | 1.40 | 0.056 | 0.052 | 0.032 |
| 231        | 14.2 | 3.6  | 1.5 | 6.8  | 0.61 | 1.60 | 0.076 | 0.024 | 0.013 |
| 232        | 22.6 | 15.0 | 6.9 | 10.5 | 1.10 | 1.20 | 0.115 | 0.053 | 0.035 |
| 233        | 10.2 | 6.0  | 4.4 | 6.7  | 0.62 | 2.40 | 0.068 | 0.038 | 0.025 |
| 234        | 13.3 | 9.1  | 3.0 | 8.8  | 0.70 | 1.60 | 0.087 | 0.041 | 0.034 |
| 235        | 12.2 | 11.3 | 1.2 | 7.4  | 0.63 | 1.60 | 0.042 | 0.027 | 0.014 |
| 236        | 13.8 | 13.1 | 1.8 | 8.0  | 0.51 | 6.20 | 0.096 | 0.045 | 0.036 |
| 237        | 14.7 | 5.3  | 3.4 | 7.7  | 0.80 | 2.10 | 0.070 | 0.044 | 0.024 |
| 238        | 17.0 | 10.2 | 4.5 | 9.3  | 0.94 | 1.70 | 0.084 | 0.063 | 0.033 |
| 239        | 14.2 | 14.5 | 4.5 | 7.9  | 0.75 | 0.82 | 0.095 | 0.038 | 0.023 |
| 240        | 17.4 | 10.1 | 3.9 | 9.9  | 0.85 | 1.70 | 0.071 | 0.054 | 0.024 |
| 241        | 12.2 | 7.7  | 3.6 | 7.8  | 0.81 | 1.80 | 0.059 | 0.040 | 0.035 |

(12) THEBES

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 242        | 11.8 | 10.5 | 5.9 | 7.4  | 0.73 | 1.60 | 0.095 | 0.082 | 0.057 |
| 243        | 15.2 | 11.2 | 3.9 | 8.1  | 0.68 | 0.67 | 0.063 | 0.051 | 0.051 |
| 244        | 17.1 | 9.3  | 4.5 | 11.6 | 0.95 | 3.20 | 0.114 | 0.150 | 0.057 |
| 245        | 14.9 | 3.6  | 3.5 | 7.0  | 0.75 | 0.48 | 0.067 | 0.042 | 0.032 |
| 246        | 13.5 | 8.6  | 3.3 | 8.2  | 0.60 | 1.60 | 0.102 | 0.032 | 0.024 |
| 247        | 23.3 | 15.3 | 6.0 | 8.6  | 0.91 | 0.53 | 0.074 | 0.058 | 0.046 |
| 248        | 13.0 | 4.9  | 7.7 | 13.0 | 0.99 | 2.10 | 0.204 | 0.180 | 0.190 |
| 249        | 21.0 | 12.9 | 3.1 | 10.5 | 0.76 | 0.33 | 0.093 | 0.032 | 0.031 |
| 250        | 10.3 | 18.6 | 2.0 | 6.3  | 0.49 | 0.72 | 0.062 | 0.023 | 0.026 |
| 251        | 21.7 | 11.2 | 6.2 | 8.4  | 0.98 | 0.39 | 0.087 | 0.055 | 0.044 |
| 252        | 17.2 | 5.7  | 5.3 | 8.2  | 0.74 | 1.20 | 0.078 | 0.054 | 0.059 |
| 253        | 15.7 | 15.6 | 3.4 | 9.0  | 0.73 | 0.95 | 0.106 | 0.068 | 0.073 |
| 254        | 18.0 | 14.0 | 3.1 | 9.6  | 0.66 | 0.68 | 0.075 | 0.039 | 0.035 |
| 255        | 17.5 | 20.4 | 6.7 | 10.5 | 0.87 | 0.78 | 0.096 | 0.078 | 0.075 |
| 256        | 17.1 | 7.1  | 5.3 | 8.1  | 0.85 | 0.74 | 0.075 | 0.046 | 0.049 |
| 257        | 11.5 | 7.9  | 3.6 | 7.6  | 0.66 | 0.50 | 0.057 | 0.057 | 0.062 |
| 258        | 16.5 | 17.0 | 6.8 | 10.7 | 0.88 | 0.68 | 0.130 | 0.102 | 0.084 |
| 259        | 14.5 | 9.7  | 2.8 | 7.9  | 0.65 | 1.05 | 0.114 | 0.028 | 0.022 |
| 260        | 12.4 | 13.4 | 4.8 | 8.4  | 0.65 | 0.67 | 0.106 | 0.105 | 0.058 |
| 261        | 15.4 | 9.1  | 3.5 | 10.5 | 0.92 | 2.30 | 0.088 | 0.096 | 0.061 |

(13) ARGISSA

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 262        | 14.2 | 6.6  | 3.7 | 6.0  | 0.72 | 2.60 | 0.110 | 0.006 | 0.006 |
| 263        | 9.2  | 0.5  | 0.7 | 7.9  | 0.49 | 2.65 | 0.094 | 0.034 | 0.014 |
| 264        | 14.8 | 7.5  | 3.3 | 8.5  | 0.74 | 1.15 | 0.140 | 0.081 | 0.042 |
| 265        | 10.2 | 3.4  | 1.5 | 7.5  | 0.56 | 1.45 | 0.077 | 0.038 | 0.030 |
| 266        | 12.4 | 6.8  | 3.0 | 8.8  | 0.68 | 0.85 | 0.127 | 0.060 | 0.053 |
| 267        | 12.8 | 4.5  | 4.0 | 5.9  | 0.71 | 2.60 | 0.118 | 0.005 | 0.005 |
| 268        | 18.6 | 8.4  | 6.0 | 11.3 | 0.97 | 1.15 | 0.173 | 0.073 | 0.051 |
| 269        | 14.5 | 1.7  | 1.1 | 7.1  | 0.68 | 2.05 | 0.128 | 0.024 | 0.015 |
| 270        | 20.8 | 13.5 | 3.4 | 8.6  | 0.86 | 1.34 | 0.094 | 0.110 | 0.030 |
| 271        | 15.4 | 13.8 | 4.3 | 8.6  | 0.83 | 1.25 | 0.140 | 0.074 | 0.048 |
| 272        | 15.5 | 6.8  | 3.2 | 9.1  | 0.80 | 1.01 | 0.149 | 0.042 | 0.041 |
| 273        | 15.4 | 4.8  | 4.4 | 9.6  | 0.89 | 0.98 | 0.108 | 0.061 | 0.050 |
| 274        | 15.5 | 4.9  | 4.1 | 7.7  | 0.90 | 2.75 | 0.113 | 0.027 | 0.020 |
| 275        | 14.2 | 1.2  | 1.0 | 7.6  | 0.75 | 2.32 | 0.086 | 0.032 | 0.004 |
| 276        | 18.1 | 2.0  | 1.5 | 8.0  | 0.86 | 2.92 | 0.110 | 0.021 | 0.011 |
| 277        | 17.9 | 5.6  | 4.1 | 8.6  | 0.89 | 1.17 | 0.124 | 0.057 | 0.050 |
| 278        | 17.5 | 8.8  | 3.9 | 9.4  | 0.80 | 1.14 | 0.139 | 0.066 | 0.043 |
| 279        | 15.9 | 8.0  | 2.7 | 7.0  | 0.76 | 0.41 | 0.059 | 0.072 | 0.043 |
| 280        | 16.0 | 2.7  | 1.9 | 7.1  | 0.69 | 2.00 | 0.092 | 0.031 | 0.018 |
| 281        | 17.9 | 6.5  | 4.1 | 8.6  | 0.87 | 0.80 | 0.072 | 0.087 | 0.047 |



(14) IOLKOS

| Sample No. | Al.  | Ca.  | Mg. | Fe. | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|-----|------|------|-------|-------|-------|
| 282        | 13.2 | 2.5  | 1.4 | 5.3 | 0.68 | 2.40 | 0.059 | 0.023 | 0.013 |
| 283        | 19.4 | 5.5  | 1.9 | 7.1 | 0.67 | 2.20 | 0.092 | 0.021 | 0.016 |
| 284        | 15.8 | 5.1  | 2.0 | 6.0 | 0.78 | 3.50 | 0.077 | 0.024 | 0.013 |
| 285        | 15.8 | 1.5  | 1.1 | 9.4 | 0.80 | 4.50 | 0.070 | 0.057 | 0.027 |
| 286        | 16.6 | 5.7  | 2.2 | 6.6 | 0.73 | 3.20 | 0.097 | 0.028 | 0.015 |
| 287        | 16.1 | 4.2  | 1.9 | 5.5 | 0.70 | 3.10 | 0.082 | 0.024 | 0.014 |
| 288        | 19.5 | 5.6  | 2.6 | 7.5 | 0.74 | 2.20 | 0.122 | 0.030 | 0.015 |
| 289        | 15.2 | 11.1 | 5.9 | 8.6 | 0.84 | 1.60 | 0.140 | 0.059 | 0.049 |
| 290        | 18.3 | 5.2  | 2.7 | 7.1 | 0.71 | 3.20 | 0.147 | 0.030 | 0.017 |
| 291        | 17.4 | 8.4  | 3.9 | 6.2 | 0.79 | 2.60 | 0.084 | 0.029 | 0.014 |
| 292        | 13.9 | 4.3  | 1.7 | 6.2 | 0.61 | 1.90 | 0.112 | 0.022 | 0.014 |
| 293        | 15.8 | 5.4  | 2.4 | 7.1 | 0.65 | 3.80 | 0.116 | 0.027 | 0.016 |
| 294        | 16.6 | 5.7  | 2.0 | 8.1 | 0.79 | 4.30 | 0.107 | 0.032 | 0.018 |
| 295        | 15.2 | 4.1  | 1.8 | 5.8 | 0.63 | 2.70 | 0.084 | 0.027 | 0.011 |
| 296        | 16.4 | 10.6 | 3.0 | 7.6 | 0.74 | 0.80 | 0.097 | 0.030 | 0.020 |
| 297        | 16.3 | 10.7 | 2.2 | 7.0 | 0.64 | 0.86 | 0.068 | 0.027 | 0.021 |
| 298        | 13.5 | 12.7 | 2.5 | 8.2 | 0.75 | 1.20 | 0.097 | 0.035 | 0.026 |
| 299        | 17.0 | 3.7  | 1.6 | 7.1 | 0.73 | 2.40 | 0.068 | 0.023 | 0.013 |
| 300        | 18.5 | 3.3  | 1.8 | 6.3 | 0.59 | 2.60 | 0.089 | 0.024 | 0.014 |
| 301        | 12.7 | 13.4 | 2.6 | 8.2 | 0.66 | 1.80 | 0.111 | 0.049 | 0.026 |
| 302        | 17.5 | 13.1 | 3.6 | 7.4 | 0.76 | 1.60 | 0.101 | 0.042 | 0.030 |
| 303        | 16.5 | 4.1  | 2.0 | 6.9 | 0.71 | 2.50 | 0.113 | 0.037 | 0.018 |
| 304        | 23.2 | 14.9 | 4.0 | 8.1 | 0.84 | 1.00 | 0.109 | 0.039 | 0.020 |

## (14) IOLKOS (Continued)

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.                  | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|----------------------|-------|-------|
| 305        | 19.6 | 16.6 | 4.1 | 9.9  | 0.76 | 1.30 | 0.134                | 0.051 | 0.029 |
| 306        | 23.6 | 19.1 | 4.4 | 8.0  | 0.82 | 1.70 | 0.128                | 0.037 | 0.019 |
| 307        | 17.1 | 16.0 | 4.4 | 9.8  | 0.73 | 1.70 | 0.157                | 0.050 | 0.031 |
| 308        | 18.9 | 13.3 | 5.3 | 7.7  | 0.86 | 1.50 | 0.082                | 0.058 | 0.025 |
| 309        | 20.0 | 4.5  | 2.6 | 6.0  | 0.72 | 2.00 | 0.088                | 0.029 | 0.015 |
| 310        | 16.6 | 13.2 | 3.1 | 7.1  | 0.77 | 0.49 | 0.072                | 0.050 | 0.034 |
| 311        | 13.7 | 3.4  | 1.7 | 5.1  | 0.66 | 1.80 | 0.069                | 0.011 | 0.012 |
| 312        | 15.2 | 6.1  | 2.8 | 7.5  | 0.68 | 1.80 | 0.074                | 0.042 | 0.023 |
| 313        | 20.1 | 5.7  | 3.0 | 7.5  | 0.76 | 3.50 | 0.117                | 0.038 | 0.019 |
| 314        | 15.8 | 12.0 | 3.0 | 7.3  | 0.66 | 1.70 | 0.099                | 0.043 | 0.025 |
| 315        | 20.8 | 22.0 | 6.6 | 10.7 | 1.01 | 2.00 | 0.113 <sup>(1)</sup> | 0.070 | 0.031 |
| 316        | 17.3 | 15.4 | 3.1 | 7.1  | 0.74 | 0.62 | 0.067                | 0.025 | 0.021 |
| 317        | 15.9 | 5.7  | 2.7 | 7.3  | 0.83 | 3.00 | 0.096                | 0.024 | 0.017 |
| 318        | 16.8 | 3.8  | 1.8 | 8.4  | 0.76 | 2.30 | 0.092                | 0.016 | 0.014 |
| 319        | 23.7 | 15.1 | 4.4 | 10.2 | 0.96 | 2.50 | 0.096                | 0.027 | 0.027 |
| 320        | 16.5 | 5.7  | 2.6 | 7.8  | 0.80 | 3.80 | 0.091                | 0.035 | 0.016 |
| 321        | 16.2 | 5.6  | 2.7 | 8.0  | 0.80 | 3.30 | 0.086                | 0.036 | 0.016 |
| 322        | 19.0 | 7.7  | 2.9 | 7.9  | 0.86 | 3.80 | 0.102                | 0.037 | 0.020 |
| 323        | 20.0 | 7.6  | 3.1 | 7.4  | 0.87 | 3.80 | 0.106                | 0.030 | 0.014 |
| 324        | 18.5 | 5.4  | 3.2 | 7.7  | 0.79 | 3.70 | 0.102                | 0.031 | 0.019 |
| 325        | 16.5 | 8.2  | 4.4 | 10.4 | 0.86 | 2.50 | 0.171                | 0.072 | 0.040 |

(14) IOLKOS (Continued)

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 326        | 18.4 | 17.7 | 2.2 | 7.7  | 0.82 | 1.80 | 0.115 | 0.067 | 0.025 |
| 327        | 21.1 | 5.7  | 3.1 | 6.9  | 0.84 | 3.60 | 0.121 | 0.027 | 0.012 |
| 328        | 15.7 | 5.3  | 2.9 | 7.5  | 0.83 | 4.30 | 0.100 | 0.032 | 0.015 |
| 329        | 20.0 | 3.6  | 3.0 | 10.6 | 1.00 | 2.50 | 0.121 | 0.048 | 0.023 |
| 330        | 17.0 | 7.6  | 2.9 | 8.6  | 0.83 | 5.40 | 0.097 | 0.040 | 0.020 |



Sherds labelled Volos, Iolkos, in the British School sherd collection.

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|------------|------|------|-----|------|------|------|-------|---------|-------|
| 689        | 12.0 | 5.1  | 2.5 | 6.9  | 0.64 | 0.61 | 0.094 | 0.034   | 0.018 |
| 690        | 10.5 | 6.5  | 2.9 | 7.0  | 0.76 | 0.62 | 0.111 | 0.039   | 0.018 |
| 691        | 11.8 | 14.7 | 3.9 | 8.1  | 0.68 | 0.84 | 0.087 | 0.036   | 0.029 |
| 692        | 18.3 | 6.0  | 1.5 | 8.0  | 0.88 | 0.77 | 0.084 | Too low | 0.016 |
| 693        | 22.1 | 25.5 | 3.8 | 7.9  | 0.78 | 0.75 | 0.125 | 0.039   | 0.023 |
| 694        | 8.2  | 3.5  | 1.4 | 8.1  | 0.47 | 0.64 | 0.155 | 0.034   | 0.018 |
| 695        | 14.1 | 9.6  | 3.1 | 7.8  | 0.71 | 0.86 | 0.094 | 0.057   | 0.050 |
| 696        | 23.3 | 5.8  | 3.0 | 7.7  | 0.90 | 1.84 | 0.138 | 0.040   | 0.018 |
| 697        | 12.8 | 2.2  | 1.7 | 7.2  | 0.66 | 0.49 | 0.090 | 0.030   | 0.012 |
| 698        | 14.5 | 5.1  | 2.0 | 5.2  | 0.64 | 0.39 | 0.095 | 0.031   | 0.013 |
| 699        | 13.1 | 11.8 | 5.0 | 7.6  | 0.80 | 0.68 | 0.084 | 0.048   | 0.021 |
| 700        | 19.5 | 5.6  | 2.9 | 8.1  | 0.83 | 0.72 | 0.128 | Too low | 0.019 |
| 701        | 13.6 | 15.9 | 3.1 | 5.8  | 0.59 | 0.45 | 0.093 | 0.027   | 0.016 |
| 702        | 13.6 | 14.5 | 3.5 | 6.4  | 0.65 | 0.48 | 0.108 | 0.029   | 0.017 |
| 703        | 17.8 | 5.7  | 2.4 | 6.4  | 0.65 | 0.45 | 0.150 | Too low | 0.013 |
| 704        | 21.0 | 4.7  | 2.6 | 5.6  | 0.76 | 0.44 | 0.085 | 0.031   | 0.012 |
| 705        | 19.1 | 4.4  | 2.7 | 5.2  | 0.58 | 0.39 | 0.093 | 0.026   | 0.010 |
| 706        | 22.4 | 6.0  | 2.8 | 6.2  | 0.76 | 0.51 | 0.166 | 0.037   | 0.015 |
| 707        | 14.1 | 9.4  | 4.2 | 7.9  | 0.57 | 0.68 | 0.114 | 0.051   | 0.049 |
| 708        | 10.6 | 6.1  | 4.5 | 8.8  | 0.65 | 0.75 | 0.125 | 0.052   | 0.028 |
| 709        | 21.0 | 7.5  | 2.3 | 6.8  | 0.73 | 3.50 | 0.112 | 0.038   | 0.015 |
| 710        | 22.3 | 15.7 | 3.7 | 11.0 | 0.77 | 2.20 | 0.143 | 0.062   | 0.031 |
| 711        | 14.2 | 7.7  | 2.7 | 8.0  | 0.59 | 2.10 | 0.104 | 0.033   | 0.020 |

(15) MARMARIANI

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 331        | 19.3 | 14.5 | 6.6 | 9.9  | 0.93 | 1.02 | 0.099 | 0.068 | 0.058 |
| 332        | 16.1 | 6.0  | 5.6 | 10.2 | 0.90 | 1.10 | 0.222 | 0.051 | 0.045 |
| 333        | 13.7 | 5.0  | 3.9 | 8.6  | 0.87 | 2.55 | 0.124 | 0.052 | 0.042 |
| 334        | 21.5 | 9.6  | 5.6 | 10.6 | 0.97 | 2.45 | 0.192 | 0.052 | 0.048 |
| 335        | 13.4 | 7.9  | 2.8 | 8.6  | 0.74 | 0.76 | 0.152 | 0.039 | 0.028 |
| 336        | 17.1 | 11.3 | 3.1 | 7.3  | 0.81 | 0.60 | 0.116 | 0.025 | 0.023 |
| 337        | 19.0 | 7.3  | 6.3 | 11.2 | 0.99 | 2.50 | 0.217 | 0.044 | 0.038 |
| 338        | 16.2 | 6.3  | 3.9 | 8.8  | 0.95 | 1.70 | 0.145 | 0.039 | 0.044 |
| 339        | 17.5 | 6.9  | 5.0 | 9.5  | 0.90 | 2.20 | 0.167 | 0.038 | 0.031 |
| 340        | 21.1 | 8.0  | 6.1 | 11.8 | 0.92 | 2.90 | 0.195 | 0.050 | 0.040 |
| 341        | 17.6 | 4.5  | 5.0 | 8.6  | 0.83 | 2.80 | 0.124 | 0.051 | 0.035 |
| 342        | 19.5 | 18.1 | 2.9 | 9.2  | 0.76 | 0.64 | 0.068 | 0.039 | 0.031 |
| 343        | 18.3 | 10.7 | 6.2 | 11.0 | 1.00 | 2.45 | 0.219 | 0.048 | 0.041 |
| 344        | 16.2 | 9.7  | 5.5 | 9.4  | 0.94 | 2.42 | 0.163 | 0.044 | 0.039 |
| 345        | 19.7 | 12.0 | 5.5 | 10.6 | 1.05 | 2.70 | 0.185 | 0.048 | 0.046 |
| 346        | 15.0 | 10.5 | 6.7 | 9.5  | 0.80 | 2.34 | 0.200 | 0.039 | 0.032 |
| 347        | 18.0 | 12.7 | 5.8 | 9.8  | 0.94 | 1.30 | 0.155 | 0.044 | 0.044 |
| 348        | 12.2 | 5.6  | 4.4 | 9.6  | 0.85 | 0.92 | 0.210 | 0.043 | 0.029 |
| 349        | 14.7 | 3.9  | 3.7 | 7.0  | 0.76 | 0.06 | 0.078 | 0.031 | 0.021 |
| 350        | 16.0 | 11.5 | 4.2 | 7.7  | 0.71 | 2.65 | 0.114 | 0.032 | 0.024 |
| 351        | 16.6 | 10.3 | 4.8 | 7.3  | 0.71 | 1.23 | 0.144 | 0.036 | 0.031 |

(15) MARMARIANI (Continued)

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|------------|------|------|-----|------|------|------|-------|---------|-------|
| 352        | 12.6 | 9.7  | 4.1 | 10.7 | 0.88 | 1.04 | 0.275 | Too low | 0.035 |
| 353        | 16.4 | 7.1  | 5.3 | 8.6  | 0.74 | 2.60 | 0.151 | 0.040   | 0.033 |
| 354        | 10.7 | 4.9  | 3.5 | 7.2  | 0.59 | 2.10 | 0.135 | 0.031   | 0.028 |
| 355        | 11.7 | 3.6  | 4.8 | 7.3  | 0.65 | 2.15 | 0.103 | 0.025   | 0.019 |
| 356        | 16.2 | 11.1 | 4.4 | 8.6  | 0.68 | 1.70 | 0.176 | 0.039   | 0.033 |
| 357        | 17.0 | 13.4 | 5.9 | 9.4  | 0.80 | 2.45 | 0.185 | 0.043   | 0.038 |
| 358        | 10.7 | 5.5  | 3.2 | 7.3  | 0.61 | 3.40 | 0.133 | 0.055   | 0.037 |
| 359        | 16.2 | 6.7  | 4.9 | 10.4 | 0.70 | 3.00 | 0.170 | 0.025   | 0.035 |
| 360        | 15.5 | 7.1  | 4.6 | 12.4 | 0.80 | 2.50 | 0.136 | 0.054   | 0.044 |
| 361        | 11.9 | 9.6  | 3.4 | 7.7  | 0.62 | 2.23 | 0.177 | 0.036   | 0.029 |
| 362        | 13.0 | 9.2  | 3.4 | 7.4  | 0.67 | 1.55 | 0.108 | 0.036   | 0.032 |
| 363        | 17.5 | 12.0 | 5.7 | 8.2  | 0.77 | 1.70 | 0.142 | 0.039   | 0.029 |
| 364        | 15.5 | 6.7  | 5.3 | 10.2 | 0.71 | 2.50 | 0.179 | 0.045   | 0.032 |
| 365        | 12.5 | 6.3  | 3.0 | 7.5  | 0.80 | 0.64 | 0.122 | 0.036   | 0.025 |
| 366        | 15.9 | 10.0 | 4.2 | 10.7 | 0.78 | 1.97 | 0.150 | 0.044   | 0.035 |
| 367        | 14.8 | 5.9  | 4.2 | 8.3  | 0.73 | 3.10 | 0.130 | 0.036   | 0.030 |
| 368        | 11.7 | 6.2  | 3.9 | 8.8  | 0.64 | 2.05 | 0.155 | 0.038   | 0.031 |
| 369        | 15.5 | 9.2  | 5.1 | 9.3  | 0.74 | 2.70 | 0.201 | 0.039   | 0.032 |
| 370        | 30.9 | 15.5 | 7.6 | 10.2 | 1.18 | 1.60 | 0.198 | 0.056   | 0.037 |



(16) PEVKAKIA  
EARLY HELLADIC

| Sample No. | Al.  | Ca.  | Mg. | Fe. | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|------------|------|------|-----|-----|------|------|-------|---------|-------|
| 371        | 13.7 | 5.9  | 1.4 | 5.6 | 0.64 | 2.80 | 0.045 | 0.008   | 0.019 |
| 372        | 15.0 | 10.2 | 2.3 | 7.0 | 0.68 | 1.20 | 0.075 | 0.025   | 0.019 |
| 373        | 16.1 | 4.6  | 1.3 | 7.2 | 0.73 | 1.70 | 0.078 | 0.015   | 0.021 |
| 374        | 17.0 | 5.3  | 3.3 | 5.6 | 0.73 | 2.10 | 0.052 | 0.022   | 0.019 |
| 375        | 19.0 | 4.5  | 1.5 | 8.2 | 0.73 | 2.90 | 0.077 | 0.025   | 0.019 |
| 376        | 15.7 | 24.6 | 3.4 | 9.7 | 0.99 | 3.20 | 0.122 | 0.065   | 0.044 |
| 377        | 17.9 | 7.0  | 2.2 | 7.1 | 0.74 | 1.70 | 0.074 | 0.011   | 0.020 |
| 378        | 16.0 | 15.2 | 2.4 | 7.8 | 0.71 | 1.50 | 0.082 | 0.034   | 0.024 |
| 379        | 16.4 | 5.1  | 1.6 | 5.6 | 0.76 | 3.20 | 0.068 | 0.028   | 0.021 |
| 380        | 15.5 | 3.9  | 1.0 | 4.2 | 0.65 | 4.30 | 0.046 | Too low | 0.019 |
| 381        | 19.4 | 5.6  | 3.1 | 8.3 | 0.83 | 2.80 | 0.077 | 0.011   | 0.021 |
| 382        | 11.9 | 10.4 | 3.0 | 6.7 | 0.76 | 2.50 | 0.079 | 0.063   | 0.029 |
| 383        | 14.5 | 10.8 | 3.0 | 8.5 | 0.79 | 0.98 | 0.100 | 0.039   | 0.025 |
| 384        | 16.5 | 6.4  | 2.0 | 7.9 | 0.86 | 2.70 | 0.068 | 0.036   | 0.034 |
| 385        | 19.0 | 4.4  | 1.5 | 8.2 | 0.67 | 2.60 | 0.080 | 0.020   | 0.020 |
| 386        | 16.5 | 3.4  | 1.6 | 6.7 | 0.71 | 2.80 | 0.053 | 0.033   | 0.019 |
| 387        | 13.9 | 4.4  | 2.5 | 8.3 | 0.79 | 1.90 | 0.096 | 0.044   | 0.034 |
| 388        | 11.5 | 3.5  | 0.4 | 3.3 | 0.60 | 3.30 | 0.046 | 0.007   | 0.028 |
| 389        | 23.0 | 5.3  | 1.9 | 9.5 | 0.88 | 2.20 | 0.091 | 0.025   | 0.020 |
| 390        | 10.8 | 6.5  | 4.2 | 8.0 | 0.78 | 4.70 | 0.088 | 0.098   | 0.044 |

(16) PEVKAKIAEARLY HELLADIC (Continued)

| Sample No. | Al.  | Ca. | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|------------|------|-----|-----|------|------|------|-------|---------|-------|
| 391        | 18.7 | 3.5 | 3.1 | 7.2  | 0.65 | 1.90 | 0.098 | 0.066   | 0.030 |
| 392        | 25.4 | 6.1 | 2.9 | 8.8  | 0.84 | 4.00 | 0.098 | 0.036   | 0.020 |
| 393        | 23.2 | 6.1 | 2.1 | 10.2 | 0.85 | 2.00 | 0.110 | 0.024   | 0.019 |
| 394        | 19.2 | 3.7 | 1.6 | 7.6  | 0.61 | 3.90 | 0.064 | 0.053   | 0.024 |
| 395        | 19.4 | 5.2 | 1.1 | 5.0  | 0.65 | 4.60 | 0.050 | Too low | 0.021 |
| 396        | 15.6 | 7.0 | 1.1 | 4.5  | 0.54 | 4.10 | 0.045 | Too low | 0.016 |
| 397        | 18.0 | 4.7 | 1.6 | 6.9  | 0.82 | 4.00 | 0.055 | Too low | 0.023 |
| 398        | 12.4 | 3.1 | 0.7 | 4.0  | 0.50 | 4.30 | 0.043 | Too low | 0.015 |
| 399        | 19.4 | 3.7 | 1.5 | 9.0  | 0.72 | 3.80 | 0.081 | 0.024   | 0.020 |

MIDDLE HELLADIC

|     |      |     |     |      |      |      |       |       |       |
|-----|------|-----|-----|------|------|------|-------|-------|-------|
| 400 | 21.0 | 3.7 | 2.5 | 10.3 | 0.87 | 3.00 | 0.044 | 0.064 | 0.028 |
| 401 | 19.8 | 3.7 | 1.5 | 10.3 | 0.99 | 2.30 | 0.088 | 0.030 | 0.022 |
| 402 | 21.1 | 3.2 | 1.9 | 9.7  | 0.88 | 2.30 | 0.081 | 0.033 | 0.037 |
| 403 | 24.2 | 7.0 | 1.3 | 8.0  | 0.72 | 3.00 | 0.071 | 0.010 | 0.016 |
| 404 | 16.0 | 4.6 | 0.6 | 5.7  | 0.72 | 3.10 | 0.044 | 0.019 | 0.023 |
| 405 | 20.5 | 4.3 | 1.9 | 9.1  | 0.75 | 2.70 | 0.102 | 0.026 | 0.019 |
| 406 | 21.1 | 5.8 | 1.8 | 9.1  | 0.74 | 2.50 | 0.102 | 0.026 | 0.022 |
| 407 | 21.1 | 6.1 | 4.8 | 17.5 | 1.00 | 1.90 | 0.162 | 0.095 | 0.044 |

## MIDDLE HELLADIC (Continued)

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|------------|------|------|-----|------|------|------|-------|---------|-------|
| 408        | 30.5 | 5.5  | 6.5 | 19.5 | 1.17 | 1.90 | 0.168 | 0.092   | 0.042 |
| 409        | 12.8 | 10.5 | 1.8 | 4.8  | 0.40 | 2.20 | 0.047 | 0.012   | 0.011 |
| 410        | 14.3 | 1.4  | 0.5 | 4.6  | 0.53 | 3.20 | 0.057 | Too low | 0.003 |
| 411        | 21.0 | 15.0 | 4.8 | 9.2  | 0.74 | 2.10 | 0.106 | 0.055   | 0.058 |
| 412        | 20.5 | 5.8  | 2.1 | 5.4  | 0.77 | 2.20 | 0.102 | 0.024   | 0.012 |
| 413        | 22.3 | 9.0  | 0.6 | 4.6  | 0.53 | 2.00 | 0.037 | 0.014   | 0.009 |
| 414        | 21.8 | 12.7 | 3.3 | 9.2  | 0.84 | 4.71 | 0.087 | 0.026   | 0.024 |
| 415        | 20.5 | 11.2 | 3.7 | 7.3  | 0.82 | 3.30 | 0.047 | 0.061   | 0.034 |
| 416        | 19.8 | 6.2  | 1.4 | 7.3  | 0.60 | 5.20 | 0.078 | 0.022   | 0.011 |
| 417        | 21.4 | 13.4 | 4.8 | 8.5  | 0.82 | 2.30 | 0.102 | 0.058   | 0.054 |
| 418        | 15.5 | 3.3  | 1.3 | 6.3  | 0.60 | 4.80 | 0.067 | 0.019   | 0.011 |
| 419        | 10.0 | 6.2  | 5.7 | 6.8  | 0.67 | 1.20 | 0.074 | 0.088   | 0.063 |
| 420        | 21.2 | 0.5  | 1.8 | 6.4  | 1.08 | 1.30 | 0.074 | 0.075   | 0.037 |
| 421        | 18.7 | 8.4  | 2.5 | 7.4  | 0.67 | 2.60 | 0.079 | 0.021   | 0.014 |
| 422        | 19.8 | 3.6  | 1.3 | 8.2  | 0.75 | 3.00 | 0.095 | 0.022   | 0.015 |
| 423        | 23.0 | 9.4  | 2.2 | 5.9  | 0.66 | 3.10 | 0.070 | 0.013   | 0.010 |
| 424        | 21.5 | 8.4  | 2.7 | 6.6  | 0.75 | 3.90 | 0.079 | 0.024   | 0.013 |
| 425        | 14.0 | 11.0 | 2.4 | 4.6  | 0.43 | 4.20 | 0.057 | 0.023   | 0.013 |
| 426        | 24.7 | 6.5  | 1.9 | 6.3  | 0.76 | 3.90 | 0.052 | 0.014   | 0.009 |
| 427        | 24.5 | 4.5  | 1.6 | 6.4  | 0.74 | 2.70 | 0.052 | 0.015   | 0.011 |
| 428        | 18.7 | 4.8  | 3.9 | 8.5  | 1.01 | 2.10 | 0.083 | 0.030   | 0.023 |



MIDDLE HELLADIC (Continued)

| Sample No.                    | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|-------------------------------|------|------|-----|------|------|------|-------|-------|-------|
| 429                           | 17.5 | 4.6  | 1.6 | 6.7  | 0.67 | 2.40 | 0.079 | 0.021 | 0.015 |
| 430                           | 20.7 | 12.4 | 4.6 | 8.2  | 0.99 | 1.40 | 0.141 | 0.068 | 0.049 |
| 431                           | 20.5 | 17.7 | 2.6 | 4.7  | 0.57 | 2.10 | 0.063 | 0.017 | 0.007 |
| 432                           | 20.5 | 10.6 | 5.1 | 7.9  | 0.80 | 1.90 | 0.102 | 0.045 | 0.040 |
| 433                           | 21.0 | 4.0  | 4.4 | 9.5  | 0.99 | 2.90 | 0.084 | 0.063 | 0.032 |
| 434                           | 26.1 | 5.9  | 2.4 | 8.4  | 0.83 | 2.30 | 0.079 | 0.023 | 0.017 |
| 435                           | 20.5 | 4.4  | 1.9 | 7.7  | 0.74 | 2.00 | 0.078 | 0.020 | 0.014 |
| <u>LATE HELLADIC GROUP 1.</u> |      |      |     |      |      |      |       |       |       |
| 436                           | 20.5 | 18.0 | 4.3 | 10.0 | 0.94 | 1.90 | 0.124 | 0.040 | 0.026 |
| 437                           | 25.5 | 27.2 | 6.2 | 11.1 | 0.98 | 3.80 | 0.139 | 0.047 | 0.031 |
| 438                           | 22.4 | 26.6 | 5.1 | 8.6  | 1.00 | 3.10 | 0.138 | 0.042 | 0.030 |
| 439                           | 19.4 | 18.7 | 3.9 | 10.0 | 0.98 | 3.40 | 0.115 | 0.048 | 0.031 |
| 440                           | 19.5 | 14.6 | 3.8 | 9.5  | 0.85 | 1.60 | 0.094 | 0.040 | 0.026 |
| 441                           | 17.0 | 14.2 | 5.5 | 9.2  | 0.96 | 2.00 | 0.080 | 0.066 | 0.035 |
| 442                           | 17.6 | 17.1 | 5.1 | 8.8  | 1.00 | 3.00 | 0.139 | 0.039 | 0.027 |
| 443                           | 20.5 | 22.5 | 3.3 | 9.5  | 0.89 | 1.50 | 0.115 | 0.053 | 0.028 |
| 444                           | 18.5 | 17.0 | 3.3 | 8.9  | 0.80 | 1.20 | 0.100 | 0.038 | 0.025 |
| 445                           | 13.2 | 16.2 | 2.6 | 8.6  | 0.69 | 1.10 | 0.102 | 0.035 | 0.025 |
| 446                           | 22.6 | 15.4 | 4.1 | 11.1 | 0.93 | 0.56 | 0.124 | 0.057 | 0.045 |
| 447                           | 16.9 | 18.0 | 3.6 | 10.0 | 0.87 | 2.00 | 0.116 | 0.039 | 0.031 |

LATE HELLADIC GROUP 1 (Continued)

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 448        | 23.4 | 22.2 | 4.4 | 8.1  | 0.85 | 1.60 | 0.121 | 0.035 | 0.022 |
| 449        | 18.8 | 17.6 | 3.2 | 8.6  | 0.73 | 1.30 | 0.095 | 0.034 | 0.024 |
| 450        | 18.0 | 15.4 | 3.3 | 10.0 | 0.77 | 1.20 | 0.094 | 0.040 | 0.032 |
| 451        | 19.5 | 12.2 | 3.9 | 9.9  | 0.89 | 1.40 | 0.090 | 0.037 | 0.025 |
| 452        | 25.0 | 8.7  | 3.4 | 9.1  | 1.06 | 2.30 | 0.080 | 0.027 | 0.019 |
| 453        | 19.0 | 14.4 | 4.3 | 10.0 | 0.93 | 1.90 | 0.118 | 0.038 | 0.030 |
| 454        | 25.3 | 6.6  | 2.9 | 8.6  | 0.93 | 2.50 | 0.107 | 0.039 | 0.022 |

LATE HELLADIC GROUP 2

|     |      |      |     |      |      |      |       |       |       |
|-----|------|------|-----|------|------|------|-------|-------|-------|
| 455 | 27.0 | 18.0 | 5.3 | 10.0 | 0.96 | 2.80 | 0.124 | 0.038 | 0.024 |
| 456 | 16.5 | 13.2 | 2.8 | 7.3  | 0.68 | 1.10 | 0.067 | 0.028 | 0.019 |
| 457 | 14.2 | 6.9  | 3.7 | 8.2  | 1.13 | 2.10 | 0.086 | 0.065 | 0.034 |
| 458 | 24.4 | 18.0 | 5.8 | 10.2 | 0.97 | 3.20 | 0.140 | 0.054 | 0.033 |
| 459 | 18.5 | 5.9  | 2.0 | 8.3  | 0.71 | 2.30 | 0.106 | 0.025 | 0.013 |
| 460 | 21.3 | 10.2 | 7.1 | 9.8  | 0.92 | 1.10 | 0.081 | 0.059 | 0.060 |
| 461 | 18.0 | 18.0 | 2.8 | 7.0  | 0.79 | 1.40 | 0.072 | 0.037 | 0.023 |
| 462 | 19.0 | 21.5 | 2.9 | 8.3  | 0.70 | 1.50 | 0.096 | 0.041 | 0.026 |
| 463 | 29.5 | 26.5 | 5.8 | 13.5 | 0.98 | 3.10 | 0.142 | 0.052 | 0.032 |
| 464 | 18.8 | 18.4 | 3.6 | 9.8  | 0.76 | 1.80 | 0.120 | 0.039 | 0.026 |
| 465 | 15.6 | 13.2 | 3.5 | 9.3  | 0.76 | 1.69 | 0.122 | 0.042 | 0.026 |
| 466 | 15.6 | 13.0 | 4.4 | 8.4  | 0.84 | 3.80 | 0.058 | 0.060 | 0.034 |
| 467 | 13.0 | 6.4  | 2.8 | 8.4  | 0.62 | 1.92 | 0.080 | 0.045 | 0.041 |
| 468 | 15.6 | 10.7 | 2.8 | 8.0  | 0.73 | 1.50 | 0.086 | 0.031 | 0.025 |

LATE HELLADIC GROUP 3.

| Sample No. | Al.  | Ca.  | Mg. | Fe. | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|-----|------|------|-------|-------|-------|
| 469        | 19.0 | 5.0  | 2.2 | 7.7 | 0.76 | 4.32 | 0.132 | 0.036 | 0.019 |
| 470        | 15.3 | 6.9  | 2.4 | 8.4 | 0.69 | 4.50 | 0.089 | 0.040 | 0.024 |
| 471        | 22.5 | 11.7 | 3.9 | 8.8 | 0.84 | 4.80 | 0.140 | 0.041 | 0.023 |
| 472        | 16.0 | 5.7  | 2.0 | 8.0 | 0.67 | 3.95 | 0.071 | 0.035 | 0.019 |
| 473        | 16.3 | 13.7 | 2.7 | 7.2 | 0.65 | 2.85 | 0.058 | 0.063 | 0.029 |
| 474        | 17.5 | 4.6  | 2.6 | 9.0 | 0.76 | 4.20 | 0.102 | 0.040 | 0.022 |
| 475        | 16.5 | 13.1 | 2.2 | 9.0 | 0.57 | 1.12 | 0.081 | 0.030 | 0.021 |
| 476        | 14.9 | 3.6  | 2.5 | 6.4 | 0.70 | 3.05 | 0.100 | 0.017 | 0.019 |
| 477        | 24.0 | 8.5  | 4.0 | 8.1 | 0.90 | 3.00 | 0.116 | 0.037 | 0.021 |
| 478        | 14.5 | 9.2  | 2.7 | 7.2 | 0.70 | 1.34 | 0.069 | 0.027 | 0.020 |
| 479        | 18.1 | 7.6  | 2.5 | 7.3 | 0.71 | 3.31 | 0.117 | 0.032 | 0.019 |
| 480        | 18.6 | 4.8  | 2.5 | 7.7 | 0.80 | 4.31 | 0.116 | 0.033 | 0.023 |
| 481        | 21.0 | 5.5  | 3.1 | 8.8 | 0.89 | 3.95 | 0.140 | 0.035 | 0.020 |
| 482        | 16.3 | 13.3 | 2.8 | 7.2 | 0.66 | 1.40 | 0.069 | 0.023 | 0.022 |
| 483        | 17.8 | 6.5  | 3.6 | 7.5 | 0.89 | 5.50 | 0.102 | 0.041 | 0.033 |



LATE HELLADIC GROUP 4.

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.                  | Ni.   |
|------------|------|------|-----|------|------|------|-------|----------------------|-------|
| 484        | 14.1 | 10.6 | 2.4 | 9.0  | 0.63 | 1.50 | 0.107 | 0.043 <sup>(1)</sup> | 0.033 |
| 485        | 20.8 | 3.0  | 1.4 | 7.3  | 0.61 | 1.80 | 0.041 | 0.013                | 0.007 |
| 486        | 23.2 | 7.8  | 2.3 | 10.5 | 0.90 | 3.40 | 0.139 | 0.044                | 0.024 |
| 487        | 18.3 | 18.3 | 7.8 | 9.0  | 0.81 | 2.30 | 0.102 | 0.052                | 0.023 |
| 488        | 19.4 | 3.8  | 2.6 | 8.0  | 0.90 | 3.40 | 0.072 | 0.039                | 0.018 |
| 489        | 20.8 | 5.8  | 3.4 | 10.0 | 0.84 | 1.30 | 0.135 | 0.100                | 0.071 |
| 490        | 16.5 | 19.0 | 4.5 | 12.4 | 0.79 | 2.30 | 0.172 | 0.058                | 0.049 |
| 491        | 15.7 | 4.3  | 1.8 | 9.4  | 0.82 | 4.10 | 0.113 | 0.028                | 0.016 |
| 492        | 17.2 | 4.7  | 2.5 | 7.7  | 0.73 | 4.30 | 0.110 | 0.036                | 0.019 |
| 493        | 19.7 | 5.5  | 3.2 | 8.0  | 0.83 | 3.20 | 0.121 | 0.036                | 0.019 |
| 494        | 14.1 | 13.8 | 5.4 | 10.2 | 0.66 | 2.30 | 0.224 | 0.069                | 0.075 |
| 495        | 16.1 | 4.1  | 2.0 | 7.1  | 0.77 | 3.00 | 0.090 | 0.037                | 0.015 |
| 496        | 21.2 | 7.0  | 3.2 | 8.3  | 0.95 | 2.80 | 0.125 | 0.044                | 0.017 |
| 497        | 19.3 | 1.1  | 2.1 | 9.5  | 0.81 | 4.10 | 0.085 | 0.029                | 0.016 |
| 498        | 18.2 | 4.7  | 2.6 | 6.8  | 0.75 | 3.50 | 0.104 | 0.030                | 0.013 |
| 499        | 17.6 | 5.7  | 2.4 | 8.3  | 0.76 | 3.00 | 0.113 | 0.037                | 0.017 |
| 500        | 18.2 | 1.3  | 2.4 | 8.9  | 0.80 | 2.30 | 0.099 | 0.058                | 0.039 |
| 501        | 16.1 | 11.4 | 7.1 | 11.3 | 0.97 | 2.80 | 0.128 | 0.081                | 0.038 |
| 502        | 17.3 | 12.4 | 3.4 | 9.0  | 0.75 | 1.20 | 0.106 | 0.041                | 0.025 |

LATE HELLADIC GROUP 6.

| Sample No. | Al.  | Ca. | Mg. | Fe.  | Ti.  | Na.  | Mn.     | Cr.     | Ni.   |
|------------|------|-----|-----|------|------|------|---------|---------|-------|
| 503        | 13.4 | 1.5 | 4.1 | 9.7  | 0.78 | 2.20 | 0.170   | 0.071   | 0.048 |
| 504        | 11.5 | 1.0 | 2.9 | 11.7 | 0.88 | 2.85 | 0.139   | 0.066   | 0.050 |
| 505        | 13.5 | 2.1 | 3.6 | 11.5 | 0.79 | 2.26 | 0.175   | 0.088   | 0.053 |
| 506        | 13.2 | 2.0 | 3.9 | 9.4  | 0.81 | 2.30 | 0.147   | 0.073   | 0.047 |
| 507        | 16.1 | 1.7 | 2.9 | 8.4  | 0.82 | 2.35 | 0.121   | 0.065   | 0.034 |
| 508        | 19.5 | 7.2 | 1.4 | 7.4  | 0.84 | 1.40 | 0.076   | 0.032   | 0.020 |
| 509        | 14.9 | 1.5 | 4.5 | 11.0 | 0.81 | 2.15 | 0.150   | 0.078   | 0.051 |
| 510        | 20.6 | 2.7 | 3.2 | 9.3  | 0.78 | 3.50 | 0.111   | 0.030   | 0.018 |
| 511        | 17.1 | 3.1 | 4.4 | 10.1 | 0.89 | 2.05 | 0.160   | 0.058   | 0.043 |
| 512        | 15.1 | 0.5 | 1.2 | 7.5  | 0.56 | 1.90 | Too low | 0.010   | 0.005 |
| 513        | 18.1 | 1.0 | 1.6 | 10.0 | 0.94 | 2.70 | 0.151   | 0.047   | 0.031 |
| 514        | 18.9 | 2.4 | 1.2 | 6.3  | 0.56 | 1.50 | Too low | 0.010   | 0.004 |
| 515        | 18.0 | 6.7 | 4.5 | 9.7  | 0.90 | 2.90 | 0.124   | 0.046   | 0.030 |
| 516        | 16.7 | 5.5 | 4.5 | 8.2  | 0.75 | 2.80 | 0.087   | 0.039   | 0.032 |
| 517        | 16.5 | 5.1 | 4.3 | 8.2  | 0.71 | 2.40 | 0.104   | 0.038   | 0.035 |
| 518        | 17.9 | 4.1 | 2.3 | 7.7  | 0.72 | 3.10 | 0.078   | 0.039   | 0.018 |
| 519        | 15.9 | 3.7 | 2.0 | 7.3  | 0.59 | 4.30 | 0.114   | 0.033   | 0.015 |
| 520        | 16.7 | 7.3 | 5.5 | 11.3 | 0.82 | 2.00 | 0.180   | 0.103   | 0.097 |
| 521        | 18.3 | 3.2 | 2.6 | 5.8  | 0.55 | 3.30 | 0.072   | 0.037   | 0.012 |
| 522        | 13.0 | 4.3 | 3.5 | 7.8  | 0.59 | 1.90 | 0.060   | 0.072   | 0.062 |
| 523        | 19.9 | 2.2 | 5.5 | 9.2  | 0.94 | 2.00 | 0.143   | 0.072   | 0.048 |
| 524        | 20.5 | 2.4 | 1.5 | 5.5  | 0.53 | 1.70 | 0.029   | Too low | 0.004 |

LATE HELLADIC GROUP 6 (Continued)

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 525        | 14.9 | 11.4 | 4.5 | 7.1  | 0.78 | 2.10 | 0.166 | 0.068 | 0.048 |
| 526        | 16.5 | 13.2 | 6.7 | 11.4 | 0.89 | 3.60 | 0.137 | 0.083 | 0.073 |
| 527        | 14.9 | 14.5 | 4.8 | 7.0  | 0.66 | 1.60 | 0.100 | 0.057 | 0.037 |
| 528        | 19.6 | 3.8  | 1.7 | 5.2  | 0.71 | 2.90 | 0.046 | 0.016 | 0.006 |
| 529        | 17.9 | 4.7  | 3.9 | 10.1 | 0.86 | 2.40 | 0.107 | 0.041 | 0.027 |
| 530        | 17.9 | 4.1  | 4.6 | 11.4 | 0.92 | 2.80 | 0.145 | 0.072 | 0.069 |

LATE HELLADIC GROUP 8.

|     |      |      |     |      |      |      |       |       |       |
|-----|------|------|-----|------|------|------|-------|-------|-------|
| 531 | 15.5 | 10.3 | 2.4 | 8.5  | 0.57 | 1.40 | 0.084 | 0.035 | 0.024 |
| 532 | 17.7 | 2.9  | 2.0 | 7.5  | 0.70 | 3.40 | 0.078 | 0.032 | 0.018 |
| 533 | 15.0 | 0.9  | 1.3 | 7.0  | 0.74 | 2.90 | 0.056 | 0.029 | 0.017 |
| 534 | 18.3 | 0.7  | 1.2 | 8.5  | 0.73 | 0.90 | 0.098 | 0.038 | 0.027 |
| 535 | 15.9 | 1.2  | 1.0 | 8.9  | 0.80 | 3.40 | 0.098 | 0.044 | 0.020 |
| 536 | 20.6 | 13.5 | 5.1 | 9.0  | 0.87 | 2.80 | 0.146 | 0.032 | 0.021 |
| 537 | 10.5 | 3.4  | 2.5 | 9.4  | 0.60 | 3.30 | 0.083 | 0.079 | 0.066 |
| 538 | 21.0 | 11.6 | 3.9 | 9.8  | 0.72 | 2.50 | 0.076 | 0.043 | 0.028 |
| 539 | 12.2 | 3.5  | 2.1 | 7.3  | 0.59 | 3.60 | 0.096 | 0.043 | 0.016 |
| 540 | 19.6 | 11.6 | 2.9 | 10.0 | 0.92 | 4.20 | 0.130 | 0.039 | 0.023 |
| 541 | 13.4 | 7.3  | 2.9 | 9.0  | 0.63 | 1.70 | 0.094 | 0.033 | 0.025 |
| 542 | 13.6 | 7.2  | 2.3 | 7.5  | 0.65 | 1.80 | 0.078 | 0.041 | 0.017 |



LATE HELLADIC GROUP 8 (Continued)

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 543        | 14.1 | 5.3  | 1.6 | 6.5  | 0.62 | 3.90 | 0.066 | 0.025 | 0.009 |
| 544        | 14.4 | 3.2  | 2.2 | 6.8  | 0.74 | 4.70 | 0.112 | 0.030 | 0.013 |
| 545        | 15.0 | 10.4 | 2.6 | 8.4  | 0.65 | 4.20 | 0.064 | 0.044 | 0.024 |
| 546        | 13.4 | 1.7  | 3.4 | 8.8  | 0.70 | 2.30 | 0.139 | 0.061 | 0.044 |
| 547        | 17.1 | 5.0  | 2.7 | 7.9  | 0.81 | 4.10 | 0.087 | 0.044 | 0.015 |
| 548        | 14.6 | 1.2  | 1.3 | 6.7  | 0.78 | 3.90 | 0.077 | 0.021 | 0.013 |
| 549        | 20.2 | 1.6  | 2.0 | 13.8 | 1.22 | 3.30 | 0.125 | 0.102 | 0.038 |
| 550        | 20.3 | 1.9  | 2.3 | 9.5  | 0.99 | 2.77 | 0.080 | 0.043 | 0.022 |
| 551        | 19.5 | 3.4  | 2.4 | 7.3  | 0.75 | 3.09 | 0.084 | 0.034 | 0.015 |
| 552        | 21.6 | 2.2  | 2.1 | 10.2 | 0.90 | 2.05 | 0.096 | 0.045 | 0.021 |
| 553        | 15.7 | 2.1  | 2.2 | 7.5  | 0.78 | 2.80 | 0.091 | 0.035 | 0.018 |
| 554        | 18.4 | 1.5  | 1.8 | 8.3  | 0.78 | 2.55 | 0.083 | 0.042 | 0.015 |

LATE HELLADIC GROUP 9.

| Sample No. | Al.  | Ca.  | Mg. | Fe. | Ti.  | Na.  | Mn.     | Cr.   | Ni.   |
|------------|------|------|-----|-----|------|------|---------|-------|-------|
| 555        | 22.0 | 10.5 | 3.0 | 7.0 | 0.84 | 2.75 | 0.079   | 0.041 | 0.013 |
| 556        | 19.5 | 7.7  | 2.7 | 7.1 | 0.70 | 3.25 | 0.087   | 0.030 | 0.011 |
| 557        | 17.6 | 7.8  | 2.3 | 6.3 | 0.67 | 2.60 | 0.082   | 0.045 | 0.010 |
| 558        | 15.0 | 5.3  | 2.6 | 7.2 | 0.61 | 3.65 | 0.095   | 0.027 | 0.015 |
| 559        | 20.0 | 12.6 | 3.7 | 8.4 | 0.82 | 2.05 | 0.098   | 0.037 | 0.026 |
| 560        | 20.5 | 7.8  | 2.5 | 6.3 | 0.69 | 2.75 | 0.065   | 0.014 | 0.007 |
| 561        | 17.6 | 5.5  | 1.6 | 5.1 | 0.76 | 3.00 | Too low | 0.036 | 0.005 |
| 562        | 13.4 | 10.4 | 3.6 | 7.9 | 0.62 | 2.60 | 0.117   | 0.029 | 0.025 |
| 563        | 15.6 | 7.6  | 2.0 | 6.5 | 0.62 | 2.75 | 0.065   | 0.049 | 0.009 |
| 564        | 12.4 | 6.4  | 2.2 | 5.7 | 0.62 | 2.85 | 0.075   | 0.014 | 0.014 |
| 565        | 16.5 | 6.0  | 2.1 | 6.5 | 0.67 | 3.44 | 0.067   | 0.041 | 0.012 |
| 566        | 17.5 | 6.3  | 2.2 | 5.3 | 0.71 | 3.30 | 0.062   | 0.032 | 0.009 |
| 567        | 15.7 | 7.3  | 2.1 | 7.6 | 0.63 | 3.90 | 0.084   | 0.024 | 0.016 |
| 568        | 15.0 | 4.5  | 1.6 | 6.5 | 0.73 | 3.25 | 0.078   | 0.045 | 0.011 |
| 569        | 11.3 | 8.2  | 2.6 | 7.7 | 0.61 | 2.64 | 0.090   | 0.045 | 0.022 |
| 570        | 17.2 | 3.1  | 2.0 | 8.2 | 0.82 | 2.76 | 0.067   | 0.038 | 0.018 |
| 571        | 16.6 | 6.3  | 2.2 | 7.7 | 0.64 | 3.30 | 0.080   | 0.042 | 0.017 |
| 572        | 17.0 | 4.1  | 2.5 | 7.8 | 0.70 | 3.10 | 0.111   | 0.051 | 0.017 |
| 573        | 21.5 | 1.3  | 2.0 | 8.6 | 0.83 | 2.05 | Too low | 0.054 | 0.020 |
| 574        | 13.0 | 8.0  | 2.3 | 8.6 | 0.66 | 1.80 | 0.101   | 0.055 | 0.063 |
| 575        | 16.5 | 2.6  | 1.5 | 7.5 | 0.78 | 3.30 | 0.107   | 0.030 | 0.014 |

LATE HELLADIC GROUP 10.

| <u>Sample No.</u> | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|-------------------|------|------|-----|------|------|------|-------|---------|-------|
| 576               | 11.0 | 10.2 | 3.3 | 9.6  | 0.60 | 3.00 | 0.111 | 0.043   | 0.028 |
| 577               | 16.3 | 13.7 | 2.7 | 8.0  | 0.75 | 1.60 | 0.098 | 0.071   | 0.034 |
| 578               | 13.6 | 0.8  | 3.3 | 10.7 | 0.70 | 4.10 | 0.154 | 0.043   | 0.026 |
| 579               | 16.0 | 0.9  | 0.6 | 5.1  | 0.61 | 3.40 | 0.031 | Too low | 0.004 |
| 580               | 21.0 | 1.0  | 1.4 | 7.8  | 0.80 | 3.20 | 0.057 | 0.024   | 0.013 |
| 581               | 14.6 | 2.0  | 1.3 | 5.3  | 0.74 | 2.95 | 0.068 | 0.022   | 0.015 |
| 582               | 21.0 | 4.6  | 2.6 | 8.1  | 0.71 | 3.30 | 0.089 | 0.032   | 0.016 |
| 583               | 16.6 | 1.0  | 0.9 | 9.7  | 0.79 | 1.60 | 0.142 | 0.040   | 0.021 |
| 584               | 20.0 | 5.6  | 1.1 | 16.0 | 1.13 | 0.95 | 0.222 | 0.072   | 0.043 |
| 585               | 19.4 | 4.4  | 4.5 | 10.7 | 0.79 | 2.30 | 0.110 | 0.063   | 0.043 |
| 586               | 16.0 | 1.8  | 2.9 | 12.9 | 0.79 | 2.60 | 0.054 | 0.064   | 0.029 |
| 587               | 21.0 | 1.3  | 0.7 | 14.6 | 0.77 | 1.00 | 0.037 | 0.088   | 0.042 |
| 588               | 13.0 | 1.6  | 3.1 | 10.8 | 0.70 | 2.70 | 0.139 | 0.093   | 0.048 |
| 589               | 16.8 | 0.5  | 1.6 | 10.7 | 0.68 | 2.30 | 0.059 | 0.017   | 0.026 |
| 590               | 16.6 | 1.9  | 3.2 | 11.4 | 0.89 | 2.40 | 0.060 | 0.061   | 0.037 |
| 591               | 18.6 | 3.9  | 2.2 | 7.6  | 0.66 | 3.70 | 0.093 | 0.031   | 0.014 |
| 592               | 14.8 | 5.7  | 2.3 | 10.0 | 0.63 | 3.10 | 0.110 | 0.043   | 0.019 |



LATE HELLADIC GROUP 11

| Sample No. | Al.  | Ca. | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|-----|-----|------|------|------|-------|-------|-------|
| 593        | 17.0 | 1.2 | 2.0 | 12.4 | 1.07 | 0.99 | 0.126 | 0.070 | 0.038 |
| 594        | 15.2 | 0.9 | 1.6 | 13.1 | 0.98 | 1.15 | 0.104 | 0.072 | 0.045 |
| 595        | 15.3 | 1.3 | 2.0 | 14.0 | 1.09 | 0.98 | 0.192 | 0.084 | 0.049 |
| 596        | 20.2 | 1.3 | 2.4 | 12.3 | 1.13 | 1.27 | 0.105 | 0.088 | 0.037 |
| 597        | 19.3 | 1.3 | 2.5 | 15.0 | 1.25 | 0.99 | 0.127 | 0.086 | 0.048 |
| 598        | 18.5 | 1.1 | 2.4 | 12.0 | 1.02 | 1.05 | 0.120 | 0.064 | 0.040 |
| 599        | 18.0 | 1.2 | 5.0 | 12.6 | 0.72 | 0.88 | 0.095 | 0.086 | 0.063 |
| 600        | 18.2 | 1.1 | 1.7 | 9.8  | 0.72 | 2.01 | 0.177 | 0.051 | 0.039 |

LATE HELLADIC GROUP 12

|     |      |         |     |     |      |      |       |         |       |
|-----|------|---------|-----|-----|------|------|-------|---------|-------|
| 601 | 15.2 | 4.6     | 1.9 | 7.9 | 0.78 | 3.50 | 0.064 | 0.028   | 0.022 |
| 602 | 12.4 | 4.0     | 1.7 | 6.1 | 0.66 | 2.50 | 0.066 | 0.019   | 0.015 |
| 603 | 15.6 | 7.9     | 2.7 | 7.1 | 0.88 | 3.80 | 0.087 | 0.028   | 0.018 |
| 604 | 12.3 | Too low | 1.0 | 6.2 | 0.76 | 2.40 | 0.063 | 0.019   | 0.016 |
| 605 | 10.9 | 5.3     | 1.5 | 4.5 | 0.49 | 2.10 | 0.043 | Too low | 0.010 |
| 606 | 17.0 | 7.6     | 2.7 | 6.9 | 0.76 | 2.10 | 0.043 | 0.017   | 0.021 |
| 607 | 17.2 | 4.3     | 1.7 | 6.6 | 0.80 | 2.40 | 0.085 | 0.022   | 0.014 |
| 608 | 13.7 | 6.3     | 2.3 | 7.3 | 0.58 | 2.30 | 0.079 | 0.025   | 0.020 |
| 609 | 15.6 | 2.0     | 1.7 | 6.2 | 0.61 | 1.70 | 0.064 | 0.018   | 0.015 |

(17) REVMATIA

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|------|------|------|-------|-------|-------|
| 610        | 18.6 | 19.5 | 1.6 | 6.6  | 0.74 | 1.20 | 0.083 | 0.038 | 0.021 |
| 611        | 15.7 | 9.5  | 3.1 | 6.7  | 0.63 | 1.00 | 0.103 | 0.029 | 0.024 |
| 612        | 17.2 | 18.0 | 1.9 | 8.6  | 0.87 | 0.72 | 0.135 | 0.034 | 0.030 |
| 613        | 18.4 | 15.4 | 3.0 | 8.0  | 0.76 | 1.15 | 0.080 | 0.038 | 0.031 |
| 614        | 14.5 | 12.0 | 1.9 | 6.9  | 0.83 | 1.80 | 0.074 | 0.041 | 0.030 |
| 615        | 16.0 | 3.6  | 5.9 | 7.2  | 0.88 | 5.60 | 0.092 | 0.009 | 0.008 |
| 616        | 21.7 | 22.1 | 2.1 | 7.9  | 0.90 | 1.33 | 0.086 | 0.149 | 0.026 |
| 617        | 17.2 | 19.0 | 2.0 | 8.5  | 0.81 | 1.60 | 0.074 | 0.047 | 0.032 |
| 618        | 15.9 | 18.0 | 2.1 | 7.5  | 0.77 | 1.23 | 0.104 | 0.040 | 0.028 |
| 619        | 18.8 | 16.5 | 2.7 | 7.6  | 0.80 | 1.64 | 0.105 | 0.032 | 0.020 |
| 620        | 17.8 | 18.4 | 2.3 | 7.4  | 0.77 | 0.73 | 0.070 | 0.037 | 0.025 |
| 621        | 16.4 | 15.0 | 2.9 | 8.8  | 0.79 | 1.63 | 0.107 | 0.043 | 0.033 |
| 622        | 16.7 | 18.6 | 2.5 | 7.3  | 0.73 | 1.20 | 0.074 | 0.040 | 0.024 |
| 623        | 17.7 | 26.6 | 2.7 | 8.4  | 0.71 | 0.70 | 0.052 | 0.042 | 0.027 |
| 624        | 17.8 | 22.5 | 2.2 | 6.2  | 0.70 | 1.45 | 0.091 | 0.027 | 0.017 |
| 625        | 17.2 | 18.7 | 2.0 | 7.8  | 0.89 | 1.20 | 0.074 | 0.049 | 0.030 |
| 626        | 14.5 | 19.2 | 2.3 | 7.1  | 0.71 | 1.33 | 0.049 | 0.040 | 0.025 |
| 627        | 20.5 | 17.4 | 3.4 | 7.5  | 0.85 | 1.25 | 0.086 | 0.042 | 0.025 |
| 628        | 18.2 | 20.0 | 2.8 | 7.5  | 0.84 | 1.42 | 0.063 | 0.054 | 0.025 |
| 629        | 21.2 | 23.7 | 2.8 | 8.8  | 0.80 | 1.26 | 0.098 | 0.055 | 0.029 |
| 630        | 21.0 | 18.9 | 2.8 | 8.9  | 0.76 | 0.88 | 0.113 | 0.037 | 0.023 |
| 631        | 33.1 | 34.0 | 3.2 | 11.2 | 1.07 | 0.82 | 0.134 | 0.044 | 0.028 |

(18) VELESTINO (PHERAE)

(a) Group thought to have been made in Iolkos

| Sample No. | Al.  | Ca. | Mg. | Fe. | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|-----|-----|-----|------|------|-------|-------|-------|
| 632        | 16.9 | 4.8 | 2.2 | 5.1 | 0.67 | 1.50 | 0.117 | 0.030 | 0.009 |
| 633        | 13.7 | 4.6 | 1.4 | 4.5 | 0.62 | 1.10 | 0.068 | 0.023 | 0.010 |
| 634        | 16.3 | 4.8 | 1.7 | 4.9 | 0.66 | 1.40 | 0.060 | 0.024 | 0.010 |
| 635        | 13.4 | 4.5 | 1.3 | 4.5 | 0.60 | 1.40 | 0.052 | 0.021 | 0.012 |
| 636        | 14.4 | 5.4 | 1.7 | 5.0 | 0.71 | 1.90 | 0.083 | 0.026 | 0.010 |

(b) Group thought to be of local manufacture

|     |      |      |     |     |      |      |       |       |       |
|-----|------|------|-----|-----|------|------|-------|-------|-------|
| 637 | 17.0 | 7.1  | 3.4 | 6.8 | 0.82 | 1.50 | 0.092 | 0.046 | 0.026 |
| 638 | 17.6 | 8.5  | 2.4 | 5.3 | 0.81 | 2.10 | 0.049 | 0.032 | 0.011 |
| 639 | 13.8 | 9.9  | 2.8 | 6.5 | 0.68 | 0.09 | 0.080 | 0.040 | 0.030 |
| 640 | 15.6 | 1.5  | 4.0 | 5.9 | 0.71 | 1.50 | 0.070 | 0.028 | 0.020 |
| 641 | 18.3 | 14.5 | 3.8 | 6.5 | 0.75 | 0.07 | 0.086 | 0.060 | 0.039 |
| 642 | 23.8 | 8.5  | 4.3 | 5.8 | 0.86 | 1.30 | 0.077 | 0.028 | 0.014 |
| 643 | 17.5 | 11.9 | 2.8 | 5.7 | 0.77 | 1.50 | 0.092 | 0.031 | 0.015 |
| 644 | 22.9 | 12.3 | 5.7 | 8.4 | 0.87 | 1.00 | 0.090 | 0.062 | 0.023 |
| 645 | 14.3 | 4.5  | 2.7 | 5.4 | 0.71 | 2.60 | 0.081 | 0.012 | 0.004 |
| 646 | 16.6 | 7.4  | 2.4 | 5.3 | 0.67 | 2.30 | 0.083 | 0.027 | 0.013 |
| 647 | 12.4 | 6.1  | 2.2 | 5.5 | 0.74 | 2.40 | 0.100 | 0.019 | 0.007 |
| 648 | 13.7 | 7.1  | 2.5 | 6.4 | 0.81 | 1.50 | 0.062 | 0.038 | 0.028 |
| 649 | 22.0 | 8.7  | 4.7 | 7.6 | 0.94 | 1.60 | 0.115 | 0.062 | 0.027 |



(b) Continued.

| Sample No. | Al.  | Ca.  | Mg. | Fe. | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|-----|-----|------|------|-------|-------|-------|
| 650        | 14.8 | 6.6  | 2.9 | 6.7 | 0.71 | 1.80 | 0.103 | 0.047 | 0.016 |
| 651        | 17.0 | 0.2  | 1.5 | 6.0 | 0.63 | 1.54 | 0.053 | 0.009 | 0.005 |
| 652        | 20.6 | 11.6 | 4.8 | 6.6 | 0.91 | 1.34 | 0.074 | 0.036 | 0.027 |
| 653        | 18.0 | 5.5  | 3.7 | 5.1 | 0.79 | 1.51 | 0.061 | 0.045 | 0.022 |
| 654        | 19.8 | 7.4  | 4.0 | 6.0 | 0.79 | 1.52 | 0.077 | 0.028 | 0.014 |
| 655        | 18.6 | 6.5  | 3.2 | 7.6 | 0.80 | 1.78 | 0.070 | 0.030 | 0.018 |
| 656        | 19.7 | 5.0  | 3.1 | 6.3 | 0.75 | 1.84 | 0.062 | 0.031 | 0.018 |
| 657        | 15.1 | 4.1  | 3.9 | 6.3 | 0.75 | 1.20 | 0.062 | 0.046 | 0.019 |

(c) Sherds thought to have been imported from the Argolid

|     |      |      |     |     |      |      |       |       |       |
|-----|------|------|-----|-----|------|------|-------|-------|-------|
| 658 | 18.5 | 9.7  | 2.8 | 5.0 | 0.69 | 0.46 | 0.059 | 0.025 | 0.013 |
| 659 | 22.9 | 9.4  | 5.4 | 5.3 | 0.86 | 0.92 | 0.112 | 0.029 | 0.020 |
| 660 | 23.6 | 9.8  | 3.7 | 6.1 | 0.84 | 1.80 | 0.071 | 0.025 | 0.014 |
| 661 | 23.4 | 10.7 | 6.3 | 6.7 | 0.95 | 1.92 | 0.104 | 0.048 | 0.021 |
| 662 | 23.0 | 9.3  | 5.0 | 6.7 | 0.72 | 1.03 | 0.088 | 0.034 | 0.034 |
| 663 | 22.3 | 14.9 | 5.6 | 6.0 | 0.84 | 0.91 | 0.067 | 0.030 | 0.017 |
| 664 | 14.2 | 7.6  | 1.8 | 4.7 | 0.52 | 0.43 | 0.081 | 0.020 | 0.013 |
| 665 | 20.5 | 10.2 | 6.4 | 7.3 | 0.93 | 1.33 | 0.070 | 0.038 | 0.023 |
| 666 | 20.4 | 10.0 | 7.1 | 7.7 | 0.94 | 0.63 | 0.078 | 0.054 | 0.027 |
| 667 | 16.9 | 14.5 | 5.8 | 9.2 | 0.85 | 0.77 | 0.084 | 0.051 | 0.031 |
| 668 | 18.5 | 9.6  | 5.1 | 7.7 | 0.82 | 0.65 | 0.073 | 0.038 | 0.028 |

(c) Continued.

| Sample No. | Al.  | Ca.  | Mg.  | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|------|------|------|------|------|-------|-------|-------|
| 669        | 19.5 | 13.5 | 3.4  | 8.1  | 0.71 | 0.62 | 0.099 | 0.031 | 0.024 |
| 670        | 14.4 | 12.6 | 3.5  | 9.2  | 0.80 | 1.90 | 0.097 | 0.056 | 0.038 |
| 671        | 22.5 | 33.0 | 7.4  | 9.0  | 0.90 | 0.74 | 0.155 | 0.054 | 0.027 |
| 672        | 18.1 | 10.6 | 6.1  | 7.0  | 0.92 | 0.63 | 0.092 | 0.032 | 0.024 |
| 673        | 16.0 | 12.4 | 3.2  | 6.9  | 0.70 | 0.51 | 0.093 | 0.037 | 0.022 |
| 674        | 18.1 | 14.0 | 5.0  | 9.8  | 0.85 | 0.51 | 0.085 | 0.036 | 0.023 |
| 675        | 17.6 | 13.6 | 7.9  | 9.4  | 0.92 | 0.84 | 0.098 | 0.045 | 0.032 |
| 676        | 20.2 | 14.2 | 7.2  | 9.2  | 0.95 | 0.73 | 0.098 | 0.048 | 0.031 |
| 677        | 23.5 | 24.0 | 3.7  | 13.5 | 1.00 | 1.40 | 0.124 | 0.070 | 0.056 |
| 678        | 15.9 | 10.6 | 6.1  | 7.9  | 0.92 | 0.63 | 0.081 | 0.030 | 0.024 |
| 679        | 19.4 | 16.5 | 5.7  | 9.1  | 0.89 | 0.83 | 0.096 | 0.052 | 0.032 |
| 680        | 25.6 | 14.3 | 11.0 | 9.4  | 1.40 | 0.77 | 0.074 | 0.043 | 0.027 |
| 681        | 15.2 | 10.7 | 3.0  | 6.6  | 0.89 | 1.70 | 0.049 | 0.050 | 0.040 |
| 682        | 15.0 | 10.1 | 2.9  | 5.8  | 0.76 | 2.60 | 0.098 | 0.029 | 0.018 |
| 683        | 19.9 | 15.5 | 7.6  | 8.5  | 0.95 | 0.69 | 0.078 | 0.028 | 0.024 |
| 684        | 24.0 | 7.8  | 6.5  | 7.1  | 0.85 | 0.51 | 0.075 | 0.042 | 0.019 |
| 685        | 23.9 | 12.6 | 6.1  | 8.0  | 0.89 | 0.64 | 0.084 | 0.042 | 0.024 |
| 686        | 19.5 | 10.1 | 4.4  | 8.0  | 0.88 | 0.65 | 0.079 | 0.028 | 0.026 |
| 687        | 25.5 | 14.4 | 4.1  | 8.0  | 0.88 | 0.73 | 0.089 | 0.020 | 0.024 |
| 688        | 16.6 | 8.4  | 4.3  | 7.1  | 0.76 | 0.65 | 0.082 | 0.031 | 0.028 |

(19) YEPHYRIA

| Sample No. | Al.  | Ca.     | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   |
|------------|------|---------|-----|------|------|------|-------|-------|-------|
| 712        | 14.7 | 7.5     | 5.9 | 9.2  | 0.70 | 0.76 | 0.158 | 0.064 | 0.054 |
| 713        | 13.4 | 6.6     | 1.7 | 7.0  | 0.54 | 0.53 | 0.071 | 0.034 | 0.019 |
| 714        | 18.5 | 6.1     | 2.6 | 7.3  | 0.63 | 0.52 | 0.068 | 0.035 | 0.019 |
| 715        | 19.4 | 19.5    | 2.7 | 7.7  | 0.74 | 0.59 | 0.094 | 0.038 | 0.027 |
| 716        | 9.2  | 6.4     | 1.7 | 6.8  | 0.50 | 0.46 | 0.056 | 0.026 | 0.017 |
| 717        | 14.6 | 3.2     | 4.2 | 11.7 | 0.78 | 1.04 | 0.138 | 0.044 | 0.036 |
| 718        | 13.6 | 8.6     | 2.4 | 10.7 | 0.64 | 0.93 | 0.120 | 0.045 | 0.037 |
| 719        | 14.1 | 5.4     | 4.0 | 9.8  | 0.63 | 0.82 | 0.134 | 0.041 | 0.043 |
| 720        | 16.5 | 1.4     | 3.7 | 7.1  | 0.74 | 0.61 | 0.096 | 0.056 | 0.025 |
| 721        | 16.5 | 20.5    | 2.4 | 8.3  | 0.58 | 0.61 | 0.129 | 0.031 | 0.023 |
| 722        | 18.8 | 4.8     | 3.7 | 9.9  | 0.80 | 0.80 | 0.090 | 0.042 | 0.032 |
| 723        | 14.2 | 21.0    | 2.0 | 7.5  | 0.62 | 0.54 | 0.092 | 0.035 | 0.022 |
| 724        | 12.2 | Too low | 3.5 | 13.6 | 0.93 | 1.64 | 0.200 | 0.060 | 0.055 |
| 725        | 14.7 | 23.5    | 2.4 | 8.6  | 0.56 | 0.64 | 0.112 | 0.041 | 0.023 |
| 726        | 12.6 | 6.6     | 5.8 | 10.0 | 0.69 | 0.76 | 0.114 | 0.037 | 0.030 |
| 727        | 19.5 | 21.6    | 3.4 | 8.4  | 0.73 | 0.61 | 0.102 | 0.042 | 0.024 |
| 728        | 15.8 | 18.2    | 3.9 | 9.8  | 0.72 | 0.76 | 0.108 | 0.057 | 0.037 |
| 729        | 18.2 | 2.6     | 4.1 | 7.3  | 0.74 | 0.59 | 0.072 | 0.033 | 0.019 |
| 730        | 18.2 | 5.3     | 3.1 | 11.3 | 1.06 | 2.65 | 0.101 | 0.063 | 0.046 |
| 731        | 13.5 | 10.8    | 2.8 | 7.2  | 0.70 | 2.55 | 0.067 | 0.043 | 0.023 |
| 732        | 11.3 | 15.2    | 1.7 | 5.8  | 0.58 | 1.53 | 0.105 | 0.049 | 0.021 |



## (19) YEPHRIA (Continued)

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|------------|------|------|-----|------|------|------|-------|---------|-------|
| 733        | 18.7 | 26.5 | 2.4 | 10.0 | 0.79 | 0.73 | 0.133 | 0.038   | 0.030 |
| 734        | 13.8 | 17.8 | 1.8 | 7.4  | 0.72 | 1.90 | 0.130 | 0.041   | 0.024 |
| 735        | 17.0 | 17.4 | 3.1 | 10.4 | 0.84 | 2.30 | 0.111 | 0.036   | 0.025 |
| 736        | 12.8 | 15.2 | 1.8 | 10.3 | 0.64 | 1.06 | 0.184 | Too low | 0.034 |
| 737        | 18.5 | 24.0 | 2.3 | 7.6  | 0.78 | 1.24 | 0.105 | 0.038   | 0.026 |
| 738        | 13.6 | 16.4 | 2.1 | 9.2  | 0.62 | 1.90 | 0.139 | 0.040   | 0.032 |
| 739        | 11.9 | 13.6 | 1.6 | 7.7  | 0.64 | 0.74 | 0.138 | 0.031   | 0.025 |
| 740        | 16.6 | 15.5 | 2.5 | 7.4  | 0.81 | 0.84 | 0.111 | 0.035   | 0.021 |
| 741        | 13.2 | 19.5 | 2.2 | 7.8  | 0.76 | 1.70 | 0.115 | 0.041   | 0.025 |
| 742        | 16.0 | 20.1 | 2.5 | 6.7  | 0.71 | 0.86 | 0.075 | 0.028   | 0.016 |
| 743        | 14.0 | 9.4  | 7.3 | 9.4  | 0.89 | 0.71 | 0.088 | 0.057   | 0.048 |
| 744        | 16.6 | 11.7 | 2.4 | 7.6  | 0.98 | 0.76 | 0.081 | 0.032   | 0.022 |
| 745        | 17.5 | 23.7 | 2.7 | 9.1  | 0.86 | 0.92 | 0.097 | 0.038   | 0.027 |
| 746        | 17.2 | 27.4 | 2.5 | 7.8  | 0.70 | 0.55 | 0.104 | 0.038   | 0.025 |
| 747        | 12.8 | 18.6 | 2.4 | 6.8  | 0.52 | 0.59 | 0.113 | 0.034   | 0.022 |
| 748        | 14.3 | 12.4 | 3.4 | 7.4  | 0.74 | 0.69 | 0.087 | 0.038   | 0.023 |
| 749        | 20.2 | 17.8 | 2.7 | 10.0 | 0.89 | 1.04 | 0.116 | 0.056   | 0.030 |
| 750        | 19.8 | 19.5 | 3.5 | 10.9 | 0.97 | 1.02 | 0.160 | 0.049   | 0.025 |
| 751        | 20.3 | 26.1 | 2.3 | 8.3  | 0.67 | 0.60 | 0.122 | 0.037   | 0.024 |

(20) YEPHYRA-ASMAKIOU

| Sample No. | Al.  | Ca.     | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|------------|------|---------|-----|------|------|------|-------|---------|-------|
| 752        | 20.0 | 9.8     | 5.7 | 9.5  | 0.83 | 3.00 | 0.201 | 0.046   | 0.043 |
| 753        | 20.5 | 14.2    | 5.9 | 8.6  | 0.77 | 3.50 | 0.183 | 0.043   | 0.036 |
| 754        | 25.5 | Too low | 2.9 | 4.8  | 0.94 | 1.40 | 0.044 | 0.052   | 0.025 |
| 755        | 19.5 | 12.8    | 5.8 | 10.3 | 0.84 | 2.80 | 0.197 | 0.052   | 0.043 |
| 756        | 21.5 | 10.2    | 3.6 | 7.8  | 0.82 | 2.30 | 0.134 | 0.035   | 0.031 |
| 757        | 10.5 | 5.4     | 3.2 | 6.5  | 0.63 | 5.50 | 0.107 | Too low | 0.016 |
| 758        | 16.5 | 14.6    | 4.7 | 9.2  | 0.67 | 3.90 | 0.206 | 0.044   | 0.041 |
| 759        | 17.5 | 11.7    | 5.6 | 9.3  | 0.75 | 2.20 | 0.158 | 0.060   | 0.049 |
| 760        | 16.4 | 9.6     | 4.0 | 8.2  | 0.71 | 3.40 | 0.141 | 0.043   | 0.034 |
| 761        | 17.3 | 10.3    | 4.7 | 7.3  | 0.73 | 2.10 | 0.133 | 0.037   | 0.028 |
| 762        | 15.6 | 8.2     | 4.1 | 12.9 | 0.88 | 5.80 | 0.156 | 0.055   | 0.056 |
| 763        | 17.5 | 18.4    | 4.8 | 9.4  | 0.82 | 4.30 | 0.178 | 0.081   | 0.051 |
| 764        | 22.5 | 10.8    | 7.8 | 10.7 | 0.95 | 2.90 | 0.163 | 0.054   | 0.043 |
| 765        | 23.1 | 6.8     | 4.9 | 11.6 | 0.78 | 3.40 | 0.184 | 0.077   | 0.046 |
| 766        | 12.3 | 10.0    | 3.9 | 9.9  | 0.65 | 2.20 | 0.197 | Too low | 0.041 |
| 767        | 26.6 | 17.7    | 9.4 | 12.3 | 1.08 | 3.80 | 0.250 | 0.056   | 0.043 |
| 768        | 17.3 | 15.6    | 7.0 | 11.5 | 0.89 | 5.20 | 0.265 | 0.056   | 0.045 |
| 769        | 24.1 | 18.3    | 7.8 | 9.2  | 0.94 | 3.10 | 0.182 | 0.051   | 0.031 |
| 770        | 20.2 | 21.9    | 6.9 | 10.4 | 0.71 | 2.40 | 0.207 | 0.046   | 0.034 |
| 771        | 13.4 | 7.0     | 3.4 | 8.9  | 0.65 | 2.10 | 0.124 | 0.046   | 0.043 |
| 772        | 13.3 | 4.6     | 1.7 | 8.1  | 0.65 | 5.50 | 0.156 | 0.049   | 0.022 |

## (20) YEPHYRA-ASMAKIOU (Continued)

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   |
|------------|------|------|-----|------|------|------|-------|---------|-------|
| 773        | 10.7 | 7.2  | 3.1 | 8.4  | 0.56 | 2.60 | 0.136 | 0.047   | 0.044 |
| 774        | 12.5 | 6.8  | 3.8 | 9.2  | 0.66 | 3.80 | 0.170 | 0.048   | 0.041 |
| 775        | 12.5 | 6.9  | 3.5 | 7.7  | 0.55 | 1.60 | 0.185 | 0.035   | 0.027 |
| 776        | 10.8 | 6.6  | 3.4 | 9.5  | 0.56 | 2.90 | 0.160 | 0.045   | 0.038 |
| 777        | 13.7 | 5.2  | 4.3 | 9.2  | 0.84 | 3.10 | 0.152 | 0.075   | 0.063 |
| 778        | 11.6 | 7.8  | 4.1 | 9.4  | 0.62 | 2.40 | 0.135 | 0.049   | 0.043 |
| 779        | 10.2 | 8.3  | 4.7 | 8.7  | 0.62 | 1.10 | 0.066 | 0.079   | 0.050 |
| 780        | 16.0 | 8.7  | 6.3 | 9.8  | 0.86 | 4.00 | 0.164 | 0.061   | 0.040 |
| 781        | 13.2 | 1.6  | 3.2 | 9.1  | 0.69 | 3.40 | 0.091 | 0.048   | 0.034 |
| 782        | 12.5 | 5.9  | 3.3 | 7.8  | 0.62 | 5.00 | 0.114 | 0.082   | 0.042 |
| 783        | 11.7 | 5.0  | 4.3 | 7.8  | 0.66 | 1.90 | 0.149 | 0.041   | 0.029 |
| 784        | 11.2 | 7.2  | 4.2 | 7.8  | 0.68 | 3.20 | 0.169 | 0.046   | 0.030 |
| 785        | 14.0 | 8.6  | 4.9 | 8.7  | 0.75 | 2.50 | 0.135 | 0.044   | 0.034 |
| 786        | 14.3 | 8.5  | 5.0 | 9.6  | 0.80 | 3.30 | 0.167 | 0.052   | 0.037 |
| 787        | 11.0 | 6.0  | 3.0 | 9.4  | 0.67 | 3.60 | 0.135 | 0.054   | 0.036 |
| 788        | 13.5 | 7.7  | 5.3 | 12.5 | 0.70 | 3.20 | 0.162 | 0.068   | 0.065 |
| 789        | 13.2 | 6.8  | 4.0 | 11.0 | 0.67 | 1.00 | 0.255 | 0.048   | 0.034 |
| 790        | 13.6 | 9.1  | 3.3 | 8.7  | 0.65 | 0.42 | 0.113 | Too low | 0.019 |
| 791        | 17.6 | 10.2 | 5.8 | 9.4  | 0.98 | 3.50 | 0.223 | 0.043   | 0.032 |
| 792        | 26.9 | 15.1 | 4.7 | 10.1 | 0.92 | 1.20 | 0.131 | 0.040   | 0.025 |



RAW CLAY SAMPLES

| Sample                    | Al.  | Ca.     | Mg. | Fe.  | Ti.  | Na.   | Mn.   | Cr.     | Ni.     |
|---------------------------|------|---------|-----|------|------|-------|-------|---------|---------|
| Amarynthos (12a)          | 15.5 | 72.0    | 3.8 | 7.1  | 0.49 | 3.00  | 0.070 | Too low | 0.004   |
| Pyrgos (17a)              | 15.5 | 19.4    | 5.0 | 9.1  | 0.68 | 6.30  | 0.080 | 0.083   | 0.049   |
| Eretria (41)              | 17.2 | 19.4    | 2.2 | 8.0  | 0.54 | 12.40 | 0.100 | 0.013   | 0.006   |
| Lefkandi<br>(brick) (22a) | 18.1 | 5.8     | 1.9 | 12.9 | 1.02 | 6.07  | 0.120 | 0.042   | 0.020   |
| Volos                     | 24.2 | 7.0     | 3.7 | 11.4 | 0.97 | 1.90  | 0.136 | 0.061   | 0.043   |
| Sesklo 1 (red)            | 25.1 | Too low | 0.3 | 6.3  | 0.64 | 0.26  | 0.013 | Too low | Too low |
| Sesklo 2 (white)          | 15.7 | Too low | 0.5 | 3.8  | 0.38 | 1.40  | 0.032 | Too low | Too low |
| Sesklo 3 (orange)         | 25.1 | Too low | 0.8 | 6.3  | 0.53 | 0.73  | 0.038 | Too low | Too low |
| Dhimini                   | 19.9 | 23.6    | 2.6 | 5.3  | 0.73 | 1.30  | 0.054 | 0.027   | 0.016   |

APPENDIX 3

STANDARD ANALYTICAL PROCEDURE FOR ATOMIC ABSORPTION ANALYSIS

Analytical Procedure

1. The data on the analytical conditions for the element to be determined was checked from the table of optimum conditions (see Table, Figure 30). Silicon was always determined first to prevent problems which might occur due to possible precipitation of silicon from the solution (Hughes et al. : 31).
2. If Si, Al, Mg, Ca or Ti was to be determined the Nitrous-Oxide burner head was installed. For other elements the ordinary burner-head with a 4 inch slot was installed. For either head it was checked that the hold-down assembly was connected to the burner clips. It was also checked that the burner shield was in place, that the drain tube had a loop in it 5 inches in diameter which contained water, that the end of the drain tube was in at least 5 inches of water in a large plastic container and that the end of the nebulizer capillary was in a beaker of distilled water.
3. The relevant lamp was installed in the lamp chamber. The power switch was turned on and the current adjusted to the recommended running current for that lamp. For the two Arc Discharge lamps (Na and K) the separate power supply was used and the lamps were given 10-15 minutes to warm up before use. The Hollow Cathode lamps do not need this warming up time.
4. The slit width (for the monochromator slit), range (U.V. or Visible) were selected according to the table mentioned above (Figure 30), and the required wavelength was selected and adjusted at the same time as the Gain control was adjusted until the needle on the energy meter settled in the dark red section of the scale on the energy meter.



The gain control changes the voltage applied to the photomultiplier detector. The phase/normal switch was set to normal.

5. The acetylene and the nitrous-oxide (if required) were turned on at the cylinder and the resistance heating tape on the neck of the nitrous-oxide cylinder was turned on to prevent the gas freezing as it left the cylinder. The air-compressor and the extractor fan above the spectrophotometer were turned on.

6. With the fuel and oxidant switches on the gas control box set to acetylene and air respectively the flow rates on the flowmeters were set according to the table. The flame is always ignited and extinguished on Air/Acetylene, never on Nitrous-oxide because of the danger of flashback. There is a switch on the front of the gas control box which allows the flow rate to be set for nitrous-oxide even though it is not going to be used initially.

7. The gases switch was set to ON and the ignite button was pressed and held until the flame ignited. If nitrous-oxide was required after the flame was ignited the gases switch was set to OTHER which introduced the nitrous-oxide as the oxidant.

8. When first switched to nitrous-oxide the flame is split in a 'V' shape. After a few minutes, as the burner head is warmed up the V will close and analysis can proceed. When nitrous-oxide is being used a deposit of carbon builds up on the burner head. It must be ensured that this deposit does not cover the slot in the burner head or a flashback may occur. If the slot needs cleaning the flame should be set to air/acetylene, then extinguished and the slot cleaned with a narrow strip of metal before the flame is relit and analysis proceeds. When this is

done the standards should always be rerun before any samples when analysis is resumed.

9. The damping control was adjusted according to the amount of background noise. The higher the setting, the greater the damping. This affects the subsequent aspiration times, and the suggested minimum times are as follows:

| Damping | Aspiration time<br>(seconds) |
|---------|------------------------------|
| 1       | 1                            |
| 2       | 6                            |
| 3       | 25                           |
| 4       | 75                           |

10. With a sample being aspirated the gas flows were adjusted until the maximum readings were obtained on the meter.

11. The chart recorder was turned on and the desired scale selected. The meter was set to zero when water was being aspirated. Periodically the instrument was checked for baseline drift by allowing it to run for 5-10 minutes while aspirating only water. Baseline wander was always found to be negligible.

12. The standards were aspirated one by one followed by the blank, the first ten samples, the standards, the last ten samples, a USGS standard and finally the standards again. If the samples were more concentrated than the strongest standard which was within the working range for that element the samples were diluted by a factor of 5.

13. The chart recorder was turned off.

14. The lamp was changed or, if a multi-element lamp was being used,

the new set of conditions was set according to the table for the next element and the new wavelength was tuned to.

15. The analytical procedure was repeated as above (9-13).

16. When analysis was completed the flame was extinguished on air/acetylene and the gases turned off at the cylinders. The fan and air compressor were turned off. The lamp was removed from the lamp chamber and the power was turned off.



APPENDIX 4

Results obtained by Atomic Absorption analysis

The results are expressed in the same oxides as the optical emission results (Appendix 2) with the addition of  $K_2O$ . The results are given site by site in the order given in Chapter 4.

(2) AMARYNTHOS

| Sample No. | Al.  | Ca.  | Mg. | Fe. | Ti.  | Na.  | Mn.   | Cr.   | Ni.   | K.  |
|------------|------|------|-----|-----|------|------|-------|-------|-------|-----|
| 21         | 14.1 | 10.9 | 3.3 | 6.0 | 1.15 | 0.82 | 0.134 | 0.088 | 0.022 | 2.7 |
| 22         | 19.0 | 3.7  | 3.7 | 6.8 | 1.42 | 0.55 | 0.040 | 0.149 | 0.055 | 3.5 |
| 23         | 11.2 | 11.1 | 5.6 | 7.7 | 0.99 | 0.42 | 0.130 | 0.147 | 0.080 | 1.7 |
| 24         | 11.9 | 13.1 | 5.8 | 6.9 | 1.25 | 0.45 | 0.128 | 0.071 | 0.074 | 1.9 |
| 25         | 15.9 | 10.9 | 3.5 | 7.3 | 1.32 | 0.23 | 0.067 | 0.153 | 0.056 | 2.7 |
| 31         | 16.4 | 6.2  | 3.3 | 7.8 | 1.30 | 1.17 | 0.121 | 0.114 | 0.044 | 3.2 |
| 32         | 19.2 | 5.3  | 2.6 | 8.4 | 1.30 | 1.05 | 0.133 | 0.114 | 0.033 | 3.2 |
| 33         | 19.2 | 3.7  | 2.3 | 7.8 | 1.17 | 0.76 | 0.121 | 0.102 | 0.039 | 3.1 |
| 34         | 14.3 | 11.3 | 3.8 | 7.6 | 1.04 | 0.43 | 0.123 | 0.115 | 0.056 | 2.4 |
| 35         | 16.0 | 12.8 | 4.2 | 8.6 | 1.30 | 0.47 | 0.137 | 0.137 | 0.060 | 2.6 |
| 41         | 13.7 | 4.3  | 1.8 | 6.2 | 1.27 | 0.70 | 0.101 | 0.086 | 0.032 | 2.4 |
| 42         | 16.2 | 8.9  | 3.3 | 7.0 | 1.27 | 0.74 | 0.147 | 0.086 | 0.032 | 2.8 |
| 43         | 14.5 | 13.3 | 5.8 | 8.2 | 1.34 | 0.45 | 0.094 | 0.105 | 0.071 | 2.4 |
| 44         | 13.5 | 12.4 | 3.3 | 7.4 | 1.25 | 0.61 | 0.142 | 0.098 | 0.042 | 2.5 |
| 45         | 15.1 | 11.7 | 3.2 | 6.5 | 1.39 | 0.70 | 0.146 | 0.110 | 0.032 | 2.4 |
| 51         | 18.3 | 6.2  | 2.5 | 8.0 | 1.30 | 0.88 | 0.102 | 0.114 | 0.043 | 3.0 |
| 52         | 15.4 | 15.8 | 5.5 | 8.4 | 1.29 | 0.50 | 0.132 | 0.149 | 0.065 | 2.8 |
| 53         | 17.8 | 13.2 | 3.8 | 8.9 | 1.64 | 0.22 | 0.089 | 0.155 | 0.079 | 2.8 |
| 54         | 19.2 | 12.9 | 3.9 | 8.0 | 1.20 | 0.34 | 0.102 | 0.114 | 0.043 | 2.5 |
| 55         | 12.8 | 16.5 | 6.0 | 9.0 | 1.05 | 0.55 | 0.121 | 0.137 | 0.084 | 2.3 |

## (4) LEFKANDI

| Sample No. | Al.  | Ca. | Mg. | Fe. | Ti.  | Na.  | Mn.   | Cr.   | Ni.   | K.  |
|------------|------|-----|-----|-----|------|------|-------|-------|-------|-----|
| 83         | 17.7 | 4.7 | 2.1 | 7.0 | 1.08 | 1.05 | 0.108 | 0.118 | 0.041 | 2.9 |
| 84         | 16.2 | 7.0 | 3.1 | 7.8 | 1.26 | 1.16 | 0.159 | 0.143 | 0.019 | 2.4 |
| 85         | 16.2 | 6.2 | 4.2 | 8.9 | 1.26 | 0.93 | 0.173 | 0.159 | 0.049 | 2.0 |
| 86         | 20.4 | 5.0 | 2.4 | 7.9 | 1.26 | 1.05 | 0.117 | 0.074 | 0.032 | 3.4 |
| 87         | 19.8 | 4.6 | 2.4 | 7.7 | 1.18 | 0.98 | 0.119 | 0.077 | 0.034 | 3.1 |
| 88         | 19.4 | 4.7 | 2.2 | 7.3 | 1.24 | 1.05 | 0.114 | 0.108 | 0.019 | 3.0 |
| 89         | 19.3 | 8.3 | 2.8 | 7.4 | 1.14 | 1.08 | 0.114 | 0.074 | 0.022 | 3.2 |
| 90         | 21.9 | 6.1 | 2.6 | 8.3 | 1.31 | 1.25 | 0.125 | 0.103 | 0.037 | 3.1 |
| 91         | 22.5 | 6.1 | 2.6 | 9.6 | 1.31 | 1.13 | 0.121 | 0.076 | 0.033 | 3.4 |
| 92         | 19.0 | 6.9 | 2.4 | 7.3 | 1.22 | 0.99 | 0.114 | 0.118 | 0.030 | 2.7 |
| 93         | 19.9 | 6.6 | 4.8 | 8.5 | 1.42 | 0.85 | 0.106 | 0.124 | 0.043 | 3.2 |
| 94         | 18.7 | 4.1 | 2.0 | 7.0 | 1.20 | 0.86 | 0.107 | 0.070 | 0.030 | 2.9 |
| 95         | 20.5 | 3.7 | 2.3 | 7.8 | 1.46 | 1.23 | 0.117 | 0.076 | 0.033 | 3.3 |
| 96         | 21.5 | 4.8 | 2.6 | 8.4 | 1.44 | 1.26 | 0.132 | 0.076 | 0.022 | 3.3 |
| 97         | 19.5 | 4.8 | 2.1 | 7.5 | 1.30 | 0.95 | 0.108 | 0.149 | 0.029 | 2.8 |
| 98         | 23.0 | 4.9 | 2.6 | 9.1 | 1.53 | 1.17 | 0.119 | 0.073 | 0.036 | 3.7 |
| 99         | 20.9 | 5.4 | 2.4 | 8.0 | 1.34 | 1.12 | 0.123 | 0.166 | 0.041 | 3.0 |
| 100        | 22.5 | 4.9 | 2.5 | 8.5 | 1.31 | 1.13 | 0.121 | 0.166 | 0.033 | 3.6 |
| 101        | 18.3 | 4.1 | 1.9 | 6.6 | 1.11 | 0.97 | 0.103 | 0.098 | 0.036 | 2.6 |
| 102        | 18.7 | 5.5 | 3.6 | 7.8 | 1.51 | 1.13 | 0.106 | 0.096 | 0.052 | 2.6 |



(6) ROVIES.

| Sample No. | Al.  | Ca.  | Mg. | Fe. | Ti.  | Na.  | Mn.   | Cr.   | Ni.   | K.  |
|------------|------|------|-----|-----|------|------|-------|-------|-------|-----|
| 123        | 10.0 | 12.6 | 6.3 | 7.7 | 1.30 | 2.47 | 0.097 | 0.049 | 0.039 | 1.3 |
| 124        | 15.9 | 4.9  | 2.4 | 8.9 | 1.12 | 1.24 | 0.098 | 0.025 | 0.023 | 3.7 |
| 125        | 15.7 | 12.7 | 6.5 | 8.5 | 1.14 | 0.58 | 0.116 | 0.136 | 0.032 | 2.0 |
| 126        | 10.2 | 16.4 | 6.6 | 7.4 | 1.67 | 0.57 | 0.097 | 0.077 | 0.060 | 1.6 |
| 127        | 15.1 | 10.1 | 5.6 | 7.8 | 1.07 | 1.39 | 0.120 | 0.140 | 0.134 | 1.7 |
| 128        | 14.3 | 8.2  | 4.6 | 6.8 | 0.95 | 1.03 | 0.125 | 0.111 | 0.182 | 1.8 |
| 129        | 15.2 | 8.4  | 7.1 | 7.9 | 0.82 | 0.66 | 0.144 | 0.145 | 0.247 | 1.1 |
| 130        | 9.0  | 11.4 | 6.1 | 6.8 | 1.42 | 0.87 | 0.099 | 0.074 | 0.061 | 1.4 |
| 131        | 16.3 | 8.5  | 5.0 | 8.4 | 1.05 | 0.70 | 0.102 | 0.104 | 0.131 | 2.4 |
| 132        | 14.7 | 10.7 | 5.2 | 8.3 | 0.94 | 0.66 | 0.128 | 0.110 | 0.139 | 1.7 |
| 133        | 15.2 | 11.4 | 8.1 | 9.6 | 1.24 | 1.03 | 0.163 | 0.190 | 0.182 | 1.4 |
| 134        | 20.2 | 1.5  | 1.9 | 6.3 | 1.90 | 1.80 | 0.057 | 0.020 | 0.029 | 4.3 |
| 135        | 16.6 | 5.2  | 2.7 | 7.8 | 1.54 | 1.66 | 0.124 | 0.034 | 0.019 | 3.6 |
| 136        | 19.0 | 8.5  | 4.3 | 6.9 | 1.15 | 0.59 | 0.053 | 0.137 | 0.170 | 2.7 |
| 137        | 17.8 | 4.6  | 2.4 | 7.9 | 1.67 | 2.32 | 0.138 | 0.034 | 0.025 | 4.0 |
| 138        | 12.6 | 10.0 | 6.4 | 8.1 | 1.12 | 0.81 | 0.125 | 0.183 | 0.180 | 1.1 |
| 139        | 16.6 | 11.1 | 6.9 | 8.4 | 0.77 | 1.19 | 0.143 | 0.158 | 0.129 | 2.0 |
| 140        | 14.4 | 8.0  | 6.3 | 9.5 | 1.62 | 0.99 | 0.154 | 0.066 | 0.038 | 2.5 |
| 141        | 13.7 | 8.7  | 6.6 | 9.5 | 1.75 | 1.40 | 0.154 | 0.051 | 0.037 | 2.4 |
| 142        | 11.2 | 13.4 | 6.9 | 7.6 | 1.82 | 1.16 | 0.115 | 0.083 | 0.041 | 1.9 |
| 143        | 14.8 | 10.4 | 6.8 | 7.9 | 0.75 | 0.74 | 0.067 | 0.110 | 0.164 | 1.6 |

(7) ANTHEDON

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   | K.  |
|------------|------|------|-----|------|------|------|-------|-------|-------|-----|
| 144        | 15.4 | 4.7  | 4.5 | 8.6  | 1.37 | 0.40 | 0.125 | 0.178 | 0.022 | 2.3 |
| 145        | 19.8 | 5.3  | 2.6 | 9.1  | 1.30 | 0.97 | 0.146 | 0.171 | 0.022 | 3.4 |
| 146        | 13.0 | 4.6  | 3.7 | 7.0  | 1.07 | 1.00 | 0.120 | 0.114 | 0.022 | 2.0 |
| 147        | 12.0 | 9.1  | 5.8 | 6.9  | 1.05 | 0.55 | 0.124 | 0.112 | 0.043 | 2.0 |
| 148        | 12.9 | 12.5 | 4.4 | 7.5  | 1.14 | 0.48 | 0.123 | 0.112 | 0.033 | 2.2 |
| 149        | 13.2 | 14.3 | 3.6 | 9.3  | 1.49 | 0.55 | 0.321 | 0.166 | 0.041 | 1.5 |
| 150        | 21.4 | 4.2  | 3.6 | 8.9  | 1.47 | 0.85 | 0.129 | 0.096 | 0.028 | 3.2 |
| 151        | 14.8 | 6.5  | 4.3 | 7.9  | 1.54 | 1.22 | 0.120 | 0.321 | 0.032 | 2.4 |
| 152        | 15.7 | 9.1  | 4.7 | 9.1  | 1.54 | 0.92 | 0.155 | 0.219 | 0.025 | 2.7 |
| 153        | 14.1 | 11.2 | 6.1 | 7.9  | 1.10 | 0.55 | 0.110 | 0.181 | 0.044 | 2.9 |
| 154        | 14.9 | 5.1  | 4.7 | 8.5  | 1.60 | 1.10 | 0.130 | 0.206 | 0.028 | 1.2 |
| 155        | 12.7 | 16.3 | 5.2 | 7.0  | 1.07 | 0.41 | 0.089 | 0.188 | 0.043 | 2.8 |
| 156        | 13.6 | 6.1  | 3.8 | 6.6  | 1.50 | 0.64 | 0.097 | 0.215 | 0.020 | 2.8 |
| 157        | 17.1 | 5.8  | 2.6 | 7.3  | 1.29 | 1.29 | 0.128 | 0.168 | 0.020 | 4.8 |
| 158        | 17.9 | 5.0  | 2.4 | 7.9  | 1.47 | 1.00 | 0.116 | 0.105 | 0.020 | 4.2 |
| 159        | 15.2 | 5.2  | 2.9 | 11.0 | 1.85 | 0.77 | 0.168 | 0.203 | 0.039 | 2.3 |
| 160        | 20.1 | 4.8  | 2.7 | 8.9  | 1.50 | 1.44 | 0.135 | 0.215 | 0.020 | 5.4 |
| 161        | 17.9 | 6.8  | 2.6 | 8.4  | 1.32 | 1.35 | 0.130 | 0.115 | 0.020 | 4.8 |

(10) ELEON

| Sample No. | Al.  | Ca.  | Mg. | Fe. | Ti.  | Na.  | Mn.   | Cr.   | Ni.   | K.  |
|------------|------|------|-----|-----|------|------|-------|-------|-------|-----|
| 202        | 17.4 | 12.0 | 3.0 | 6.9 | 0.78 | 0.95 | 0.194 | 0.037 | 0.029 | 2.9 |
| 203        | 14.3 | 14.2 | 5.9 | 8.0 | 0.73 | 0.32 | 0.310 | 0.111 | 0.093 | 2.3 |
| 204        | 15.9 | 9.7  | 6.0 | 8.3 | 1.57 | 0.42 | 0.194 | 0.107 | 0.072 | 2.6 |
| 205        | 12.9 | 17.1 | 4.5 | 6.4 | 1.09 | 0.30 | 0.108 | 0.110 | 0.046 | 3.0 |
| 206        | 21.5 | 6.4  | 2.7 | 8.0 | 1.29 | 0.78 | 0.206 | 0.104 | 0.029 | 3.1 |
| 207        | 13.2 | 12.9 | 5.3 | 7.3 | 1.12 | 0.47 | 0.206 | 0.112 | 0.064 | 1.9 |
| 208        | 19.1 | 9.2  | 4.9 | 8.0 | 1.37 | 0.46 | 0.206 | 0.083 | 0.088 | 3.0 |
| 209        | 14.6 | 15.6 | 5.4 | 7.6 | 1.82 | 0.49 | 0.206 | 0.112 | 0.076 | 2.4 |
| 210        | 13.9 | 8.5  | 5.7 | 8.2 | 1.44 | 0.59 | 0.232 | 0.105 | 0.079 | 2.3 |
| 211        | 15.3 | 8.1  | 5.6 | 8.2 | 1.10 | 0.49 | 0.219 | 0.111 | 0.076 | 2.9 |
| 212        | 12.3 | 13.1 | 5.0 | 7.4 | 1.39 | 0.51 | 0.219 | 0.112 | 0.076 | 2.8 |
| 213        | 13.4 | 15.0 | 4.1 | 7.3 | 1.00 | 0.43 | 0.258 | 0.077 | 0.057 | 2.7 |
| 214        | 13.6 | 13.1 | 4.8 | 6.7 | 0.85 | 0.61 | 0.206 | 0.099 | 0.065 | 2.5 |
| 215        | 12.6 | 10.0 | 5.7 | 7.3 | 1.20 | 0.58 | 0.219 | 0.107 | 0.072 | 2.0 |
| 216        | 13.7 | 2.8  | 6.0 | 8.9 | 1.84 | 0.66 | 0.194 | 0.099 | 0.097 | 2.3 |
| 217        | 13.7 | 9.8  | 5.3 | 7.4 | 0.87 | 0.69 | 0.219 | 0.088 | 0.055 | 2.1 |
| 218        | 12.2 | 11.3 | 6.4 | 7.9 | 1.35 | 0.47 | 0.219 | 0.095 | 0.074 | 1.9 |
| 219        | 14.5 | 13.5 | 7.4 | 9.2 | 1.45 | 0.63 | 0.232 | 0.133 | 0.107 | 2.9 |
| 220        | 10.8 | 8.5  | 5.6 | 7.3 | 1.02 | 0.57 | 0.206 | 0.089 | 0.080 | 1.7 |
| 221        | 10.7 | 10.3 | 5.2 | 6.6 | 0.94 | 0.59 | 0.232 | 0.082 | 0.074 | 1.6 |



(12) THEBES

| Sample No. | Al.  | Ca.  | Mg.  | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   | K.  |
|------------|------|------|------|------|------|------|-------|-------|-------|-----|
| 242        | 11.7 | 13.2 | 6.5  | 8.0  | 0.97 | 0.50 | 0.120 | 0.146 | 0.044 | 1.7 |
| 243        | 14.5 | 13.5 | 4.7  | 7.4  | 1.00 | 0.50 | 0.097 | 0.088 | 0.037 | 2.2 |
| 244        | 13.9 | 7.2  | 4.7  | 7.5  | 1.37 | 0.70 | 0.097 | 0.074 | 0.030 | 2.2 |
| 245        | 14.6 | 5.3  | 3.1  | 7.4  | 1.40 | 0.69 | 0.108 | 0.086 | 0.037 | 2.1 |
| 246        | 17.0 | 13.5 | 4.1  | 8.0  | 1.37 | 0.58 | 0.125 | 0.088 | 0.025 | 2.7 |
| 247        | 15.7 | 14.0 | 5.4  | 8.9  | 1.14 | 0.50 | 0.110 | 0.112 | 0.043 | 2.7 |
| 248        | 12.5 | 5.7  | 10.9 | 12.7 | 1.14 | 0.65 | 0.292 | 0.321 | 0.107 | 1.3 |
| 249        | 17.2 | 13.0 | 3.7  | 8.7  | 1.14 | 0.62 | 0.124 | 0.086 | 0.025 | 2.6 |
| 250        | 12.7 | 27.2 | 3.7  | 6.2  | 1.09 | 0.39 | 0.093 | 0.083 | 0.022 | 2.0 |
| 251        | 15.6 | 9.9  | 5.5  | 8.4  | 1.22 | 0.59 | 0.107 | 0.099 | 0.037 | 2.4 |
| 252        | 14.0 | 10.7 | 5.5  | 8.2  | 0.94 | 0.43 | 0.112 | 0.107 | 0.041 | 2.3 |
| 253        | 13.0 | 14.8 | 5.1  | 8.4  | 1.47 | 0.59 | 0.159 | 0.171 | 0.052 | 1.9 |
| 254        | 15.6 | 13.6 | 4.0  | 8.1  | 1.15 | 0.77 | 0.083 | 0.114 | 0.030 | 2.5 |
| 255        | 11.8 | 17.8 | 6.1  | 7.3  | 0.94 | 0.43 | 0.106 | 0.187 | 0.043 | 1.6 |
| 256        | 14.7 | 7.4  | 6.3  | 8.7  | 1.05 | 0.36 | 0.121 | 0.185 | 0.046 | 2.0 |
| 257        | 13.6 | 11.5 | 5.7  | 8.0  | 1.04 | 0.58 | 0.097 | 0.204 | 0.044 | 1.9 |
| 258        | 11.2 | 11.9 | 5.6  | 7.2  | 1.02 | 0.36 | 0.125 | 0.120 | 0.055 | 1.3 |
| 259        | 16.7 | 12.7 | 2.4  | 7.8  | 1.34 | 0.65 | 0.137 | 0.093 | 0.043 | 2.8 |
| 260        | 13.3 | 13.4 | 6.1  | 8.0  | 0.84 | 0.49 | 0.124 | 0.115 | 0.098 | 1.7 |
| 261        | 17.2 | 11.3 | 5.1  | 8.4  | 1.47 | 0.61 | 0.108 | 0.150 | 0.044 | 2.0 |

(14) IOLKOS (VOLOS SHERDS FROM THE BRITISH SCHOOL AT ATHENS)

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.     | Ni.   | K.  |
|------------|------|------|-----|------|------|------|-------|---------|-------|-----|
| 689        | 16.6 | 5.3  | 3.1 | 6.3  | 0.73 | 1.54 | 0.146 | Too low | 0.011 | 2.8 |
| 690        | 15.7 | 6.0  | 3.1 | 6.1  | 0.99 | 1.58 | 0.128 | "       | 0.024 | 2.4 |
| 691        | 16.9 | 14.7 | 4.2 | 8.8  | 1.02 | 1.11 | 0.108 | "       | 0.024 | 2.4 |
| 692        | 19.2 | 5.9  | 2.5 | 9.1  | 1.27 | 1.36 | 0.108 | "       | 0.019 | 3.6 |
| 693        | 15.2 | 9.0  | 3.6 | 8.7  | 1.08 | 0.88 | 0.129 | "       | 0.023 | 2.7 |
| 694        | 16.4 | 5.8  | 3.6 | 6.7  | 1.03 | 1.53 | 0.155 | "       | 0.023 | 2.7 |
| 695        | 16.0 | 11.1 | 5.4 | 8.2  | 0.97 | 1.04 | 0.119 | "       | 0.027 | 2.4 |
| 696        | 16.1 | 4.4  | 3.0 | 6.7  | 1.28 | 1.67 | 0.128 | "       | 0.024 | 2.6 |
| 697        | 18.0 | 2.7  | 3.1 | 7.1  | 1.18 | 1.88 | 0.123 | "       | 0.023 | 2.9 |
| 698        | 17.9 | 5.0  | 1.5 | 6.8  | 1.13 | 1.89 | 0.130 | "       | 0.024 | 2.8 |
| 699        | 13.2 | 10.7 | 5.8 | 7.2  | 1.22 | 1.82 | 0.092 | "       | 0.024 | 2.2 |
| 700        | 17.4 | 5.5  | 3.0 | 6.5  | 1.06 | 1.93 | 0.126 | "       | 0.022 | 2.6 |
| 701        | 15.0 | 14.8 | 3.1 | 7.2  | 1.18 | 1.03 | 0.119 | "       | 0.027 | 2.3 |
| 702        | 15.6 | 13.3 | 3.8 | 7.6  | 1.06 | 1.11 | 0.126 | "       | 0.024 | 2.2 |
| 703        | 17.3 | 4.2  | 2.9 | 6.2  | 1.15 | 1.89 | 0.123 | "       | 0.013 | 2.6 |
| 704        | 16.3 | 3.5  | 2.5 | 6.0  | 1.27 | 2.01 | 0.114 | "       | 0.022 | 2.4 |
| 705        | 13.6 | 3.0  | 2.3 | 4.9  | 1.14 | 1.35 | 0.090 | "       | 0.024 | 1.7 |
| 706        | 13.6 | 5.3  | 3.0 | 7.2  | 1.26 | 1.80 | 0.172 | "       | 0.027 | 2.9 |
| 707        | 14.1 | 7.6  | 4.1 | 6.5  | 1.11 | 1.30 | 0.111 | "       | 0.036 | 2.4 |
| 708        | 21.9 | 10.0 | 8.3 | 10.9 | 1.90 | 2.94 | 0.182 | "       | 0.041 | 2.7 |
| 709        | 16.5 | 3.5  | 2.6 | 6.1  | 1.10 | 1.71 | 0.111 | "       | 0.027 | 2.4 |
| 710        | 16.9 | 10.6 | 3.9 | 7.1  | 1.30 | 0.70 | 0.117 | "       | 0.029 | 2.8 |
| 711        | 17.7 | 11.2 | 4.0 | 7.2  | 1.16 | 0.76 | 0.123 | "       | 0.038 | 2.8 |

(15) MARMARIANI

| Sample No. | Al.  | Ca.  | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.     | K.  |
|------------|------|------|-----|------|------|------|-------|-------|---------|-----|
| 331        | 14.1 | 11.5 | 5.8 | 8.2  | 0.87 | 1.00 | 0.150 | 0.111 | Too Low | 2.4 |
| 332        | 13.8 | 5.7  | 5.3 | 7.7  | 1.02 | 1.12 | 0.205 | 0.093 | "       | 2.3 |
| 333        | 14.1 | 5.8  | 4.7 | 8.1  | 1.04 | 1.54 | 0.209 | 0.095 | "       | 2.2 |
| 334        | 13.2 | 6.8  | 4.5 | 7.3  | 0.97 | 1.08 | 0.219 | 0.074 | "       | 2.0 |
| 335        | 13.9 | 5.3  | 3.6 | 6.3  | 0.84 | 1.61 | 0.146 | 0.048 | "       | 2.0 |
| 336        | 16.5 | 15.3 | 3.8 | 8.5  | 0.85 | 0.59 | 0.183 | 0.088 | "       | 2.8 |
| 337        | 14.6 | 7.0  | 5.3 | 8.0  | 1.25 | 1.32 | 0.243 | 0.074 | "       | 2.3 |
| 338        | 15.0 | 5.2  | 4.8 | 8.2  | 1.24 | 1.12 | 0.209 | 0.086 | "       | 2.2 |
| 339        | 23.0 | 10.6 | 8.3 | 12.4 | 1.82 | 2.19 | 0.320 | 0.128 | "       | 3.7 |
| 340        | 14.6 | 8.6  | 5.1 | 7.9  | 1.00 | 1.28 | 0.213 | 0.102 | "       | 2.2 |
| 341        | 15.7 | 6.8  | 5.4 | 8.8  | 1.05 | 1.35 | 0.173 | 0.105 | "       | 2.4 |
| 342        | 15.0 | 21.2 | 3.2 | 8.3  | 1.10 | 0.59 | 0.101 | 0.114 | "       | 1.6 |
| 343        | 14.4 | 9.7  | 5.6 | 7.6  | 0.99 | 1.23 | 0.221 | 0.074 | "       | 2.0 |
| 344        | 15.0 | 11.1 | 6.1 | 8.7  | 1.02 | 1.19 | 0.205 | 0.093 | "       | 2.3 |
| 345        | 15.0 | 9.4  | 5.0 | 7.8  | 1.50 | 1.32 | 0.224 | 0.126 | "       | 2.4 |
| 346        | 14.3 | 12.0 | 6.7 | 8.1  | 1.19 | 1.49 | 0.221 | 0.095 | "       | 2.4 |
| 347        | 14.9 | 10.2 | 5.3 | 7.8  | 1.07 | 0.78 | 0.170 | 0.085 | "       | 2.0 |
| 348        | 15.4 | 7.2  | 5.3 | 7.9  | 1.22 | 1.24 | 0.228 | 0.073 | "       | 2.0 |
| 349        | 15.7 | 6.3  | 5.0 | 7.5  | 0.97 | 1.32 | 0.129 | 0.096 | "       | 2.2 |
| 350        | 14.3 | 10.4 | 4.2 | 6.7  | 0.97 | 1.34 | 0.154 | 0.070 | "       | 1.6 |



(16) PEVKAKIA GROUP II

| Sample No. | Al.  | Ca. | Mg. | Fe.  | Ti.  | Na.  | Mn.   | Cr.   | Ni.   | K.  |
|------------|------|-----|-----|------|------|------|-------|-------|-------|-----|
| 593        | 19.5 | 1.4 | 3.0 | 13.9 | 2.22 | 0.55 | 0.133 | 0.245 | 0.016 | 2.2 |
| 594        | 16.5 | 1.2 | 2.6 | 11.6 | 1.92 | 0.53 | 0.106 | 0.204 | 0.019 | 2.1 |
| 595        | 16.4 | 1.1 | 2.7 | 12.2 | 1.82 | 0.42 | 0.164 | 0.204 | 0.024 | 1.8 |
| 596        | 15.5 | 1.1 | 2.3 | 11.0 | 1.86 | 0.46 | 0.093 | 0.234 | 0.022 | 1.8 |
| 597        | 16.0 | 1.2 | 2.5 | 12.1 | 1.97 | 0.34 | 0.108 | 0.234 | 0.022 | 1.7 |
| 598        | 15.7 | 1.2 | 2.6 | 11.8 | 1.87 | 0.35 | 0.120 | 0.239 | 0.020 | 2.0 |
| 599        | 15.7 | 1.5 | 5.1 | 12.5 | 1.88 | 0.47 | 0.112 | 0.216 | 0.027 | 1.2 |
| 600        | 17.6 | 1.2 | 2.4 | 9.7  | 1.87 | 0.92 | 0.165 | 0.093 | 0.018 | 2.3 |

(17) REVMATIA

| Sample No. | Al.  | Ca.  | Mg. | Fe. | Ti.  | Na.  | Mn.   | Cr.   | Ni.   | K.  |
|------------|------|------|-----|-----|------|------|-------|-------|-------|-----|
| 610        | 13.3 | 11.0 | 1.9 | 5.4 | 0.89 | 0.53 | 0.104 | 0.197 | 0.044 | 1.2 |
| 611        | 15.1 | 9.3  | 3.0 | 6.0 | 0.70 | 0.31 | 0.125 | 0.105 | 0.042 | 2.3 |
| 612        | 16.8 | 14.9 | 2.4 | 7.4 | 1.10 | 0.35 | 0.147 | 0.119 | 0.072 | 1.4 |
| 613        | 17.0 | 14.0 | 4.8 | 6.9 | 0.84 | 0.54 | 0.116 | 0.151 | 0.064 | 1.9 |
| 614        | 16.2 | 11.5 | 3.3 | 6.7 | 0.82 | 0.93 | 0.112 | 0.150 | 0.062 | 1.8 |
| 615        | 20.7 | 4.1  | 7.4 | 6.7 | 0.94 | 1.89 | 0.146 | 0.102 | 0.020 | 2.9 |
| 616        | 15.0 | 12.8 | 2.2 | 6.3 | 0.97 | 0.65 | 0.107 | 0.151 | 0.032 | 1.5 |
| 617        | 18.6 | 16.8 | 3.4 | 7.3 | 1.00 | 0.55 | 0.079 | 0.108 | 0.055 | 1.8 |
| 618        | 19.2 | 18.7 | 3.5 | 7.5 | 1.12 | 0.78 | 0.126 | 0.105 | 0.053 | 1.9 |
| 619        | 14.6 | 14.0 | 2.8 | 6.8 | 1.35 | 0.59 | 0.125 | 0.147 | 0.067 | 1.8 |
| 620        | 17.8 | 17.9 | 3.1 | 7.2 | 0.82 | 0.38 | 0.101 | 0.113 | 0.052 | 1.8 |
| 621        | 15.7 | 14.5 | 2.9 | 7.4 | 0.70 | 0.73 | 0.142 | 0.116 | 0.064 | 1.7 |
| 622        | 13.4 | 19.5 | 2.9 | 7.4 | 0.80 | 0.62 | 0.104 | 0.160 | 0.056 | 1.7 |
| 623        | 13.5 | 19.2 | 2.7 | 6.0 | 0.72 | 0.41 | 0.076 | 0.158 | 0.072 | 1.6 |
| 624        | 15.5 | 21.0 | 2.6 | 7.9 | 0.82 | 0.36 | 0.148 | 0.115 | 0.062 | 1.6 |
| 625        | 15.5 | 19.0 | 2.8 | 8.9 | 1.00 | 0.70 | 0.114 | 0.140 | 0.089 | 1.8 |
| 626        | 12.3 | 21.7 | 2.8 | 6.7 | 0.92 | 0.66 | 0.090 | 0.144 | 0.060 | 1.5 |
| 627        | 13.3 | 12.0 | 3.0 | 6.7 | 0.85 | 0.51 | 0.106 | 0.108 | 0.055 | 1.6 |
| 628        | 15.1 | 19.4 | 3.2 | 7.9 | 0.89 | 0.65 | 0.092 | 0.161 | 0.056 | 1.7 |
| 629        | 12.8 | 15.6 | 2.9 | 7.7 | 0.43 | 0.66 | 0.089 | 0.158 | 0.066 | 1.5 |
| 630        | 13.1 | 15.3 | 2.9 | 7.5 | 0.57 | 0.53 | 0.123 | 0.165 | 0.065 | 1.7 |
| 631        | 13.9 | 20.9 | 3.3 | 9.1 | 0.57 | 0.42 | 0.133 | 0.192 | 0.076 | 1.8 |

APPENDIX 5.

SAMPLE GROUPINGS AFTER ANALYSIS AND COMPUTING



All samples analysed by optical emission after Discriminant Analysis.

Group 1.

|                |                                                  |
|----------------|--------------------------------------------------|
| Aliveri        | 2, 3, 4, 5, 8, 12, 13, 14, 15, 16, 18            |
| Amarynthos     | 22, 23, 25, 26, 35, 37, 50                       |
| Gialtra        | 63                                               |
| Lefkandi       | 84, 93                                           |
| Psakhna        | 104, 108                                         |
| Rovies         | 125, 131, 133, 136, 138, 139                     |
| Anthedon       | 147, 153                                         |
| Chalia         | 164, 177                                         |
| Dramesi        | 185, 186, 187, 188, 191, 196, 199, 200, 201      |
| Eleon          | 205, 207, 208, 212, 214                          |
| Kynos          | 222, 223, 225, 226, 227, 228, 230, 237, 238, 241 |
| Thebes         | 242, 243, 245, 252, 253, 256, 257, 260, 261      |
| Argissa        | 266, 271, 272, 273, 277, 278, 279, 281           |
| Iolkos         | 308, 310                                         |
| Volos (Iolkos) | 695, 699                                         |
| Marmariani     | 333, 338, 348                                    |
| Pevkakia       |                                                  |
| EBA            | 376, 384, 387, 390                               |
| MH             | 419, 420                                         |
| LH Gp. 1       | -                                                |
| LH Gp. 2       | 457, 464, 466                                    |
| LH Gp. 3       | -                                                |
| LH Gp. 4       | -                                                |
| LH Gp. 6       | 506, 509, 522                                    |
| LH Gp. 8       | -                                                |

Group 1 Continued.

|                     |                                             |
|---------------------|---------------------------------------------|
| LH Gp. 9            | -                                           |
| LH Gp. 10           | -                                           |
| LH Gp. 11           | 594                                         |
| LH Gp. 12           | -                                           |
| Revmatia            | -                                           |
| Velestino (Iolkos)  | -                                           |
| Velestino (Local)   | 637, 641, 648, 652, 657                     |
| Velestino (Argolid) | 663, 668, 670, 672, 674, 678, 681, 686, 688 |
| Yephyria            | 720, 726, 744                               |
| Yephyra-Asmakiou    | 779                                         |

Group 2.

|                     |                                                                                   |
|---------------------|-----------------------------------------------------------------------------------|
| Aliveri             | 17                                                                                |
| Amarynthos          | 21, 27, 28, 29, 31, 32, 33, 38, 39, 41, 42,<br>47, 48, 49, 51, 56, 57, 58, 59, 61 |
| Gialtra             | 62, 64, 70, 71, 72, 73, 74, 75, 76, 78, 81                                        |
| Lefkandi            | 86, 87, 88, 89, 91, 94, 96, 97, 98, 99, 100<br>101, 102                           |
| Psakhna             | 112, 114, 121, 122                                                                |
| Rovies              | 124, 135, 137                                                                     |
| Anthedon            | 144, 145, 146, 150, 151, 152, 157, 158, 160, 161                                  |
| Chalia              | 174, 181                                                                          |
| Dramesi             | 189, 193, 195                                                                     |
| Eleon               | 202, 206                                                                          |
| Kynos               | 231                                                                               |
| Thebes              | -                                                                                 |
| Argissa             | 263, 269, 274, 275, 276, 280                                                      |
| Iolkos              | 288, 317, 318, 321                                                                |
| Volos (Iolkos)      | 692, 694, 696, 697, 698, 700, 703, 704, 706                                       |
| Marmariani          | 349                                                                               |
| Pevkakia            |                                                                                   |
| EBA                 | 373, 377, 381, 389, 393                                                           |
| MH                  | 401, 405, 406, 434, 435                                                           |
| LH Gp. 1            | 454                                                                               |
| LH Gp. 2            | 459                                                                               |
| LH Gp. 3            | -                                                                                 |
| LH Gp. 4            | 486, 491, 496, 499                                                                |
| LH Gp. 6            | 507, 508, 510, 513                                                                |
| LH Gp. 8            | 534, 535, 540, 550, 552, 553, 554                                                 |
| LH Gp. 9            | 570                                                                               |
| LH Gp. 10           | 578, 583, 589, 592                                                                |
| LH Gp. 11           | 600                                                                               |
| LH Gp. 12           | -                                                                                 |
| Revmatia            | -                                                                                 |
| Velestino (Iolkos)  | -                                                                                 |
| Velestino (Local)   | 643, 650, 655                                                                     |
| Velestino (Argolid) | 658                                                                               |
| Yephyria            | -                                                                                 |
| Yephyra-Asmakiou    | 756, 775, 781, 791                                                                |



Group 3.

|                     |                                                               |
|---------------------|---------------------------------------------------------------|
| Aliveri             | 20                                                            |
| Amarynthos          | 24, 36, 40, 43, 52, 53, 55                                    |
| Gialtra             | 77, 79, 80, 82                                                |
| Lefkandi            | -                                                             |
| Psakhna             | 107, 116, 117, 118                                            |
| Rovies              | 123, 126, 127, 129, 130, 132, 140, 141, 142, 143              |
| Anthedon            | 155                                                           |
| Chalia              | 163, 165, 166, 167, 169, 170, 171, 173, 179, 180              |
| Dramesi             | 182, 183, 184, 188, 190, 192, 197, 198                        |
| Eleon               | 203, 204, 209, 210, 211, 215, 216, 217, 218,<br>219, 220, 221 |
| Kynos               | 232                                                           |
| Thebes              | 247, 248, 251, 255, 258                                       |
| Argissa             | 268                                                           |
| Iolkos              | 289, 315                                                      |
| Volos (Iolkos)      | -                                                             |
| Marmariani          | 331, 347, 370                                                 |
| Pevkakia            | -                                                             |
| EBA                 | -                                                             |
| MH                  | -                                                             |
| LH Gp. 1            | 441                                                           |
| LH Gp. 2            | 460                                                           |
| LH Gp. 3            | -                                                             |
| LH Gp. 4            | 485, 490, 501                                                 |
| LH Gp. 6            | 526                                                           |
| LH Gp. 8            | -                                                             |
| LH Gp. 9            | -                                                             |
| LH Gp. 10           | -                                                             |
| LH Gp. 11           | 599                                                           |
| LH Gp. 12           | -                                                             |
| Revmatia            | -                                                             |
| Velestino (Iolkos)  | -                                                             |
| Velestino (Local)   | -                                                             |
| Velestino (Argolid) | 665, 666, 667, 671, 675, 676, 679, 680, 683                   |
| Yephyria            | 712, 743                                                      |
| Yephyra-Asmakiou    | 752, 767                                                      |

Group 4.

|                     |                                                                                                       |
|---------------------|-------------------------------------------------------------------------------------------------------|
| Aliveri             | 6, 7, 10                                                                                              |
| Amarynthos          | 44, 45, 60                                                                                            |
| Gialtra             | 68                                                                                                    |
| Lefkandi            | 90, 92                                                                                                |
| Psakhna             | -                                                                                                     |
| Rovies              | -                                                                                                     |
| Anthedon            | 148, 159                                                                                              |
| Chalia              | 162, 168, 175                                                                                         |
| Dramesi             | -                                                                                                     |
| Eleon               | 213                                                                                                   |
| Kynos               | 224, 229, 233, 234, 235, 239                                                                          |
| Thebes              | 246, 250, 254, 259                                                                                    |
| Argissa             | 264, 265, 270                                                                                         |
| Iolkos              | 296, 297, 298, 301, 302, 305, 307, 309, 314, 316, 326                                                 |
| Volos (Iolkos)      | 689, 690, 691, 693, 701, 702, 707, 708, 711                                                           |
| Marmariani          | 335, 336, 342, 350, 351, 354, 355, 356, 358,<br>361, 362, 365, 368                                    |
| Pevkakia            |                                                                                                       |
| EBA                 | 372, 378, 382, 383, 391                                                                               |
| MH                  | -                                                                                                     |
| LH Gp. 1            | 443, 444, 445, 447, 449, 450                                                                          |
| LH Gp. 2            | 456, 461, 462, 465, 467, 468                                                                          |
| LH Gp. 3            | 473, 475, 478, 482                                                                                    |
| LH Gp. 4            | 484, 494, 502                                                                                         |
| LH Gp. 6            | 525, 527                                                                                              |
| LH Gp. 8            | 531, 537, 541, 542, 546                                                                               |
| LH Gp. 9            | 562, 569, 574                                                                                         |
| LH Gp. 10           | 576, 577, 588                                                                                         |
| LH Gp. 11           | -                                                                                                     |
| LH Gp. 12           | -                                                                                                     |
| Revmatia            | 610, 611, 612, 613, 614, 616, 617, 618, 619, 620,<br>621, 622, 623, 624, 625, 626, 627, 628, 629, 630 |
| Velestino (Iolkos)  | -                                                                                                     |
| Velestino (Local)   | 639, 340 .                                                                                            |
| Velestino (Argolid) | 664, 669, 673                                                                                         |

Group 4. (Continued)

|                  |                                                                                                                                                          |
|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Yephyria         | 713, 714, 715, 716, 718, 719, 721, 723, 725,<br>727, 728, 729, 731, 732, 733, 734, 735, 736,<br>737, 738, 739, 740, 742, 743, 746, 747, 748,<br>749, 751 |
| Yephyra-Asmakiou | 760, 761, 766, 771, 773, 774, 776, 778, 783,<br>784, 787                                                                                                 |



Group 5.

|                     |                                                                                                       |
|---------------------|-------------------------------------------------------------------------------------------------------|
| Aliveri             | 1, 9, 19                                                                                              |
| Amarynthos          | 30,34, 46, 54                                                                                         |
| Gialtra             | 65, 66, 67, 69                                                                                        |
| Lefkandi            | 85                                                                                                    |
| Psakhna             | 103, 105                                                                                              |
| Rovies              | 128                                                                                                   |
| Anthedon            | 149, 154, 156                                                                                         |
| Chalia              | 176, 178                                                                                              |
| Dramesi             | 194                                                                                                   |
| Eleon               | -                                                                                                     |
| Kynos               | 240                                                                                                   |
| Thebes              | 244, 249                                                                                              |
| Argissa             | -                                                                                                     |
| Iolkos              | 303, 304, 306, 319, 325, 329                                                                          |
| Volos (Iolkos)      | -                                                                                                     |
| Marmariani          | 332, 334, 337, 339, 340, 341, 343, 344, 345, 346,<br>352, 353, 357, 359, 360, 363, 364, 366, 367, 369 |
| Pevkakia            |                                                                                                       |
| EBA                 | -                                                                                                     |
| MH                  | 400, 402, 407, 408, 411, 415, 417, 428, 430, 432,433                                                  |
| LH Gp. 1            | 436, 437, 438, 439, 440, 442, 446, 448, 451, 452, 453                                                 |
| LH Gp. 2            | 455, 458, 463                                                                                         |
| LH Gp. 3            | 477                                                                                                   |
| LH Gp. 4            | 489, 500                                                                                              |
| LH Gp. 6            | 503, 504, 505, 511, 515, 516, 517, 519, 522, 528, 529                                                 |
| LH Gp. 8            | 536, 538, 549                                                                                         |
| LH Gp. 9            | 559                                                                                                   |
| LH Gp. 10           | 584, 585, 586, 587, 590                                                                               |
| LH Gp. 11           | 593, 595, 596, 597, 598                                                                               |
| LH Gp. 12           | -                                                                                                     |
| Revmatia            | 631                                                                                                   |
| Velestino (Iolkos)  | -                                                                                                     |
| Velestino (Local)   | 644, 649                                                                                              |
| Velestino (Argolid) | 659, 661, 662, 677, 684, 685, 687                                                                     |
| Yephyria            | 717, 722, 724, 730, 750                                                                               |
| Yephyra-Asmakiou    | 753, 755, 758, 759, 762, 763, 764, 765, 768, 769,<br>770, 777, 780, 785, 786, 788, 789, 791, 792      |

Group 6.

|                |                                                                                                                                   |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------|
| Aliveri        | 11                                                                                                                                |
| Amarynthos     | -                                                                                                                                 |
| Gialtra        | -                                                                                                                                 |
| Lefkandi       | 83, 95                                                                                                                            |
| Psakhna        | 106, 109, 110, 111, 113, 115, 119, 120                                                                                            |
| Rovies         | 134                                                                                                                               |
| Anthedon       | -                                                                                                                                 |
| Chalia         | 172                                                                                                                               |
| Dramesi        | -                                                                                                                                 |
| Eleon          | -                                                                                                                                 |
| Kynos          | 236                                                                                                                               |
| Thebes         | -                                                                                                                                 |
| Argissa        | 262, 267                                                                                                                          |
| Iolkos         | 282, 283, 284, 285, 286, 287, 290, 291, 292, 293,<br>294, 295, 299, 300, 303, 309, 311, 313, 320, 322,<br>323, 324, 327, 328, 330 |
| Volos (Iolkos) | 705, 709                                                                                                                          |
| Marmariani     | -                                                                                                                                 |
| Pevkakia       |                                                                                                                                   |
| EBA            | 371, 374, 375, 379, 380, 385, 386, 388, 392,<br>394, 395, 396, 397, 398, 399                                                      |
| MH             | 403, 404, 409, 410, 412, 413, 414, 416, 418, 421<br>422, 423, 424, 425, 426, 427, 429, 431                                        |
| LH Gp. 1       | -                                                                                                                                 |
| LH Gp. 2       | -                                                                                                                                 |
| LG Gp. 3       | 469, 470, 471, 472, 474, 476, 479, 480, 481, 483                                                                                  |
| LH Gp. 4       | 485, 488, 492, 493, 495, 497, 498                                                                                                 |
| LH Gp. 6       | 512, 514, 518, 519, 521, 524, 528                                                                                                 |
| LH Gp. 8       | 532, 533, 539, 543, 544, 545, 547, 548, 551                                                                                       |
| LH Gp. 9       | 555, 556, 557, 558, 560, 561, 573, 564, 565,<br>566, 567, 568, 571, 572, 573, 575                                                 |
| LH Gp. 10      | 579, 580, 581, 582, 591                                                                                                           |
| LH Gp. 11      | -                                                                                                                                 |
| LH Gp. 12      | 601, 602, 603, 604, 605, 606, 607, 608, 609                                                                                       |

Group 6 (Continued)

|                     |                                             |
|---------------------|---------------------------------------------|
| Revmatia            | 615                                         |
| Velestino (Iolkos)  | 632, 633, 634, 635, 636                     |
| Velestino (Local)   | 636, 642, 645, 646, 647, 651, 653, 654, 656 |
| Velestino (Argolid) | 660, 682                                    |
| Yephyria            | -                                           |
| Yephyra-Asmakiou    | 754, 757, 772, 782                          |



Samples analysed by atomic absorption after discriminant analysis  
and without chromium or nickel

Group 1.

|                   |                                                                              |
|-------------------|------------------------------------------------------------------------------|
| Amarynthos        | 21, 25, 34, 35, 41, 42, 43, 44, 45, 52, 53, 54, 55                           |
| Lefkandi          | -                                                                            |
| Rovies            | 125, 131, 132, 136, 143                                                      |
| Anthedon          | 146, 148, 153, 155, 156                                                      |
| Eleon             | 205                                                                          |
| Thebes            | 243, 244, 245, 246, 247, 249, 251, 253, 254,<br>255, 256, 257, 259, 260, 261 |
| Volos (Iolkos)    | 693, 695, 710, 711                                                           |
| Marmariani        | -                                                                            |
| Pevkakia LH Gp II | -                                                                            |
| Revmatia          | 611, 613                                                                     |

Group 2.

|                    |                                                                              |
|--------------------|------------------------------------------------------------------------------|
| Amarynthos         | 22, 31, 32, 33, 31                                                           |
| Lefkandi           | 83, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95,<br>96, 97, 98, 99, 100, 101, 102 |
| Rovies             | 124, 134, 135                                                                |
| Anthedon           | 145, 150, 157, 158, 160, 161                                                 |
| Eleon              | 206                                                                          |
| Thebes             | -                                                                            |
| Volos (Iolkos)     | 692                                                                          |
| Marmariani         | -                                                                            |
| Pevkakia LH Gp. II | -                                                                            |
| Revmatia           | -                                                                            |

Group 3.

|            |                                                                              |
|------------|------------------------------------------------------------------------------|
| Amarynthos | 23, 24                                                                       |
| Lefkandi   | 85                                                                           |
| Rovies     | 123, 126, 129, 130, 133, 138, 140, 141, 142                                  |
| Anthedon   | 147, 149, 151, 152, 154                                                      |
| Eleon      | 203, 204, 207, 208, 209, 210, 211, 212, 213,<br>215, 216, 218, 219, 220, 221 |

Group 3 (Continued)

|                    |                    |
|--------------------|--------------------|
| Thebes             | 242, 248, 253, 258 |
| Volos (Iolkos)     | -                  |
| Marmariani         | 347                |
| Pevkakia LH Gp. II | -                  |
| Revmatia           | -                  |

Group 4.

|                    |                                                                                                  |
|--------------------|--------------------------------------------------------------------------------------------------|
| Amarynthos         | -                                                                                                |
| Lefkandi           | -                                                                                                |
| Rovies             |                                                                                                  |
| Anthedon           | -                                                                                                |
| Eleon              | -                                                                                                |
| Thebes             | 250                                                                                              |
| Volos (Iolkos)     | 691, 701                                                                                         |
| Marmariani         | 336, 342                                                                                         |
| Pevkakia LH Gp. II | -                                                                                                |
| Revmatia           | 610, 612, 614, 616, 617, 618, 619, 620, 621,<br>622, 623, 624, 625, 626, 627, 628, 629, 630, 631 |

Group 5.

|                    |                                                                                   |
|--------------------|-----------------------------------------------------------------------------------|
| Amarynthos         | -                                                                                 |
| Lefkandi           | -                                                                                 |
| Rovies             | 127, 128, 139                                                                     |
| Anthedon           | -                                                                                 |
| Eleon              | 214, 217                                                                          |
| Thebes             | -                                                                                 |
| Volos (Iolkos)     | 708                                                                               |
| Marmariani         | 331, 332, 333, 334, 337, 338, 339, 340, 341, 343,<br>344, 345, 346, 348, 349, 350 |
| Pevkakia LH Gp. II | -                                                                                 |
| Revmatia           | 615                                                                               |

Group 6.

|                    |                                                                              |
|--------------------|------------------------------------------------------------------------------|
| Amarynthos         | -                                                                            |
| Lefkandi           | 84                                                                           |
| Rovies             | 137                                                                          |
| Anthedon           | 144                                                                          |
| Eleon              | 202                                                                          |
| Thebes             | -                                                                            |
| Volos (Iolkos)     | 689, 690, 694, 696, 697, 698, 699, 700, 702,<br>703, 704, 705, 706, 707, 709 |
| Marmariani         | 335                                                                          |
| Pevkakia LH Gp. II | -                                                                            |
| Revmatia           | -                                                                            |

Group 7.

|                    |                                        |
|--------------------|----------------------------------------|
| Amarynthos         | -                                      |
| Lefkandi           | -                                      |
| Rovies             | -                                      |
| Anthedon           | 159                                    |
| Eleon              | -                                      |
| Thebes             | -                                      |
| Volos (Iolkos)     | -                                      |
| Marmariani         | -                                      |
| Pevkakia LH Gp. II | 593, 594, 595, 596, 597, 598, 599, 600 |
| Revmatia           | -                                      |



APPENDIX 6.

### An Alternative Method of Calibration

As mentioned in Chapter 5.2.10 a calibration graph was drawn for sodium (Figure 25) and although the slope of the graph thus obtained was almost the same as that of the master graph used in Athens, some of the points were transposed. Standard 269, for example, has about half of the sodium content of the standard sherd Mycenae 22, yet it had a higher relative intensity value. Overall, however, the 2 graphs were comparable and the horizontal displacement of the line drawn relative to the master line was no more than that which is expected for the reasons given above (Chapter 5.2.3).

It is gamma tables, also described in Chapter 5.2.9, which enable compensation for the background contribution to be subtracted from the line plus background reading. The tables perform the equivalent function to calculating the Seidel density for each galvanometer deflection and then plotting the Seidel densities against the  $\log_{10}$  exposure curve and they enable the light intensity for the background and for the line with background to be determined. The background intensity can then be subtracted to leave the light intensity for the elemental line.

There remains some uncertainty as to the details of the 1974 recalibration (see above, Chapter 1.1 and Chapter 6) and it was thought that an attempt should be made to find an alternative method of calibration which could also serve as a check on the one used in Athens.

The alternative method of calibration which was tried involves the determination of relative intensities at constant density. Since measured densities for given exposures are dependent on several factors,

this method is not dependent on underlying assumptions governing the relationship between gamma and exposure. Although either optical or Seidel densities can be used, the Seidel density is preferred as the Seidel density over  $\log_{10}$  exposure curve is linear to lower densities than the equivalent curve using the optical density. The filtered and unfiltered values are used to define the lines.

What is required is the intensity of the line emission ( $I_L$ ) above the intensity of the background ( $I_B$ ) but what is actually measured through the Seidel density over  $\log_{10}$  exposure graph is  $I_L + I_B$  at the position of the line and  $I_B$  in the background region beside the line. It is not possible simply to subtract  $I_B$  from ( $I_L + I_B$ ) and hence obtain the desired  $I_L$ .

Graphs must be drawn for Seidel density over  $\log_{10}$  exposure for lithium (the internal standard) and for an element for the line with background and the background values (see Figure 59). At a selected, constant density the horizontal separation between lithium and background, element and background and between the two backgrounds are measured. The separation between the line with background and the background, the intensity difference, is called  $\delta'$  which can be measured.

$$\delta'_{Li} = \log_{10}(I_{Li} + I_{BLi}) - \log_{10} I_{BLi}$$

$$\delta'_E = \log_{10}(I_E + I_{BE}) - \log_{10} I_{BE}$$

From this  $\delta''$  and  $\Delta$  can be derived and  $\delta''$  is defined as:

$$\delta''_{Li} = \log_{10}(I_{Li} + I_{BLi}) - \log_{10} I_{Li}$$

$$\delta''_E = \log_{10}(I_E + I_{BE}) - \log_{10} I_E$$



and  $\Delta$  is defined as:

$$\Delta_{\text{Li}} = \delta' - \delta'' = \log_{10} I_{\text{Li}} - \log_{10} I_{\text{BLi}}$$

$$\Delta_{\text{E}} = \delta' - \delta'' = \log_{10} I_{\text{E}} - \log_{10} I_{\text{BE}}$$

$$\begin{aligned} \text{Therefore } \Delta_{\text{E}} - \Delta_{\text{Li}} &= \log_{10} \frac{I_{\text{E}}}{I_{\text{Li}}} - (\log_{10} I_{\text{BE}} - \log_{10} I_{\text{BLi}}) \\ &= \log_{10} \frac{I_{\text{E}}}{I_{\text{Li}}} - \delta_{\text{b}} \end{aligned}$$

and the ratio of the concentrations can be expressed as:

$$\log_{10} \frac{I_{\text{E}}}{I_{\text{Li}}} = \Delta_{\text{E}} - \Delta_{\text{Li}} + \delta_{\text{b}}$$

where  $\delta_{\text{b}}$  = the separation between the backgrounds.

Values of  $\Delta$  can be derived from the measured values of  $\delta'$  using tables of subtraction logarithms (Mitchell 1964: 212-3). S. E. Warren and J. G. Crummett of the University of Bradford have written a computer program to derive the values of  $\Delta$ .

Measurement of the differences in log relative intensities from the separation on the graph give values for  $\delta'_{\text{Li}}$ ,  $\delta_{\text{E}}$  and  $\delta_{\text{b}}$  and the corresponding values of  $\Delta_{\text{L}}$  and  $\Delta_{\text{E}}$  can be read off from the tables.

Theoretically, if a set of standards is run and plotted as before, with  $\log_{10}$  concentration of the element over  $\log_{10} \frac{I_{\text{E}}}{I_{\text{Li}}}$ , a standard calibration curve may be obtained.

However, when calibration by this method was attempted a series of problems was encountered which prevented the method being completely successful despite its theoretically firm base. It was decided to use

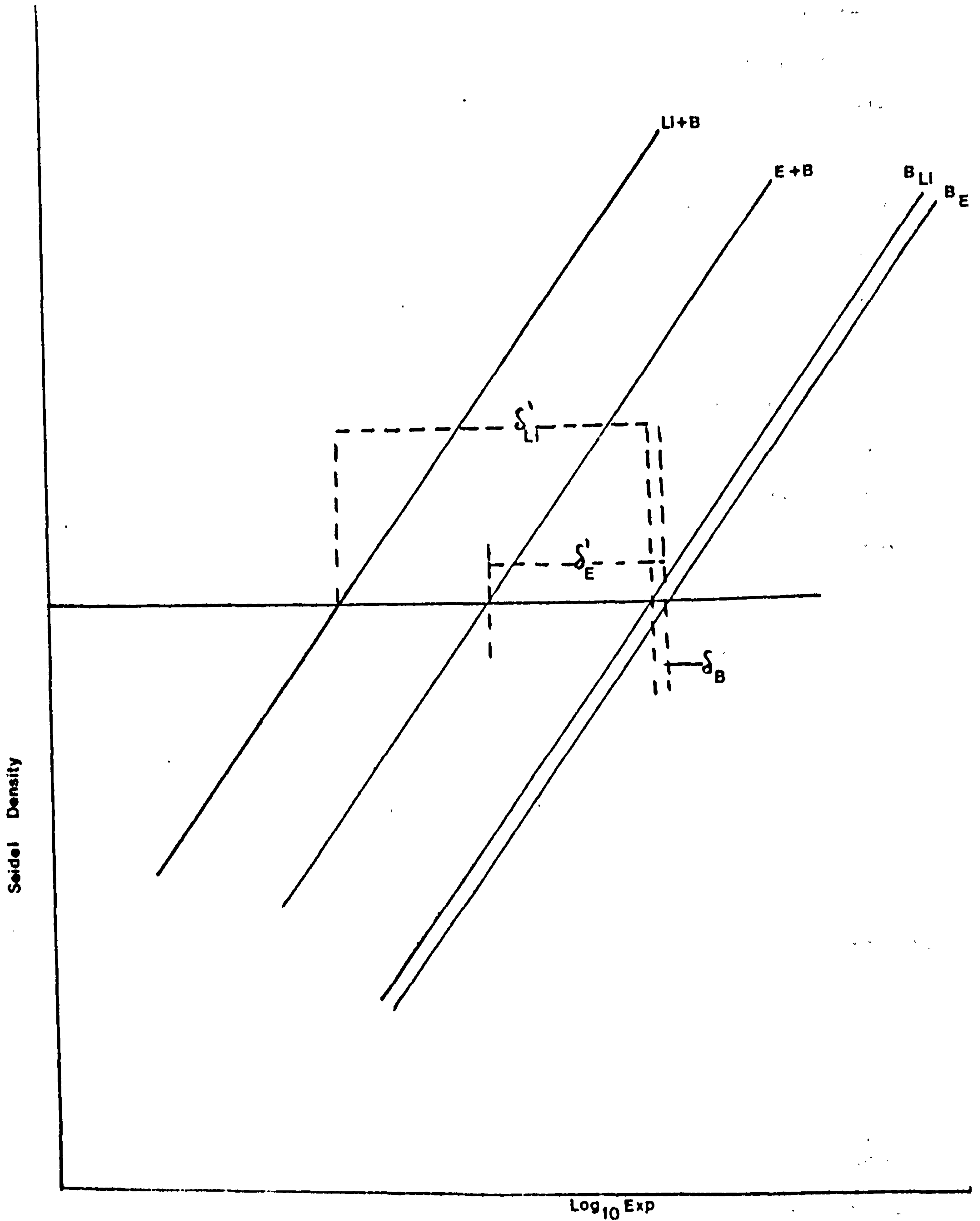


Fig 59 Graph of Seidel Density over Log<sub>10</sub> Exposure to show the positions of  $\delta'_L$ ,  $\delta'_E$  and  $\delta_B$

sodium as the test element since it had been used for the test of the Athens calibration mentioned above (Chapter 5.2.10). The graphs in Figures 60 and 61 show the lines drawn for lithium and sodium respectively, together with their respective backgrounds for three standards: G2, Mycenae 22 and 269, using the filtered and unfiltered values to calculate the Seidel densities. Assuming that the filter is indeed filtering the light by a factor of ten it would be expected that all the lines for the same element on the same plate would have the same slope. The standards plotted here were taken from the plate of standards mentioned in Chapter 5.2.10 and it was expected that the lithium lines (and their backgrounds) would have a slope of 55' and the sodium lines (and their backgrounds) a slope of 57' (gamma plus 2). As Figures 60 and 61 illustrate, the slopes of the lithium lines shown range from 52' (269) to 65' (G2) and their backgrounds from 49' (269) to 50' (G2). The sodium lines varied from 48' (G2) to 60' (269) and their backgrounds from 52' (G2) to 63' (269). It was expected that there would be little separation between the lines for lithium since it is present in a constant amount in all the samples but a considerable variation was seen. It was also surprising how much variation there was in the slope of the background lines. Although the lines were in the right order according to their relative sodium contents, G2 being the highest and 269 the lowest, but their relative separations are not what was expected since G2 contains 4.07% sodium, Mycenae 22, 0.76% and 269 only 0.36%. Because the lines had such a range of slopes it was not possible simply to measure the separation between the lines at a constant density.

This discrepancy between the expected and the experimental slopes of the lines may be attributed to several factors. One of these is our



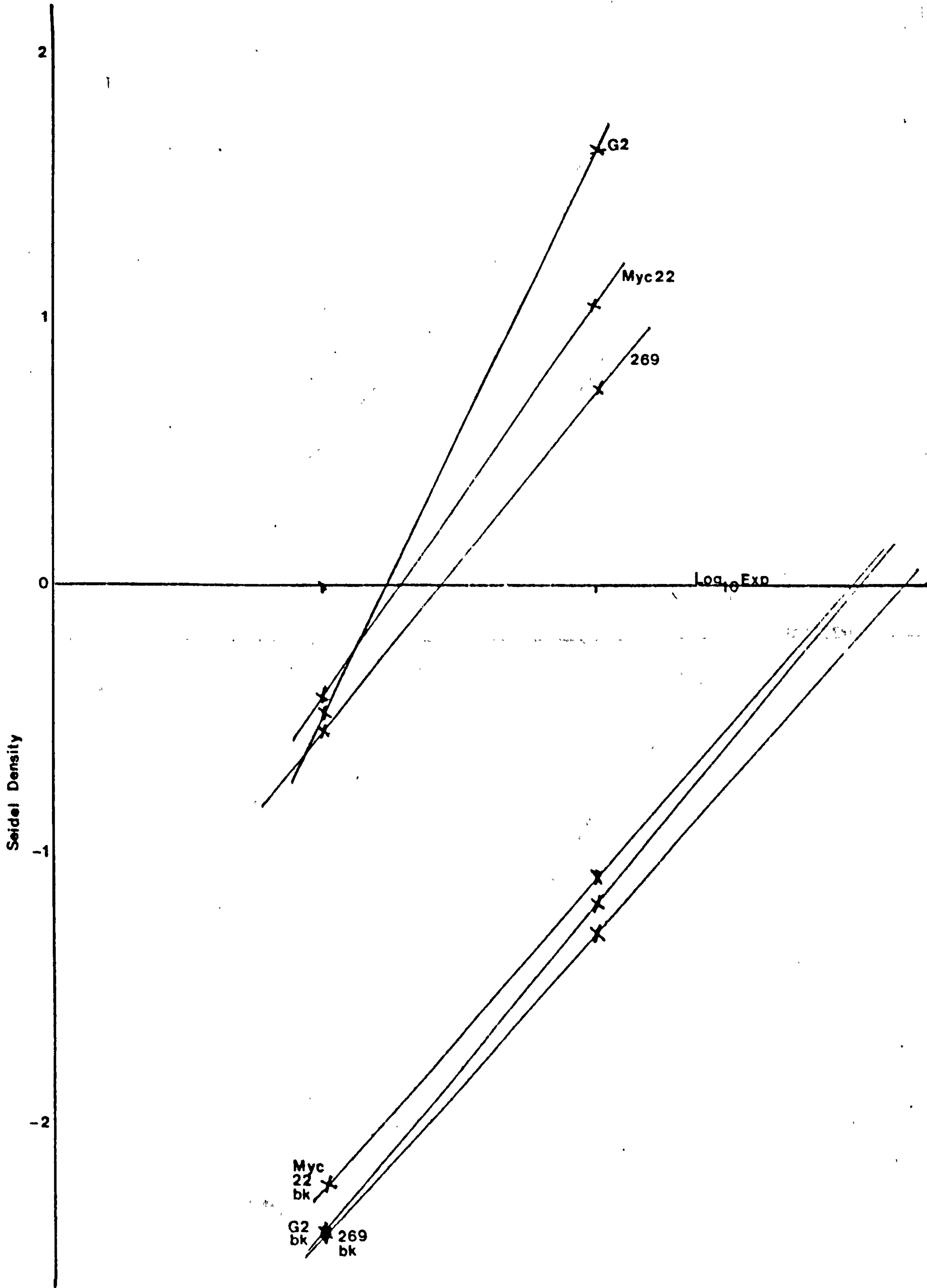
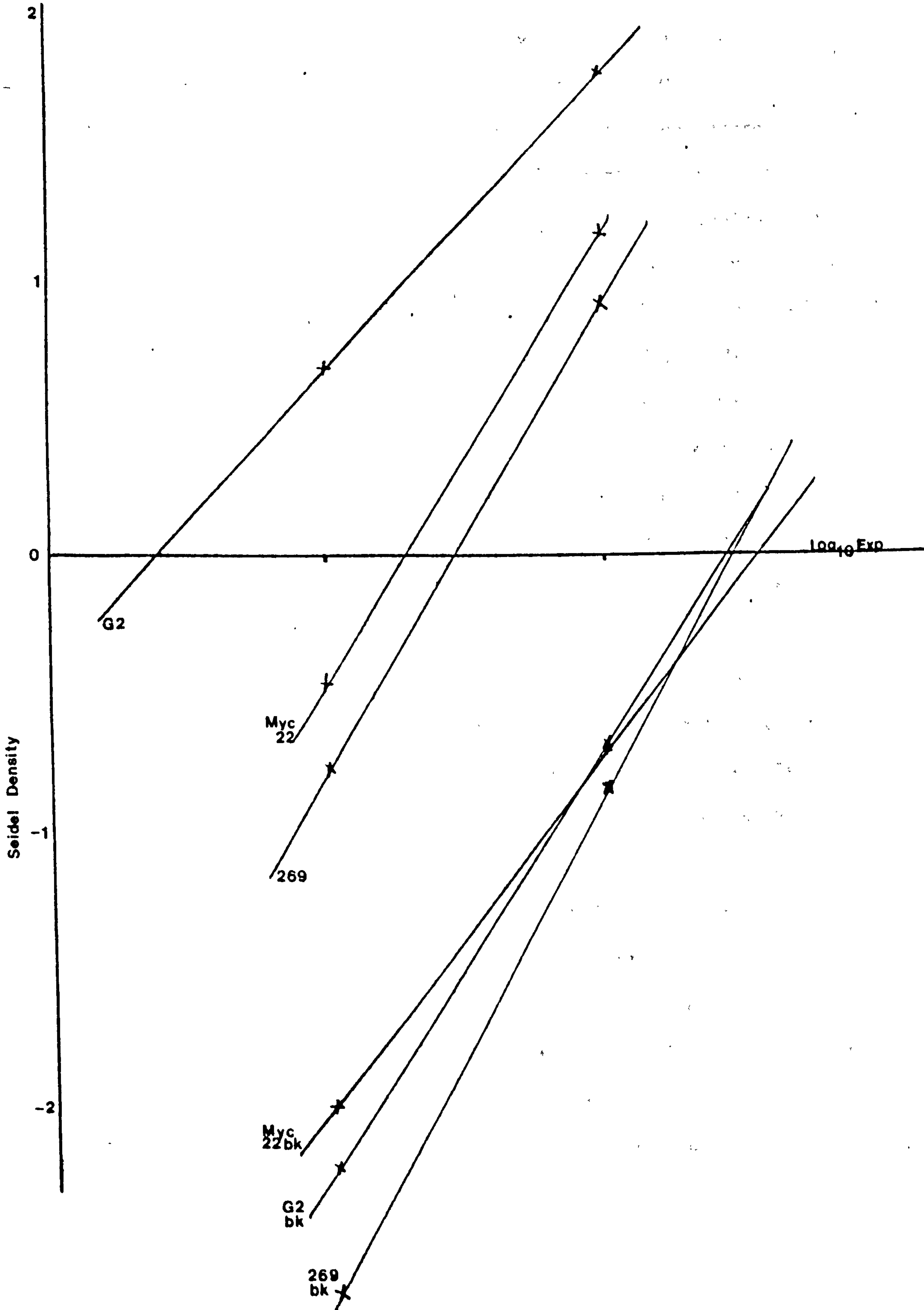


Fig 60 Graph of Element with background and Background lines for Ithium



lack of information about the characteristics of the photographic emulsion over the full range of working densities. In the graph provided by the manufacturers and enlarged in Figure 62 the curve appears to reach a plateau at low densities rather than approaching 0 as might be expected. It can also be seen that the gamma for the manufacturers' curve is greater than the expected slope of 55' for this plate. There also remains some uncertainty over whether or not the gamma tables were freshly computed after the 1974 recalibration so that they do in fact relate to the plates currently being used, or whether this was omitted in the recalibration. When graphs like Figure 18 for Seidel density over  $\log_{10}$  exposure were plotted for various gamma values it was found that some, but not all, of the graphs curved at the very low and very high densities and that these curves were the opposite way to that generally associated with a density over  $\log_{10}$  exposure curve. On the graphs where this happens the background values, and especially the filtered background values for the Seidel densities are so low that they fall on the part of the line where the response is reduced. In such cases it would be difficult to simply extrapolate a line at the expected slope and could lead to the variation in slopes described above. Seidel densities for the backgrounds are typically between -1 and -2 which are equivalent to optical densities of .004-.04 and as reference to Figure 61 shows, this would be well below the linear portion of the graph. In the method of calibration used in the Athens laboratory steps are taken to ensure that the straight-line portion of the graph is being used in each case. While this is true for the elemental lines, it may not always be true for the backgrounds. There may also be problems in accurate reading of the galvanometer at extreme values, especially where the clear



glass reading and the filtered background readings are very close. In some cases the galvanometer deflection for the filtered background for lithium has a higher value than the clear glass reading.

If there were general background scatter within the spectrograph which was not being affected by the filter it could have the effect of making the  $\gamma$  appear lower as plotted. However, the majority of the lines tested were steeper than expected rather than shallower.

While there is no obvious inherent reason for the failure of this method, some of the problems mentioned above remain unsettled. The method could be tested more satisfactorily if a stepped sector could be used during the analysis of standards so that the average slope of the line could be defined more fully. It would also be better if the sample mass, and hence the exposure, were increased so that the lines would have a greater density and would be more securely placed on the linear portion of the graph. There would also be advantages in selecting a spectral line on the same portion of the plate as lithium which might be expected to have the same gamma value rather than sodium which is known to have a higher gamma value. It would also help to have fuller information about the characteristics of the photographic emulsion being used.

This attempt to find an alternative method of calibration was carried out in Bradford and therefore had to be restricted to the available data. Had it been possible to conduct the attempt in Athens, and had it been successful, it would not have led to an alteration in the method used, since comparability with past analyses done in Athens was an important part of this project. It would, however, have been possible to apply the alternative calibration to older data using the location standard

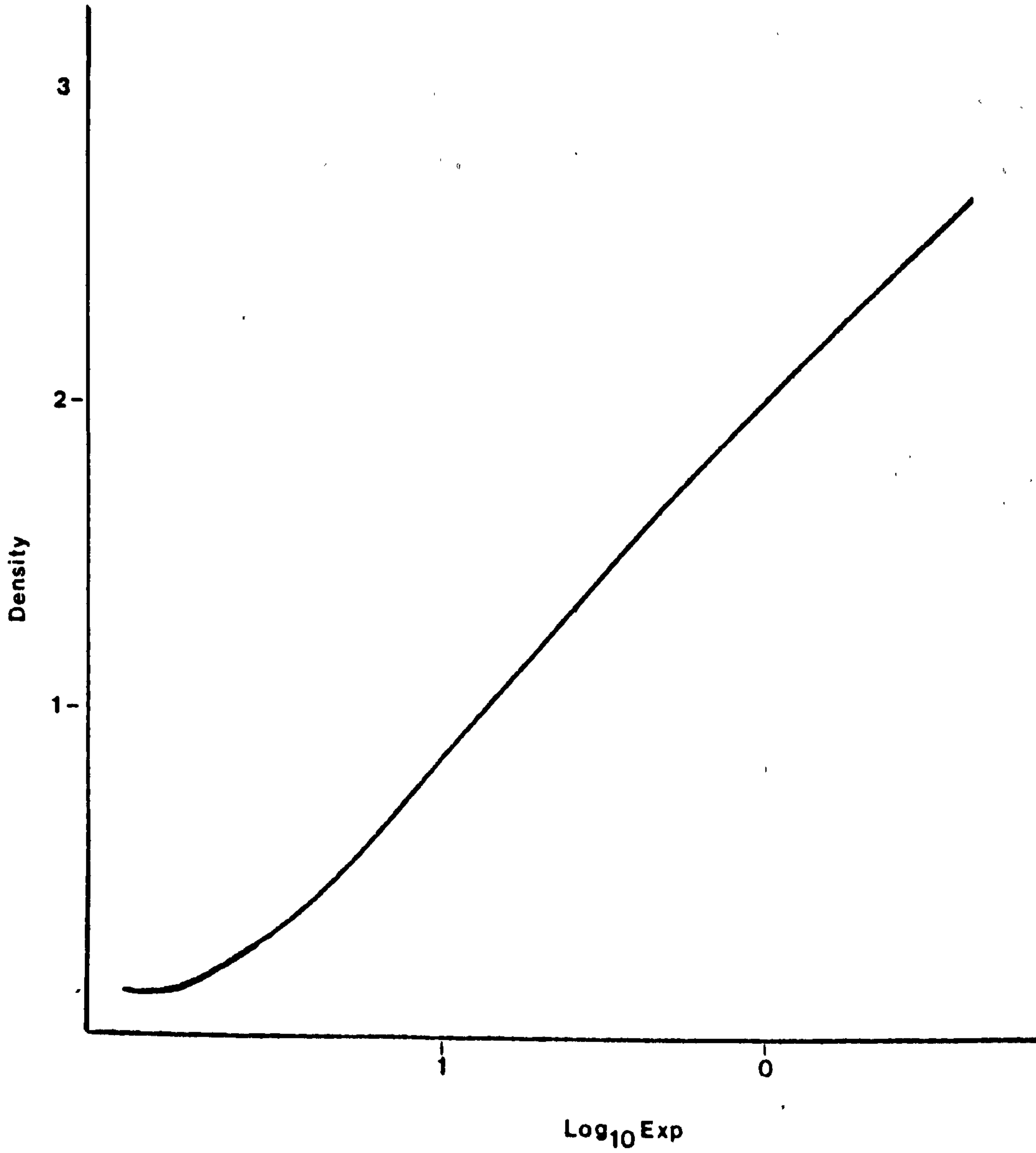


Fig 62 Manufacturer's graph of Density over Log<sub>10</sub> Exposure for the photographic plates

Mycenae 22 and the points for the filtered and unfiltered lines. To improve the nature of the data available would have involved an extra trip to Athens being made especially for this purpose at the end of the project, for which neither the time nor the resources were available.

The inference which can be drawn at this stage is, therefore, that it appears to be limitations in the available data and associated information rather than the calibration method itself which caused its failure.



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