## An Analytical Study of Obsidian from Europe and the Near East by examination of Magnetic Parameters .

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# AN ANALYTICAL STUDY OF OBSIDIAN FROM EUROPE AND THE NEAR EAST BY EXAMINATION OF MAGNETIC PARAMETERS.

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An Abstract to a dissertation submitted in part fulfilment of the requirement for the Degree of Master by Advanced Study in Scientific Methods in Archaeology. by Joan M. McDougall B.A. (Manchester) Postgraduate School of Studies in Physics. University of Bradford, 1978.

The present research aims at the characterisation of obsidian by examination of magnetic properties and relies on the presence within the obsidian of a small percentage of magnetic minerals disseminated throughout the predominantly non-magnetic matrix of the rock, causing it to respond to the ambient magnetic field conditions in which it cooled. Magnetic properties of different materials vary in accordance with their thermal and chemical history, composition and grain size and it seems likely that different obsidian flows will exhibit different magnetic properties dependent on the mode and occurence of their ferrimagnetic oxides. The merit of the method lies in its inexpensive, swift and non-destructive nature.

Over a four-month period, 216 samples, including both geological and archaeological pieces from the Aegean, the West Mediterranean, Central Europe and the Near East, were analysed at Newcastle University. The bulk of measurements were made using the Balanced Fluxgate Rock Magnetometer as developed by Dr. Lindsay Molyneux. (Dept. of Geophysics and Planetary Physics, Newcastle University)

Of the magnetic parameters determined, remanent intensity and saturation magnetisation provide the best source discrimination, whilst low-field susceptibility can also be diagnostic.

Distinct subdivisions emerge within the data from Lipari and Sardinia in the West Mediterranean and from Acigol in the Near East suggestive of separate flows of different magna type within geographically restricted areas. Hallar et al. (1976) report three elementally distinct subdivisions within Sardinian obsidian, magnetic analysis confirms this and documents a fourth sub-group, unreported in the literature but recently recognised by neutron activation.

Adequate discrimination is effected between Aegean sources and similarly between Near Eastern material analysed. Of West Mediterranean obsidians, the only real discrimination problem is to separate one Sardinian sub-group from one Liparian sub-group.

This limited research predicts the potential of magnetic analysis for obsidian source identification. Further work in this field may determine the magnetic characteristics of particular sources and ultimately the technique should prove useful in a study of the changing patterns of trade and contact in prehistory. CONTENTS

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#### PREFACE

The aim of the present research programme was primarily to establish the sensitivity of magnetic analysis as a method for obsidian characterisation. In particular, if successful, analysis of magnetic parameters would provide an alternative, swift, inexpensive means of source identification to add to the multifarious analytical techniques already in use for provenance studies.

In the first instance examination of geological 'source' material is required in an attempt to identify the magnetic properties, ideally, unique to that particular source. Neutron activation analysis has been effectively applied to archaeological specimens for provenance determination, thus where geological hand samples for analysis are lacking, archaeological specimens, attributed to a source by way of neutron activation analysis, are assumed to be typical of that source. I have availed myself of the results of neutron activation analysis of archaeological pieces carried out at the Postgraduate School of Studies in Physics of the University of Bradford (Hallam et al., 1976; McDaniels, University of Bradford M.A. dissertation, 1976; Williams, University of Bradford PhD thesis, forthcoming).

Measurements of the intensity of magnetisation of samples were carried out using a 'Digico' balanced Fluxgate Rock Spinner Magnetometer, credit for the development of which belongs to Dr. Lindsay Molyneux of Newcastle University.

For provision of material for analysis I owe thanks to many people, too numerous to name here, but whose help is specifically acknowledged in table 1.

I must emphasise my debt to many people who gave help and encouragement at every stage of my research. To Olwen Williams and Brian Hallam I am grateful for information on specific points. Sincere thanks go to Mr. S.E. Warren (Postgraduate School of Studies in Physics, University of Bradford.) and Dr. D.H. Tarling (Department of Geophysics and Planetary Physics, University

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PART 1.

#### CHAPTER 1.

### PROGRESS OF RESEARCH ON OBSIDIAN : A REVIEW

#### 1:1 Introduction

'Obsidian, or volcanic glass, is a form of lava, which has been completely fused, and it is found in most volcanic districts'..... Just as flint or chert can only be derived from particular strata, and must have been carried by trade if found at any distance from these centres, so the presence of obsidian objects in a non-volcanic country is proof of trade with some centre of volcanic activity' (Wainwright, 1927,77). Thus, by the 1920's Wainwright demonstrates an awareness of the potential usefulness of obsidian as an indicator of contact and communications. If obsidian artefacts, associated with archaeological sites, can be identified with a particular geological source from which the material was obtained, then the geographic extent of cultural contact and indeed the routes followed by the 'traders' can be proven.

Obsidian is the earliest object of trade for which material evidence remains (Renfrew et al., 1966,30), and though not necessarily the principal object of such exchange, 'obsidian is for us the indicator that contact was taking place' (1966,50).

Renfrew and his co-workers (1966,30) see a study of obsidian as the most promising avenue for elucidating the extent of the contact between the different early neolithic cultural and ecological regions. 'Obsidian is a raw material that was widely used and traded in most major areas of the world. For this reason alone it is worthy of enquiry' (Wright, 1969,2). Renfrew and his colleagues (Renfrew et al., 1966) suggest the importance of obsidian as establishing 'trade' routes which might serve as channels for the passage \* exchange of ideas, and along such channels we might see the development of a

more sedentary economy and the beginnings of farming.

That contact between cultural groups was occurring in prehistory is in itself greatly significant, however, 'Trade is not a panacea for explaining problems of culture change and the appearance of non-local raw materials and craft items on prehistoric sites. To assert that trade occurred answers nothing. One must attempt to demonstrate how the system operated, what its consequences were and the hypotheses must be testable' (Wright, 1969, 84). Obsidian has proved to be a most suitable material for a study of trade mechanisms. Known geological sources are neither too numerous to render adequate characterisation impossible, nor too few to make characterisation worthless, and there generally exists, in the lithic assemblage of an archaeological site a sufficient number of obsidian artefacts to warrent statistical analyses.

'Obsidian analyses contribute a great deal to a more thorough understanding of the scope of trading activities in the early Meolithic period and obsidian would appear indeed to be the earliest object of trade which can be recognised and characterised with some accuracy today' (Cann et al., 1969, 590). Before discussing in further detail the various analytical techniques involved it seems expedient to define with greater accuracy the terms 'characterisetion' and 'trade' as applicable in the present context.

The 'procedure of distinguishing the sources from one another may be termed characterisation' (Cann et al., 1969, 577). A characterisation study involves the detection of properties of the samples under study which are, ideally, uniquely characteristic of material from a particular obsidian flow. When all the geological obsidian sources in a particular archaeological region have been thus 'fingerprinted' the archaeological material can be assigned to its source. An adeouate characterisation of obsidian thus entails demonstrating homogeneity within geological sources and heterogeneity between them. This necessitates intensive within-source sampling, to show the degree of internal consistercy as exhibited by a single obsidian source and

to suggest bounds within which the material may be considered as homogeneous, in addition to extensive sampling of the different sources.

Following Renfrew's interpretation 'trade' is 'to be understood in its widest sense : the reciprocal traffic, exchange or movement of materials or goods through peaceful human agency' (Renfrew, 1969,152). In prehistoric communities this is not intended to imply commercial transactions or the presence of professional traders.

'The scientific identification of any given piece of obsidian with specimens from any one deposit is beset with difficulties...... yet, however, within limits it is possible to attain a considerable degree of probability as to the place of origin and further to eliminate other places as hitherto having produced nothing comparable to the material under discussion' (Wainwright, 1927,77). 'The development of a battery of sophisticated scientific methods has diminished the importance of typological analyses and opened up the possibility of writing prehistory without the encumbrance of meaningless cultural tags.' (Higham, 1969,149). The archaeologist no longer has to rely on the all too tenuous evidence of typological similarities as a definitive indication of trading links.

Trade's particular and sometimes crucial importance lies in a dual status : as the indicator for us today that intercultural contact was taking place, and as a prime motive among prehistoric groups, for such contact.' (Renfrew, 1969,151)

### 1:2 Obsidian Characterisation Methods

Several different methods of analysis have been employed in an attempt to characterise obsidian. Wainwright (1927) made use of refractive index, colour and density to suggest an Armenian source for Egyptian and Mesopotamian material and to refute the long-cherished belief that obsidian recovered from Egyptian sites is a product of the remote little island of Melos in the Aegean. He

examined obsidian objects from Abu Shahrein and Warka and made a distinction between two apparently different forms of obsidian known to exist in Armenia : the opaque coal-black type and the 'translucent varying from a cylinder of almost glassy-grey transparency to flakes which are quite opaque in the middle only becoming translucent where the material thins towards the edges' (Wainwright, 1927,84). He suggests that the opaque type is more common than the transparent in Egypt whilst the situation is reversed in Mesopotamia.

Frankfort (1927,190-192), compiled a comparative table of the physical qualities of specimens of obsidian from various sites and on this basis demonstrated that Melian obsidian bore the least resemblance to a specimen from Egypt. and indeed the Egyptian specimen could be seen to stand separate from all West Mediterranean and Aegean samples included in the comparison. Lynch(Wainwright, 4) reports that obsidian from Nemrut Dag near Lake Van is of two types:- one coal black and the other dark green. Wainwright in an examination of Nemrut Dag museum samples again confirmed the presence of the two kinds, the opaque and the translucent 'of yellowish-green tinge'. On the grounds of similarity of the two types to Egyptian archaeological material he suggests an origin at Nemrut Dag (indeed the only sources known in the North East at the time). With the greater bank of information now to hand regarding obsidian and its sources, some of these earlier observations are no longer credible. There was an awareness, however, of the limitations of this type of study and the need for back-up analyses and as early attempts at characterisation the efforts are worthy of credit.

Refractive index and density of obsidians were considered by Renfrew and Cann (1964) for a number of samples in and around the Mediterranean, the systematic variation between sources was not, however, considered adequate, for although green obsidians of groups 4b (Pantelleria), 4c (Lake Van) and 4d (Abyssinia, Arabia, Tibesti, Auvergne, Kenya), generally exhibited higher

refractive indices and densities than the others, the overlap was considerable.

Obsidian is divided into three broad geological types:- alkaline, peralkaline and calc-alkaline. A division into these types is reflected by variation in the physical properties (Renfrew et al., 1968). Obsidians with refractive indices less than 1.495 are generally alkaline or calc-alkaline and included in this division are obsidians from Hungary, Slovakia, Melos, Armenia, Southern Anatolia, Sardinia, Lipari and the Pontine Islands - Renfrew's groups 1,2,3 and 4a. Obsidians with refractive indices greater than 1.505 belong to the peralkaline type and include samples from Pantellaria, Lake Van, Abyssinia, Arabia, Tibesti, Auvergne, Kenya and Sardinia - Renfrew's group divisions, 4b, 4c, 4d, 5 and 6 (1968,581). Appearance provides a more reliable guide than either refractive index or density, peralkaline obsidians appearing greenish or brown in transmitted light and calc-alkaline and alkeline obsidians appearing grey or colourless.

In their analysis of Mediterranean obsidians Cann and Renfrew (1964) first investigated obsidian in terms of appearance and found fit to describe it in terms of 6 properties : 'colour in transmitted light, colour in reflected light, facture, translucency, transparency with internal structure and lustre' (114).

Appearance is not alone sufficiently diagnostic but can serve as a good general indicator when in agreement with the results of physical methods of chemical analysis.

Appearance criteria have nevertheless been established for obsidians from certain geological regions. Thus a pearly lustre has been taken as an indication of a Melian origin (Cann and Renfrew, 1964,114), a greenish colour in transmitted light as indicative of obsidian from Pantelleria, Lake Van, Abyssinia and other sources contributing to groups 4b, 4c and 4d of Cann and Renfrew's analysis (Cann and Renfrew, 1964), and the presence of spherulitic inclusions together with the absence of striations at being suggestive of an origin on the Aegean

island of Giali (Renfrew et al., 1965).

When chemical analysis fails to differentiate successfully between sources, as for example, between Carpathian obsidians and those of Melos, then a distinction has been effected using appearance as a criteria. Carpathian obsidian is black, fracturing conchoidally and showing a glassy lustre. In transmitted light it appears watery-grey, fairly translucent and transparent though at times somewhat cloudy (Renfrew et al., 1965), and on this basis a separation from the grey-black almost opaque obsidian of Melos is suggested.

A greenish colour in transmitted light has been used to distinguish Pantellerian obsidian from that of Lipari in the early strata on Malta and on similar grounds a separation of the peralkaline obsidian source at Nemrut Dag seems justifiable (Renfrew et al., 1966).

Recent investigations have challenged some of the appearance criteria as established by Renfrew et al. (1965), for the Aegean sources of Melos and Giali. Shelford (1974) conducted a detailed investigation of the two obsidian sources on Melos : Sta Nychia near Adhamas and Dhemenegaki. In a discussion of the geochemistry of the Adhamas and Dhemenegaki flows it is stated that 'pearly lustre is not a common feature of any Sta Nychia obsidian ' (Cosgrove et al., forthcoming).

Torrence and Cherry visited and described in detail the location and extent of obsidian outcroppings on Giali (Personal Communication) and concluded on the basis of the findings of atypical striated obsidian objects on the beach at the north-east end of Giali bay, that the presence of striations is insufficient in itself to rule out a Giali source. A non-Giali source for these samples (since not in situ) cannot be ruled out prior to their examination by chemical techniques, but the intort of foreign obsidian with a plentiful supply so close to hand seems inherently unlikely.

The use of a purely non-technical approach severely limits the formulation

of any definitive statements, and a case in point where indications of appearance can be a misleading guide to provenance is illustrated in the presence of red and black mottling which, although uncommon, occurs in obsidian from many of the Near Eastern sources (Renfrew et al., 1966).

Petrological examination is of limited value in a characterisation study due to the fine texture of the obsidian. Different outcrops can have a similar mineralogy and the better the obsidian the smaller and fewer are the crystalline inclusions.

Analysis of major element composition has also been attempted as a means of differentiation between sources, but the restricted range of major elements forming obsidian sets a limit to the usefulness of the method. (Georgiades, 1956) employing this method achieved a meaningful difference between source material from the Aegean islands of Giali, Antiparos and Melos, though that effected between Melos and Giali was only slight. Gordus and his colleagues comment that a knowledge of the aluminum content of obsidian is not particularly useful in identifying the geological source of the sample, since the aluminum content of obsidian does not vary markedly between sources. (Gordus et al., 1967,88). Cornaggia, Fussi and d'Agnolo (1962 and 1963) have attempted characterisation by several of these methods and found them in general to be inconclusive. They decided to base their analyses on concentrations of manganese and phosphorus as determined by Optical Emission Spectroscopy (henceforth OES) and by this means drew a distinction between Palmerola (Pontine Islands ), Lipari, Melos and Pantelleria. The validity of their conclusions is perhaps debateable since the small number of samples analysed may not have been representative of the range of material from the respective sources, and indeed their suggestion of a Melian origin for Maltese obsidian is at variance with that reported by Cann and Renfrew

(1964).

An adequate characterisation of obsidian has been achieved through determination of trace and minor element concentration, OES, as previously mentioned, and more recently, Neutron Activation Analysis (henceforth NAA) being especially effective. The use of X-ray Fluorescence, (henceforth XRF) with either solid or powdered samples, has also provided satisfactory results (Stevenson, et al., 1971).

Obsidian provides an almost ideal material for such a characterisation study: as a volcanic glass which solidified from a molten state the effective homogeneity of trace and minor element concentrations within a single source can generally be demonstrated. In recent years NAA of Borax Lake obsidian by Bowman et al., (1973) displayed in terms of variation of 6 trace-elements relative to iron, shared a wide range of compositional variation. Other research suggests that the Borax Lake compositional picture is not a common one. NAA of 1,000 specimens from 60 well defined lava flows in distinct volcanic regions were reported by Gordus and his associates (Gordus et al., 1968). The variations deduced were from samples 'wholly random from various points on the flow' and based on an estimation of manganese, scandium, lanthanum, rubidium, samarium, barium, and zirconium concentrations showed a range of 40% in a single flow as compared with 100% up to 1,000% between two flows.

The West Mediterranean, Aegean and the Near East have perhaps focused most attention in characterisation studies of Old World obsidian, though in more recent times, the central European sources of north-east Hungary and south-east Slovakia have received due consideration.

The pioneering work of Renfrew and his fellow-workers from the early

sixties onwards, has led to a more thorough understanding of the situation regarding obsidian sources and supply, answering bewildering questions which had previously obscured the issue. In an early paper (Cann and Renfrew, 1964) they reviewed the current situation listing the sources known in Europe and Western Asia and assigning them a numerical classification, based on determination of trace-element concentrations, specifically of barium and zirconium, by OES. Thus, group 1 included sources of Hungary, Slovakia, Melos, Giali, Armenia, South Anatolia; group 2, Sardinia (2a) and South Anatolia (2b); group 3, Armenia; group 4, Lipari and Palmarola (4a), Lake Van (4c), Abyssinia, Arabia, Tibesti, Auvergne and Kenya (4d); group 5 Kenya; and group 6, Sardinia. These early established group divisions have since been modified and refined and in certain cases, though the group members have remained unchanged, the group terminology has been revised.

The progress of research on obsidian will now be discussed relative to the source areas of the Aegean, the West Mediterranean, the Near East and Central Europe (Fig. 1).

As an essential preliminary to their investigations Renfrew and Cann (1964,118) demonstrated internal consistency within sources, using geological specimens from different locations on Lipari and Vulcano and also that the change in trace element concentration, brought about by burial over many hundreds of years, appears insignificant.

### 1:3:a. Aegean

Research in the <u>Aegeen area</u> will now be considered in its group 1 context. Renfrew et al., (1965) conclude that the only two sources deserving

400 800 1200 km CARPATHIAN SOURCES LAKE VAN 57 PONTINE IS. , acigöl Çiftlik BINGOL SARDINIA LIPARI IS. PANTELLER

FIG.1 Sources of obsidian in Europe and the Near East.

consideration in the Aegean are these of Melos (Fig. 2) and Giali (Fig. 3). Antiparos is noted as a source area but is considered unimportant. Appearance of the obsidian is described in detail and when necessary, used to confirm the analytical determinations.

Mackenzie (BSA 111 1896-97,77), late in the 19th Century described the two Melian quarries of Adhamas and Dhemenegaki, trace element analysis by OES did not, however, effect an entirely adequate separation, no differentiation between Adhamas and Dhemenegaki material being suggested by the ba-zr plots and all samples falling with group 1.

The analyses did, however, suggest the wide extent of prehistoric trade in the Aegean, particularly in Melian obsidian, as early as the 6th or 7th millenium B.C. - a fact borne out by more recent analyses (Durrani et al. 1971; Aspinall et al., 1972). Melian obsidian was reaching Knossos on Crete and Nea Nikomedeia in Macedonia in the early neolithic. On the basis of their analyses Renfrew and his colleagues tentatively outline the changing pattern of usage and distribution of Aegean obsidian with time, thus the early neolithic sites in Thessaly and south Greece were fairly well supplied with Melian obsidian, while in Thrace and Macedonia its presence was rare. In the later neolithic they predict an expansion of trade witnessed by finds from Nea Nikomedeia and Servia. Samples of Melian Origin were analysed from the early Chalcolithic site of Morali in Western Anatolia and both Melos and Giali material was in evidence in Aspripetra cave sites on Kos. In the early Bronze Age Melian obsidian was common in the islands of the eastern Aegean (Poliochos, Samos and Lemnos) and at the Minoan sites of Knossos and Phaistos. The pattern of trade throughout the period seems to be restricted to the southern Aegean, with Macedonian sites such as Nea Nikomedeia and Sitagroi representing the northerly limit of Melian distribution (Aspinall et al., 1972, 334).



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Fig. 3 After Torrence & Cherry, priv.comm.

A firm separation was achieved between Melian and Liparian obsidian which solved much confusion regarding the presence of Melian obsidian in the West Mediterranean or Liparian obsidian in the Aegean. Evidence of obsidian indeed suggest little or no contact between the West Mediterranean and Aegean.

Melian obsidian appears to have been utilized in Crete from earliest times. Sir Arthur Evans referred to obsidian uncovered in the early levels at Knossos as 'Liparite', inferring an origin on the island of Lipari, but analyses disprove the theory and suggest Giali as an alternative source, belonging as it does to group 1, and exhibiting a similar appearance to that cited by Evans. At Knossos and Platanos artefacts of transparent glass-like appearance have been found in late neolithic contexts. Renfrew, Cann and Dixon disputed the suggestion of a Giali origin, in the first instance on grounds of appearance (viz. no spherulitic inclusions) and, secondly supporting their assumptions by analyses which placed similar pieces in group 2b. A connection between South Anatolia and Crete was thus suggested rather tentatively (Renfrew et al., 1965,239), the hypothesis gaining credence after analysis by NA4 (Aspinall et al., 1972,334) proved obsidian from the Early Bronze Age settlement mounds of Sitagroi in Northern Greece, to originate from the 2b source. The reciprocity of this traffic in obsidian is inferred from analysis of obsidian samples from Abydos and Myndos in Western Anatolia, which proved attributable to a Melian source, and further implied by the presence also of spherulitic obsidian at Myndos suggestive of a Giali origin (Renfrew et al., 1968).

Late Minoan finds of obsidians in the form of luxury goods rather than purely functional objects, from Aghia Triadha, Palaikastro, Knossos and Kato Zakro are manufactured of blackish spherulitic obsidian, probably from the source on Giali.

The predominance of the Melian source as supplied for the Aegean area

is noted whilst the obsidian of Giali was exploited by the Minoans as an attractive material for their stone vases.

The analyses, though a progressive step, had various shortcomings. Problems were encountered in a division of group 1, and the tentative separation based on strontium, yttrium, niobium, and magnesium concentrations was less than adequate. Sufficient data were available for Melos and South Anatolia, to allow the use of a statistical technique of discriminatory analysis on trace-element results, in order to effect a separation between the two, by further division on the grounds of selected elements in convenient proportions. This rather tenuous division was supported by the implications of appearance and distribution and as predicted all specimens from mainland Greece and the Cyclades were classed as Melian, whilst those from South Anatolia or further east were ascribed to South Anatolian sources.

No full characterisation of Giali obsidian was achieved in the early analyses and a hint that a low calcium content might be diagnostic (Renfrew et al., 1965,235) is completely contradicted in a later article where the high calcium content of Giali obsidian is used to distinguish it from Melian material (Dixon et al., 1968,42).

A different approach, through fission track analysis, was thus attempted in an effort to distinguish between obsidian from several different sources when a convergent trace-element composition was causing confusion (Durrani et al., 1971), as in the case of differentiation of Melos and Giali obsidian from that of the Tokaj region of Hungary and that of Anatolian Acigol, respectively, 1,300 Km. to north-west and 1,000 Km. to the east of Helos.

The determination of the date of eruption of the flows by fission track analysis was attempted using group 1 samples previously analysed by OES (1965 and 1966), so that the established trace-element concentrations could

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serve as a basic guide. In addition three samples from the Mesolithic site of Francthi Cave were chosen for fission track dating. Inherent in the method, however, are certain limits, since in two geographically remote areas eruptions may be of a similar date or indeed successive eruptions might have taken place over a prolonged period of time. Uranium content has thus been used as a further parameter.

The method due to concurrence of eruption dates was none too successful in adequately separating the source members of group 1 obsidians from one another and it would seem that only in exceptionally favourable circumstances can uranium content and eruption date be fully suitable as criteria for source identification.

The eruption ages for two Hungarian samples gave very similar dates, whilst the ages for Aegean and Central Anatolian samples, rather than giving unique dates from each, suggested periods of general volcanic activity in the area. A certain sequence of eruption was observed, samples from Adhamas, Dhemenegaki, Acigol (locality 3) and Giali showing eruption ages between 8 and 9 million years. (Durrani et al., 1971,244), whereas others from Bor and Acigol (locality 3), Giali and Dhemenegaki showed dates of c. 2 million years.

It is, however, suggested that uranium content and age determination effect a clear discrimination between Acigol, Giali and Dhemenegaki.

From fission track analysis of Francthi Cave samples an origin in either Melian source or indeed Giali is predicted, though it is necessary to revert to appearance criteria and geographic location to suggest a Melian source as the more likely. Attribution of Francthi obsidian to a source on Melos is important in evidencing maritime traffic as early as the 8th or 7th millenium B.C. It should be mentioned at this juncture that a discrepancy exists between the date of eruption of the Melian flows as determined by fission track analysis

(Durrani et al., 1971) and that determined more recently by Potassium-Argon dating (Fytikas et al., 1976). The latter technique suggested a date of 1.5 million years for Dhemenegaki and 0.5 million years for Adhemas compared to the fission track determination of c. 8 - 9 million years and c. 2 million years for Adhamas and Dhemenegaki. A further discrepancy exists between the potassium concentrations reported as the results of separate analysis programmes, a value of 2.67% (Fytikas et al., 1976) being compared with one of c. 2.16% reported by Cosgrove and his co-workers (personal communication). The dating problem still awaits resolution.

In 1972 Neutron Activation Analysis was applied to the problematic group 1 (Aspinall et al., 1972). A complete discrimination among sources was achieved using Cs, Ta, Rb, Th, Tb, Ce and Fe, expressed relative to Sc. The function:

$$\frac{1}{Sc} \qquad (Cs + Ta + \frac{Rb}{1CO} + \frac{Th + La + Ce}{1C})$$

was plotted against Fe/Sc on an arbitrary scale (Aspinall et al., 1972, 333). The analyses though small, show adequate separation of all sources and a close correlation between the geological and the archaeological material. The results allowed a novel distinction to be made between the two Melian sources of Adhamas and Dhemenegaki, only 10 Km. apart and analyses of 4 samples from the Mesolithic site of Francthi Cave (c. 7,000 B.C.) could all be attributed to the Adhamas source. The current opinion of an absence of contact between Central Europe and the Aegean, received ratification through the analyses; pieces of obsidian from Neolithic Vinca proving to be of Central European origin.

A study of the geochemistry of Adhemas (Melos "A") and Dhemenegeki obsidians (Melos "D") observed that the uniformity of composition in major element 'within group' variation is such that the coefficient does not exceed  $\mathcal{T}_{2}^{\prime}$  (Cosgrove, private communication). The uniformity is such that small chapters between the groups are of

statistical significance. Cosgrove and his associates effect a discrimination between Melos, Adhamas and Dhemenegaki on the basis of their results. Adhamas obsidians 'have higher silica potash and water content and lower titania, alumina, iron, magnesium, calcium and sodium values', whereas 'variation in opposite directions causes the mean soda/mean potash ratio to rise from 1.08 in the Sta Nychia (Adhamas) group to 1.23 for the Dhemenegaki group. They report, however, discordance between their own Ba/Zr data obtained by XRF and those obtained by OES as described by Renfrew et al., (1965 table 2,246-247), the latter giving higher Ba (790 p.p.m.) and lower Zr (66 p.p.m.) contents, thus a mean Ba/mean Zr content of 12 in contrast with 4.04 for Adhamas and 3.53 for Dhemenegaki as obtained by XRF. This inconsistency in elemental abundance determinations (noticed also between OES and NAA) should not, however, detract from the credibility of source attributions, provided both the geological source and the archaeological site material have been subject to the same method of analysis.

Despite the absence of gross differences between Adhamas and Dhemenegaki obsidians: the between-group variation of such trace and minor element constituents as Ni, Cu, Ga, Sr, Y, Sr and Ba appears significant, and by selecting the abundance of some of these elements a discriminant function is achieved where

$$D = \frac{Ba + Y}{Zr + Ga + Sr}$$

Adhamas obsidian has higher Y and Ba concentrations but lower Ga, Sr and Zr, thus the D value for Adhamas is quoted as 2.27 and that of Dhemenegaki as 1.90.

A further source of obsidian has been provisionally suggested (Cosgrove priv. comm. ) at Mandrakia, though no samples have yet been analysed.

#### 1:3:b. <u>West Mediterranean</u>

Turning to the <u>West Mediterranean</u>, the initial results from analyses by

Cann and Renfrew (1964,111) using OES, served to establish a basis for the later research programmes. These early characterisation studies confirmed that four main sources were utilised in the West Mediterranean, namely Lipari, Sardinia, Pantelleria and Palmarola (Pontine Islands). Sardinian obsidian was, at this stage, divided into two chemically distinct groups (Cann and Renfrew's groups 2a and 6), though due to inadequate representation no adequate separation was achieved between Pontine Islands and Lipari material. Since these early findings the progress of research has been marked : a discrimination between Pontine Island and Lipari obsidian has been effected on the grounds of caesium content (Dixon et al., 1968,42) whilst work undertaken at Bradford University, using NAA as part of an extensive project on Old World obsidian, has done much to refine and extend early conclusions.

Hallam et al., (1976) were not able to check, by NAA techniques, the results obtained by OES, since wide differences in elemental abundance determinations were found to exist between the two methods. Indeed, barium and zirconium, the discriminant pair in OES could not be detected with sufficient accuracy by NAA to permit direct comparison. (Hallam et al., 1976,89). Attribution to source by both NAA and OES does, however, seem to be in agreement.

In NAA of West Mediterranean obsidians the elemental concentrations of lanthanum, scandium and caesium are used as discriminators. By plotting lanthanum/scandium against caesium/scandium the four sources were successfully separated, and in addition a further subdivision of Sardinian obsidian was effected. The suggestion in 1968 (Dixon et al., 42) that caesium content could efficiently discriminate between Lipari and Pontine Islands material was borne out later by OES work, the latter material containing a significant quantity of caesium (Hallam et al., 1976,92). The original numerical classification of 1964 is revised and a new literal terminology established, thus group 2a (Sardinia A) becomes SA; SE is the new subdivision of Sardinian obsidian; group 6 becomes

SC (Sardinia C); group 4a, (Lipari) becomes LI; group 4a<sub>2</sub> (Palmarola) becomes PI and group 4b (Pantelleria) becomes PA.

The Monte Arci region of Sardinia, has over many years been cited in the literature as a source of obsidian (Fig. 4). Puxeddu (1955-57) reported early findings of Sardinian obsidian : Lilliu commented on its occurrence on San Stefano and Maddalena between Corsica and Sardinia; Ferton in 1900 made the far-sighted suggestion that obsidian on Elba was of a Monte Arci origin; whilst Braa (1947,15) supported a Sardinian source for Ligurian material. Puxeddu's research served to confirm the Monte Arci area as the main region containing obsidian quarries and workshops.

Only few geological hand samples from Sardinia were available for NAA by Hallam et al., and in many cases it was necessary to assume archaeological material found close to source areas as representative of that particular source.

On analysis, geological hand samples from a source near Uras in the Monte Arci region grouped within the SA subdivision (Hallam et al., 1976,95), and archaeological material from the same area fell within groups SA and SC. Two obsidian sources east of Uras in the Roja Cannas district have been described (Puxeddu, 1957, 33), and these are therefore suggested as likely sources for SA and SC material. Indeed more recently, geological samples have been collected (by Brian Hallam) in the Monte Arci locality; from Conca Cannas (in situ), Santa Maria Zuarbara and PérdasUrias (Fig. 4). Hallam's survey failed to locate Puxeddu's reported source at Sonnixeddu, and doubts arise as to its existance (Hallam, B.R., personal communication). Analysis has, however, proven Conca Cannas to be the source for SA material and further detailed examination should provide useful information on a more precise location of the SB and SC sources. Basing their assumptions on evidence afforded by archaeological material from Conca Ilionis and by Puxeddu's mention of two outcrops of obsidian to the north of Monte Arci Hallam and his associates postulate this northern area as the likely SB source.



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Guided by the analyses, a distribution pattern for SA, SB and SC is put forward. Outside Sardinia itself, SB obsidian appears to be restricted to Corsica and Liguria, where it occurs at Curacchiaghui (on Southern Corsica) and at Arene Candide. In the early levels at Curacchiaghui obsidian is found in association with impressed ware, and not only provides the earliest dated archaeological context available for the appearance of obsidian in the West Mediterranean, at c. 5,650 and 6,610 bc., but also gives proof of early contact between Sardinia and Corsica. SC obsidian, outside Sardinia, occurs on Corsica, Elba, in Northern Italy (at Servirola a San Polo) and in Southern France (at Marres). SA material appears to be of a wider distribution occurring in Chassey, contexts in Southern France and in Northern Italy, mainly associated with squaremouthed pottery sites, though sometimes with Lagozza.

At least 4 individual flows have been reported on Lipari (Fig. 5) though two, Forgia Vecchia and Rocche Rosse, have been shown by fission track dating to have formed within historic time (Bigazzi and Bonadonna, 1973) and have therefore no relevance as sources from which prehistoric obsidian artefacts were ultimately derived. The sources of importance are those of Gabellotto and Acquacalda, but as yet differentiation between the historic and prehistoric flows by NAA has proved troublesome.

NAA confirmed the early assertions (Cann and Renfrew, 1964) for the importance of Lipari obsidian in Malta after c. 4,000 B.C. Obsidian from the Lipari Islands, indeed, appears to be widely distributed 'in Malta and Sicily through most of Southern Italy, to some extent in Central Italy and then again in Tuscany, Umbria and the Marche area' (Hallam et al., 1976,99). 2 samples from Southern French Chasseen contexts were attributed to a Lipari source using NAA and offered the first evidence of Lipari material in that region.

It was supposed as likely then that the distribution patterns of Liparian and Sardinian obsidian were complementary rather than coincident, with Sardinian material to a large extent monopolizing the trade with Provence, Liguria, Lombardy

Geologic sketch map of the island of Lipari

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and Emilia and Lipari obsidian (and Pontine Islands) being predominantly used throughout the larger part of Italy.

Further analyses on North Italian and Southern French archaeological finds were conducted to clarify the position regarding this northernmost part of the distribution (Williams, 1975, Bradford University M.A. Thesis). For the first time a Lipari origin was proven for obsidian from sites in Northern Italy, appearing at Servirola a San Polio, Arene Candide, Isolino, Fiorano, Chiozza and Razza di Campegino. The evidence for Lipari material in the South of France (as suggested by the two finds from Fonte-Marthe and La Bertaude) was substantiated by material from Grotte de l'eglise superieure. Obsidian from Isolino and Servirola a San Polio in Northern Italy and Beaumajour and Camp Plan in Southern France were analysed and designated SA.

Thus, far from being mutually exclusive, the geographical occurrence of material from the two sources overlaps considerably, presenting a situation far more complex than was first conceived.

Nevertheless, contra Brea and Cavalier (1956,92) who suggested Lipari as a more amenable source for North Italian obsidian when considering maritime travel of a commercial nature, analyses by NAA, when expressed in numerican terms, still favour a predominance of Sardinian obsidian in North Italy as indeed in South France.

Material of a Lipari derivation is generally to be found in association with Middle Neolithic square-mouthed pottery of c. 4,000 - 3,000 B.C. and it has been suggested as reaching North Italy via the painted ware cultures of South Italy and from Italy some may have been transported to the Chasseen contexts in which it appears in South France. Again though, evidence is slight, Italy is suggested as the intermediary via which Sardinian obsidian reached France. In early work (Renfrew and Cann, 1964) obsidian from the natural source Punta Vardella on the island of Palmerola, one of the Pontine Island group, was analysed by QES.

2 blades of glassy obsidian on the nearby island of Ponza, another belonging to the Pontine Island group, were attributed to the 4a source (Renfrew and Cann, 1964,129). Analysis by NAA has proven a Palmarolan origin for glassy obsidian artefacts occurring on Ponza (Hallam, et al., 1976,95), indeed devitrified material cropping naturally on Ponza and neighbouring Procida, is unsuitable for artefact manufacture. Obsidian from these two latter localities proved to be of different trace element composition.

Analyses show a wide distribution of Palmarolan obsidian throughout Central Italy and its occurrence has been noted at sites on the Adriatic coast of Italy and at Vlasca Jamma in Dalmatia. Thus, its presence on the Tremiti Islands (Cornaggia - Castiglioni et al., 1963,310) is likely, though its existence on Arene Candide in Liguria (ibid. 310) awaits confirmation.

The distinctive chemical nature of the peralkaline obsidian of Pantelleria has been borne out by analysis and a high concentration of zirconium (Renfrew and Cann, 1964,119) corresponds to the properties of Pantelleritic obsidians (Carmichael, 1962, Zeis, 1960). Analysis by OES demonstrated Maltese obsidian to be of Pantellerian origin (Cann and Renfrew, 1964,121), it is documented from the earliest neolithic levels on Malta and suggests contact between the two islands from c. 5,000 B.C. Material uncovered on sites on the immediate coast of North Africa has also been suggested as of a Pantellerian type. Until very recently this was thought to represent the total span of distribution of Pantellerian obsidian but two obsidian arrowheads from the Copper Age dolmen of San Sebastien in Southern France, proved on analysis to belong to group Pa.(Williams, O., M.A. Thesis, Bradford 1975) though belonging to a later and separate distribution phase.

It should be noted that there is as yet no evidence for the occupation of Sardinia in the Middle Meolithic (when finds were reaching Morth Italy) nor for the prehistoric occupation of Pantelleria. (Fig. 6).





FIG. 7 SKETCH MAP OF THE C<sup>L</sup> ANATOLIAN OBSIDIAN SOURCE AREA (AFTER DIXON, 1976)



Anomalous samples from Southern France, Southern Germany and North Italy, have not fallen into any currently established group divisions and the existence of, albeit minor sources not previously recognised, cannot be ruled out.

Obsidian in the West Mediterranean did not form a major part of the stone industry but as an indicator of the extent of prehistoric contact by land and sea it assumes a position of some importance.

#### 1:3:c. Near East

The situation in the <u>Near East</u> is very different, with 'obsidian reported from nearly every neolithic settlement, although many of these sites are distant from the natural sources' (Renfrew et al., 1966,30). Indeed Wright comments (1969,5) that 'in terms of the amount of integrated work on both source and site specimens there are more data currently available on the percentages of different chemical elements present in Near Eastern obsidian than for obsidians from any other area'.

Early analysis by OES (Cann and Renfrew, 1964) laid emphasis on the complexity of the situation in the Near East, for example the site of Arpachiyah in Northern Iraq was utilising 3 different obsidian sources: Lake Van (4c), Eastern Armenia (3) and a group 1 source. At this stage difficulties became evident when attempting a separation between obsidians from Armenia, South Anatolia and Kenya, also between those of Lake Van (4c) and Abyssinia, Arabia and Tibesti (4d) due to inadequate representation.

Research on Near Eastern obsidian shortly identified the two geographical foci of the major groups as Central Anatolia and Lake Van, more specifically defined by Renfrew et al., as the district west of Kayseri in Southern Anatolia, formerly Cappadocia and that of Eastern Anatolia with Armenia from Lake Van to Erevan.

In 1965 (Renfrew et al.) findings based on analysis of a geological hand
sample collected by Professor H.E. Wright from Acigol proved this to be the principal group 1 source in South Anatolia.

Cann and Renfrew state that no sources are believed to exist between Anatolia and Arabia, west of the Zagros range (1964,122), and indeed Wright (1969,5) holds the same opinion. Spectrographic analysis of samples from PPNA levels at Jericho proved attributable to group 2b, along with specimens from Neolithic Mersin and from surface scatter at Bor and Gazi in the Kayeri region of South Anatolia. The Kayseri region, more specifically Hasan Dag, was tentatively suggested as the source for 2b obsidian (Renfrew et al., 1965,237).

In 1966 (Renfrew et al.) an attempt was made to class the analyses of Near East specimens in their respective groups ; to establish new groups and to define more precisely the old groups. They defined two element groups with sources in Central Anatolia - 1e - f and 2b.

The Near Eastern sub-divisions of group 1 are distinguished by high barium and low to moderate zirconium content. 3 sub-groups are identified within the group - 1h with low zirconium, lanthanum and rubidium; 1g with high zirconium and 1e - f with a zirconium content between the two extremes. Karakapu, south of Hasan Dag is the source for 1h material, the source is, however, of little importance and as yet no artefacts of 1h obsidian have been discovered. Group 1g will be discussed in its proper context with the additional Lake Van sources.

Although the geographical separation between Kars in Armenia, (theoretically group 1f) and Acigol in Cappadocia, (theoretically group 1e) is considerable, trace element analysis by OES could not effect any distinction between the two. For this reason Renfrew and his fellow-workers classed them together as group1e-f.

The Acigol-Topada source (Fig. 7) islocated 8 Km. east of Acigol Topada, 11 Km. south-west of Nevsehir on the Aksaray road. Todd's survey of the area reported

several sources in the Acigöl region, the most important area being the northern face of Hotamis Dag, but a thorough survey of the whole mountain was felt necessary.

On analysis of geological hand samples collected by Mr. A. Renfrew, the source for group 2b material was precisely identified for the first time as Ciftlik, near Meleniz Dag (Renfrew et al., 1966,33). Todd's field survey in the Ciftlik locality resulted in the discovery of 2 sizeable sources on the mountain of Gollu Dag, east of Ciftlik, but again the need for more detailed survey of the whole mountain was recognised. Nevertheless the importance of Ciftlik and Acigöl as source areas of Central Anatolia had gained confirmation.

Gordus et al., (1967) report that analysis of sodium and manganese, by NAA provided useful data for preliminary identification of geological sources, since their contents may differ respectively by a factor of two or more and by a factor of 10 or more. The Na and Mn content for a specific geological source exhibit a range probably not greater than 1.35. Gordus and his associates have refined and adapted the system so that an accuracy of 5% can be achieved and as many as 10,000 samples run per year. For final identification, five additional elements, namely lanthanum, iron, rubidium, scandium and samarium have been successfully employed.

Wright (1969) makes use of combinations of the above listed elemental concentrations to effect a separation between the geological sources of the Near East. 7 localities were investigated, in the Aksaray - Nevsehir - Nigde region of Central Turkey. Localities 1 - 5 are east of Acigöl, locality 6 crops out on the eastern slope of Kokuyu ridge (part of the Gollu Dag mass), 30 Km. south of Acigöl and the 7th locality is that of Ciftlik (Fig. 7). Wright reports results from localities 2,3,5,6 and Ciftlik.

The Acigoi-Topada source (group 1e - f) as defined by Renfrew et al., (1966)

is synonymous with localities 2 and 3 as identified by Wright (1969,6), whilst Ciftlik is their group 2b. Adequate separation of the localities was achieved using scandium, manganese and rubidium concentrations as identification criteria. No significant difference was noticed between localities 2 and 3, only a few kilometres apart, but together they shared a significantly lower scandium content than other flows and a lower manganese content than samples from locality 5 and Ciftlik. The 6 million year age difference established between 2 samples from Acigol locality 3 by fission track analysis (Durrani et al., 1971) has already been noted and suggests that this locality is not a single source. Locality 5 showed a higher rubidium and manganese content than the remaining 6 localities.

Wright, Gordus and their fellow-workers carried out NAA of samples of Near Eastern obsidian previously analysed by OES. In general the results from the two methods have proved to be in harmony, though re-analysis of several samples placed in groups 2b and 1 e-f by Renfrew et al., have shown an interesting outcome.

Wright expressed doubt that only 2 sources were exploited in Central Anatolia, indeed Benedict's survey in the Nevehir-Aksaray-Nigde region, located 5 exposures previously unreported (Wright et al., in press). On reconsideration of the data obtained by Renfrew et al., Wright draws attention to the wide variation of barium and zirconium content as exhibited by samples contained within their group 2b, and considers it likely that material from more than one element group is included. Repeat analysis were conducted serving to strengthen the credibility of Wright's hypothesis: a sample from Trebizond (of Renfrew et al., group 2b), displayed a lower manganese and a higher sodium/manganese content than 4 of Wright's geological hand samples from Ciftlik. The average strontium content of 7 Ciftlik geological samples was 13 p.p.m. whereas that of the

Trebizond specimen was 63 p.p.m. and for a second specimen 120 p.p.m. (Wright, 1969,19)

Analyses were conducted on samples from 4 sites in Central Anatolia: Catal Huyuk West, Catal Huyuk (Neolithic), Cukurkent and Hacilar II. Renfrew et al., placed samples from Neolithic Catal Huyuk, Hacilar and Cukurkent into their group 1 e - f (Renfrew et al., 1966,33 and table 1,62). NAA, however. presented results incompatible with these earlier group allocations. Na/Mn ratios for Catal Huyuk West samples fell in 1 e - f range, but those for Catal Huyuk, Hacilar and Cukurkent were closer to group 2b. Although the Na/Mn ratio for Catal Huyuk samples suggested a 2b origin, a lower scandium content than Ciftlik samples and a higher Sc/Ta ratio than either Ciftlik or Acigol, again suggested the likelihood of a separate group. The analyses of Renfrew et al, (1968) and Wright (1969) and subsequent survey in the field makes clear then the existence of several sources in both the Ciftlik and Acigol regions. The resolution of the 'fine structure' of the Acigöl-Ciftlik region is fraught with complications which will perhaps remain until information comes to the fore relating the obsidian localities to eruptive centres and correlating them stratigraphically.

A distribution pattern of Central Anatolian obsidian nevertheless emerges from the data. Material from group 1e, notionally Acigöl, has been identified at early Neolithic Mersin and as far south as Byblos, later exploitation of this source is evidenced by finds from Bogazkoy and Kultepe. Analysis by Wright of a sample from Munhata also places this in group 1 e - f (Wrights Central Anatolia Locality 3). Attribution of a vase from Tepe Gawra of the late 4th millenium B.C., to group 1 e - f provides an instance of Cappadocian material appearing east of the Syrian desert, whilst another group 1 e - f find from Bahrain (c. 2,000 B.C.) on the Persian Gulf, nearly 2,000 Km. south east of the Cappadocian source area

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represents to date the southernmost extent of Anatolian obsidian (Renfrew et al., 1968).

Group 2b obsidian makes its early appearance in Aurignacian levels at Oklizini and Karain, near Antalya (before 8,000 B.C.). Upper Palaeolithic material from Curkini is attributed a 2b source, though neolithic material from the same site falls within the 1 e - f group (Dixon, 1976). 2b obsidian has also been recognised at Mersin, as with 1 e - f in an early neolithic context. The distribution and density of archaeological finds of 2b obsidian in Cyro-Silicia and the Levant suggest it as the all important source for that region during pre-pottery Neolithic A and B. The exclusive use of 2b obsidian at PPNA Jericho has already been mentioned. During PPNB times 2b is present at Jericho (though no longer the sole group present) and Beidha (Renfrew et al., 1966) in the first and second phases at Ghoraife and Tell Aswad and throughout the occupation of Aby Hureyra (Warren, S.E., personal communication), and in aceramic levels at Tabbat al-Hamman and Tell-al-Judiadah, Tell Ramad, Ras Shamra and Beisamoun (Renfrew et al., 1966 and Wright and Gordus, 1969). The importation of Lake Van obsidian to the area by c. 6,500 B.C. is documented by the presence of obsidian at Beidha, Tell Ramad and Beisamoun and later, c. 4,000 B.C. 2b 4c material is found in association with 1g and 4c at Munhata and Hazorea (Wright, 1969.26). A first instance of its occurrance east of the Syrian desert is documented by a find from Tepe Sabz (Renfrew and Dixon, 1976,144).

It seems convenient at this juncture to include archaeological material from Cyprus in the discussion. Obsidian formed only a very minor part of the lithic assemblage at pre-pottery neolithic Khirokitia, a reported 6 pieces out of a total of 1,051, 4 of these pieces were analysed (Renfrew et al., 1968,325) and a 2b origin proposed. A radiocarbon date of 5,690 B.C. exists for aceramic Khirokitia, and analyses suggest maritime trade with Cyprus at this time. This general conclusion has been confirmed by results of samples from aceramic

Dhali-Agridhi, 12 miles south of Nicosia, submitted to the Bradford laboratories for analysis by NAA (Warren, S.E., personal communication). These again fell within the range of variability of the 2b source material. The aceramic deposits at Dhali Agridhi have a radiocarbon date of  $5,340 \stackrel{+}{-} 465$  B.C., thus demonstrating their contemporary nature with aceramic Khirokitia.

The eastern Anatolian sources, located with the boundaries of present-day Turkey (principally in the Kars and Van Vilayets) in the Azerbaijan province of Iran and in the Armenian Soviet Socialist Republic of the U.S.S.R., were formerly designated by the term 'Armenian' (Renfrew et al., 1966 and 1968), however, for political reasons the terminology has been altered and the region is now designated by Renfrew and Cann (1975), the Van-Azerbaijan-Armenian S.S.R. region, abbreviated to V.A.A. The shortened form will be employed here.

Groups 1e - f, 1g, 3 and 4c, as defined in the original numerical classification based on barium and zirconium contents determined by OES, have their sources in the VAA region (Cann and Renfrew, 1964). Together with Cappadocian obsidian groups, the VAA groups are listed in numerical order by Renfrew and his colleagues with reference to their characteristic trace and minor element concentrations (Renfrew et al., 1966, 33-35).

Wright and Gordus effect a preliminary separation between VAA and Central Anatolian obsidians on the basis of sodium and manganese content. All central Anatolian source specimens have less than 3.5% sodium, whilst Lake Van source specimens have more than 3.95% sodium (Wright and Gordus, 1969,75). Within this somewhat crude division a more refined structure isestablished and separation of groups is purported, based on sodium and manganese contents and ratios and on samarium and lanthanum content where necessary.

Obsidian studies in the VAA region are still in their infancy. Dixon defines a four-stage heirarchical progression to illustrate the ultimate aim in a characterisation study (stage 4) and the stages through which the research

must advance on the road to this goal (Dixon, 1976,289). The VAA region is yet at Dixon's stage 1, the source location or source confirmation stage, establishing the link between analytical groups and major sources, or merely attesting the presence of sources. Indeed only two exploited sources have been located with any degree of precision and certainty : the peralkaline sources of Nemrut Dag on the west side of Lake Wan and the source c. 50 Km. east of Bingol, 100 Km. west of Lake Van.

Renfrew et al., (1968) effected no discrimination between Bingol and Nemrut Dağ obsidian (only noting the presence of caesium in the former) and placed both in their group 4c, Wright, however, was able to show disparity in the manganese contents of the two (1969,15) and Aspinall and Pearson, using NAA were able to define more precisely the caesium content, that of Bingol being approximately twice that of Nemrut Dağ material. A Cayonu specimen (Wright, 1969,22) was the first to be attributed to the Bingol source, appearing with 1g and 4c material, but the unpublished work of Jill McDaniels (M.A. dissertation, University of Bradford, 1976) using NAA documents its presence in small quantities throughout the neolithic occupation of Tell Abu Hureyra in Syria. This is the first indication of exploitation of Bingol obsidian from sites outside Anatolia. McDaniels designates obsidian from the Bingol source G 2, and variations in elemental concentrations observed within this group suggest the presence of sub-groups as likely.

NAA distinguishes at least two separate flows within the Nemrut Dag source on the basis of the elemental concentrations of scandium, manganese, iron and zirconium (Wright, 1969,16). Wright terms these Nemrut Dag A and B and suggests that visual re-examination of the Nemrut Dag analytical results as presented by Renfrew et al., supports this division. Nemrut Dag B (with higher average zirconium content), is equated with site material analysed by OES and attributed a 4c source.

NAA conducted at Bradford University using the method of Aspinall et al., (1972), defined groups of green peralkaline obsidian (G1 and G3) at Tell Abu Hureyra (McDanels, 1975). G1 has been equated with Renfrew's Nemrut Dag 4c source. G3 is represented by two specimens in the ceramic neolithic levels; and although no comparison with geological material was possible, it is perhaps to be equated with the alternate Nemrut Dag source, and if so would represent its first appearance on an archaeological site.

Sources imprecisely located include the 1f group. 2 1f sources are documented in the Kars and Erivan regions and Dixon suggest (1976) the volcano Atis or the obsidian source at Gutansar as the likely source for the Erivan Armenian obsidian. The need for back-up analyses is obvious.

The need for modification and revision of the 1966 group 3 subdivisions was realised and a view division outlined by Renfrew and Dixon (1976). It was noted in 1966 that the group 3 analyses were not so closely convergent as those of other groups, the implications being that one is dealing with a multisource, rather than a unique source group. Renfrew and Dixon ze-examined the concentration of 15 elements, eventually identifying 4 subordinate groups on the basis of zirconium, yttrium, lithium and rubidium contents. The homogeneity of 3a and 3c analytical results lends support to the idea of a single source for both sub-groups. Within this structure further tentative and purely hypothetical divisions of 3a and 3c are outlined on the basis of high iron and manganese contents. For reference it can be noted that groups 3a and 3b plus sub-groups, and group 3c are analogous respectively with 3a and 3c groupings of the 1966 division (Renfrew et al., 1966).

Renfrew et al., (1966), on the basis of their analysis of a geological hand sample from Bayezid, suggested this as the locality of their 1966 3a group. The 1966 3a group is now equated with 3a and 3b and reappraisal of their own work and that of Gary Wright (1969) supports the non-equivalence of Bayezid

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with their new 3a group and suggests its reallocation to the 1976 group 3b.

Both Renfrew and co-workers (1968) and Wright (1969) document the occurrence of 3a obsidian in the earliest levels (c. 5,000 B.C.) at Tilki Tepe on the eastern shores of Lake Van and suggest some correlation with the early exploitation of group 3a. The source or sources of 3a obsidian, whose products though occurring mainly in the Urmia region, extend also south to Khuzistan. Susa and Tepe Sabz and Tal-i-Bakun and west to Tilki Tepe and Arpachiyah, perhaps lie, like Bayezid, to the north or north-east of Lake Van (Renfrew and Dixon, 1976). The more limited distribution of 3c obsidian almost exclusively in the Urmia region and Solduz valley, perhaps suggests a source 'more accessible from the Urmia area than from Lake Van and probably closer to Shahpur than Tilki Tepe' (Renfrew and Dixon, 1976,147). 3d obsidian is documented by finds from Ras Shamra, Ubaid and Dahran on the Persian Gulf, and the recognition of 3a together with 1g and 4c at Dahran suggests the exclusive use of VAA obsidian in the Persian Gulf.

A shift in source emphasis in the VAA area is implied by the distribution pattern throughout the neolithic period. 4c and 1g from c. 7,500 to 5,000 B.C. occur at many sites along the Zagros range, from c. 5,500 B.C. group 3 makes its appearance, replacing 1g in the Zagros, and group 1g shifts westward to the Levant. The enigmatic group 1g is suggested as having its origin in the Lake Van region, partly due to its similiarity of distribution to 4c obsidian and also on account of the absence of Çiftlik material in Mesopotamia or Iran.

Dixon mentions a geological approach to the problem by the application of plate tectonic principles (Dixon, 1976,304ff.). The tectonic activity of the VAA area is the result of complex dynamic interaction of large and small plates, this process is continually changing so that the chemical character of any associated vulcanism, at any one centre through time and indeed at any one time at different centres, might be expected to change. Since in tectonically active

regions along major faults vulcanism produces vast quantities of obsidian (Taylor, 1976), a study of plate tectonics could provide useful general limits to the area of search for missing obsidian sources, but introduces no real constraints on composition.

Suitable artefact material occurs in the Agh Kand to Keyah Dag area of Iran and in the volcanoes of Artenis, Aris and Gutansar in the Armenian S.S.R. Tentative suggestions that these may represent respectively the sources of 3c and 3a archaeological material await analytical confirmation (Dixon, 1976). The occurrence of geological obsidian at Suphan Dag was documented by Altinli (Altinli, 1964,67). NAA of a poor quality specimen from this 'source' (Mahdavi and Bovington, 1972), compared with Wright's 1a analyses leads Dixon to postulate Suphan Dag as the missing 1g source (Dixon, 1976, Fig,15, '). The results of OES<sup>1</sup> on a good quality Suphan Dag geological sample are awaited with interest. (Dixon, 1976, 309f.)

# 1:3:d. Central Europe

The present state of knowledge as regards obsidian in <u>Central Europe</u> (Fig. 8) seems retarded when a comparison is drawn with the vast bank of information obtained from an impressive array of analytical techniques available for the West Mediterranean, Aegean and Near Eastern regions. The brevity of this section is commensurate.

Cann, Renfrew and Dixon in their early reports (1964, 1965, 1968) present in tabular form results of spectroscopic analyses from Slovakian and Hungarian source material and from Hungarian, Yugoslavian and Rumanian site material. Geological hand samples from Tolcsva and Mad in the Tokay region of Hungary fell in group 1a, whilst those from Hlinik in Slovakia formed a group 1b. Archaeological samples from Vinca in Yugoslavia, Borsod, Herpaly and Derekegyhaza in Hungary and Lumea Noua in Rumania compared with Hungarian source specimens (1a). No samples

1. Dixon states that a phenocryst free sample from Suphan Dag is now to hand and analysis for Ba and Zr is intended in the near future.



from Rumania were subject to analysis, though the existence of a Rumanian source centred on Mt. Hargitta was noted (Renfrew et al., 1965,113).

Fission track analysis and NAA conducted on Carpathian material have been considered in context with other group 1 material (Aspinall et al., 1972: Durrani et al., 1971).

An examination of the literature and history of research on obsidian in South-East Europe leads Nandris to discount Rumanian and Transylvanian 'sources' and to conclude that much confusion in the literature arose from the visual similarity of, for example, opalites with obsidian.

The 'sources' of Central Europe do not generally (Tokaj and perhaps Viničky are exceptions) occur as primaryobsidian flows but as geologically redeposited material in the form of volcanic ejecta or weathered out matrix of less glassy rhyolitic lava flows (Williams and Nandris, 1977). This gives rise to problems in location of sources and in differentiating between archaeological site deposits and geological source deposits.

Fieldwork in 1974 and 1975 concentrated on the Zemplen mountains in the Tokay-Zemplen region of north-east Hungary. These short but intensive field surveys located sources at Erdöbenye, Csepegö Forras, Telkibanya and Tokaj, the latter two, probably of unworkable obsidian and so of less relevance (Nandris, 1975, Williams and Nandris, 1977).

The much quoted source at Tolscva in Hungary has been investigated by Dr. D. Backsay of the Hungarian Geological Survey, Budapest, and 3 obsidian localities reported, whilst the occurrence of a primary source of glassy obsidian at Viničky (Szolloska) in south-east Slovakia is reported by Dr. Rozloznik of Kosice University. Further 'sources' in eastern Slovakia are suggested at Býsta, Streda nad Bodrogam, Mala Toroňa and Cejkov and in the U.S.S.R. in the Gertsovtse-Fedelshovtse region (Williams and Nandris, 1977).

Samples from Csepegö Forrás, Telkibanya, Erdöbénye, Tolscva, Malá Toroňa, Streda nad Bodrogam and Viničky have all been subject to analysis by NAA at Bradford University.

In a paper presented at the International Symposium on Archaeometry and Archaeological Prospection research conducted at Bradford University in collaboration with Dr. Nandris of the London Institute of Archaeology is described (University of Pennsylvania Conference, March 1977, Warren, Williams and Nandris). Carpathian archaeological obsidian from 66 sites in Hungary, Czechoslovakia, Rumania, Austria, Yugoslavia and the north-east Adriatic coast of Italy, has been analysed by NAA. The analytical results suggested a division into two groups, supported by appearance criteria, called Carpathian 1 and 2. The majority group Carpathian 1, comprised of black or grey transparent obsidian and the minority Carpathian 2 group of black opaque samples. Geological hand samples from the south-east Slovakian and north-east Hungarian Zemplen mountains sources were analysed and equated respectively with Carpathian 1 and 2.

NAA has identified Liparian and Carpathian 1 material, together at the cave site of Grotta Tartaruga this evidence, together with previous determinations of a Lipari origin for obsidian from North Italy and other Italian cave sites on the Adriatic coast, and a Pontine Islands origin for a single piece from Vlaeca Jana, Warren et al., postulate that the north-east Adriatic coast might represent the north eastward extent of West Mediterranean obsidian and the westward extent of Carpathian material.

On the basis of analytical results the geographical and chronological overlap of Carpathian 1 and 2 obsidian is evident; both are used from Upper Palaeolithic through Neolithic times and Carpathian 1 appears even into the Bronze Age.

Further research on Central European obsidian is also being undertaken in the States, using XRF and OES techniques (Rasson et al., University of Pennsylvania

Conference, March 1977). Archaeological obsidian artefacts from Obre, Vinca and Potporanj were examined and the K alpha spectra of rubidium, zirconium, niobium, yttrium and strontium determined by a modified rapid scan XRF method. Barium content was determined by OES. Computer classification of the results by stepwise discriminant analysis was used to effect a final discrimination. Rasson et al., suggest that Bosnia (Western Yugoslavia) was importing obsidian exclusively from the west and the Danubian area to the east was receiving obsidian from West Mediterranean sources as well as from the Carpathians. They place some of their material in Renfrew's 'old' Sardinian group 2a, and view this as evidence of an eastward extension of the limits of Sardinian obsidian, stretching over 800 Km. from its source area well into Yugoslavia. The hypothesis seeks confirmation.

The distribution pattern of Central European obsidian, on the basis of current information, appears to stretch eastwards to the Black Sea and finds are documented from North and Central Poland, Austria, Southern Yugoslavia and Greek Macedonia (Warren et al., 1977).

The unpublished work of Olwen Williams on NAA of Central European obsidian (Ph.D. thesis in preparation. Bradford University) will be of much interest.

## 1:4 Quantitative Statistical Analyses

The study of prehistoric exchange systems and trade mechanisms in the West Mediterranean, Aegean and Near East has been approached by quantitative statistical analyses.

A common type of quantitative information is the percentage of obsidian from a known source at a number of archaeological sites. In its simplest form this can involve the use of two variables; the percentage of obsidien on a site and the distance of the site from the source. Regression analysis has been employed as a means of examination of the relationships between the variables -

establishing that one variable changes in a predictable manner as the other changes. A third variable (e.g. 'attractiveness' of obsidian) may also be related to changes in the first variable with the second.

For a detailed discussion of such models reference should be made to the work of Renfrew and Wright (Renfrew, 1969, 1970, 1972; Wright, 1969; Hallam et al., 1976; Renfrew and Dixon, 1976).

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### CHAPTER 2.

Practicable Physical Techniques of Obsidian Analysis.

### 2:1 Macroscopic and Microscopic Examination

'In the past identification of unique products has sometimes been made on the basis of simple inspection. Lapis Lazuli, Polish banded flint, Grand Pressigny flint and Olonetz slate are examples of raw materials which can very probably be assigned to a limited source area on the grounds of visual inspection along'. (Renfrew, 1969, 151). Unfortunately, as already mentioned (Chapter 1. p.567) source attribution based wholly on the examination of visual characteristics is not, as a rule, possible. To quote yet another instance:a single piece of obsidian from Sardinia was coloured red and black with a sharp dividing line between the two, yet chemical analysis proved it to be indistinguishable from other Sardinian samples! The pearly lustre of Melian obsidian and the distinctive greenish colour of peralkaline Pantellerian obsidian have been consistently quoted as distinguishing features of these two well-known island sources, yet rather than serving assunique source indicator, these attributes have been used in corroboration of tried and tested chemical analyses.

Griffin et al. (1969,2) noted variations in the colour of obsidian within a single flow and also found both translucent and opaque obsidian in fairly close association within one flow. Macroscopic characteristics can thus only be of superficial use. In the early stages of obsidian research microscopic examination was seen as a possible avenue of extension, supplementing the evidence from direct visual inspection.

Tariations in the petrographic pattern of similar rock types (as seen in the minerals present, their phape, size, rolative properties and textural relations to each other) are known to exist and through the examination of

the mineralogical pattern and composition of thin sections of specimens and their comparison with rocks of known provenance it is, in cases, possible to match the section with its parent source.

Of prime consideration in petrological examination is the damage done to an artefact in preparation of a thin section. The technique is essentially destructive in its nature, involving the removal of a thin slice from the object by two parallel cuts of a diamond wheel, leaving a gap c. 1mm. in depth and 2cm<sup>2</sup> in area (which can later be filled with plaster). After removal the section is ground to a smooth surface with successively finer grades of silicon carbide papers and this polished surface attached to a glass slide by way of a suitable transparent adhesive (i.e. Canada Balsem or Lakeside). The section is further abraded until c. 0.03mm. in thickness and a corer glass cemerted on the slide which may now be examined under a polerizing microscope.

The first recorded use of petrology for concluding that an object has been imported from some considerable distance comes from William Dugdale's Antiquities of Warwickshire, published in 1656, it is not, however, until the late 19th and early 20th century that the method becomes of more common usage.

A classic application of petrological examination is Thomas's (1923) study of the 'bluestones' at Stonehenge and his conclusion that the spotted dolerite matched that from Carn Meini in the Prescelly mountains, some 150 miles away. (It should be noted that in a recent article, Kellaway, 1971, the presence of spotted dolerite in Wiltshire is concluded to be the result of glacial erratics).

The pioneering work, stretching over some 25 years, on British Meolithic and Early Bronze Age stone axes stands out as a successful application of thin section work. Over 20 petrological categories have been defined and in some cases axes from known factory sites or from particular categories have been successfully matched with their parent source. Shotton, however, mentions the failure of petrological work to generate the fliats of Yorkshire from those of

Lincolnshire, Suffolk, Kent, Sussex or Antrim (1969,572). With obsidian, as with flint, petrological examination has proved unrewarding as a guide to provenance.

The interpretation of thin sections of obsidian (and flint) is hampered by the very nature of the mineral. Obsidian's isotropic and amorphous character generally precludes the identification of any distinctive microcharacteristics which might give to obsidian from individual sources a uniqueness hitherto recognizeable.

The usefulness of examination of obsidian under the polarizing microscope appears limited to effecting the broad division between alkaline, calcalkaline and peralkaline types by way of inspection of phenocrysts or embryonic crystals (and indeed the better quality the obsidian the fewer the phenocrysts) or again in corroboration of chemical analyses.

Petrological methods were used in a study of Mexican obsidian as early as 1892 (Ordonez, 1892), a more recent instance where petrographic work has been brought to bear on obsidian characterisation is in a study of material from the prehistoric site of Melka Konture in Ethiopia. (Muir and Hivenel, 1976). Thin sections of material from the site were examined and compared with those from the nearby obsidian quarry at Baltchit. Baltchit obsidian contained less than 1% of crystalline material, nearly all in the form of microlites of anorthoclase, and whereas specimens from the site itself reveal a somewhat more advanced stage of devitrification and bydration, in every other respect, source and site material are virtually identical in petrographic character. Wet chemical analysis and trace element analysis confirmed the likelihood of a Baltchit origin.

As with appearance criteria, petrological characteristics serve only to give evidence of a confirmatory nature.

#### 2:2 Refractive Index and Density Determination.

Muir (1967) quotes refractive index as the most diagnostic of all the optical properties of a substance. Determination of the principal refractive indices, under a polarizing microscope, are generally achieved using variations of the immersion technique and depend on the fact that when refractive indices of crystal and immersion medium approach, the contrast between the two is reduced. In monochromatic light a liquid may be found where the refractive indices of mineral and liquid match exactly, at this point the margins of the mineral fragment become invisible. The procedure, in simple form is, to place mineral fragments into a liquid of approximately the same refractive index and to achieve a match by addition of drops of a liquid of higher or lower refractive indices, the refractive index of the liquid then being determined with a refractometer. The refractive indices of liquids decrease with rising temperature to a greater extent than solids and, especially in the high index range, dispersion of liquids is generally greater than solids. These properties have been utilised in accomplishing the metching of refractive indices of immersion media and mineral by way of wavelength or temperature variation methods. An integral part of the equipment is a set of liquids of known refractive index from c. 1.44 -1.78 in intervals of .01, though where smaller intervals are useful (i.e. .002 or better) over selected ranges then this may be achieved by mixing.

Refractive indices have been used as a tentative guide to provenance. Campbell Smith (1963) used this property to aid differentiation between jadeite and nephrite, the former having a higher refractive index than the latter. He concluded that the majority of British Neolithic 'jade' axes were of jadeite and since this mineral is not indigeneous to Britain, an origin in Europe, perhaps Brittany has been suggested but not confirmed. Formaseri and his colleagues (Formaseri et al., 1975) determined the refractive indices for

pumices found along the north coast of Cyprus, as an aid to establishing provenance. The samples were grouped in intervals of .002 of refractive index and the overall variation, from 1.4956 - 1.5099 showed a clear bimodal distribution, with one group having a maximum in the range 1.498 - 1.500 and the other group ranging from 1.504 - 1.510 (Fornaseri, 1975,112). On the basis of this initial division, chemical analyses were performed on each group of pumices. One group proved to be of rhyolitic composition and the other of dacitic composition, each in agreement with the refractive index determinations. On grounds of refractive index, in conjunction with heavy mineral content and chemical composition, the pumice groups have been compared with material from sources on Melos, Giali, Kos and Santorini and the two latter sources, Kos and Santorini, singled out as the two probable source localities,

The refractive indices of obsidian are quoted by Read and Watson (1968, 388) as between 1.48 - 1.61, tending to increase with decreasing silica content or with an increase in the number of crystalites and microlites present, whilst Cann, Dixon and Renfrew (1969, 580) give figures as between 1.49 and 1.52. The similarity between the refractive indices of obsidian and those of pumice is evident.

The use of refractive indices as an aid to identification of obsidian sources has been applied with some success. The early research efforts of Frankfort (1927) and Wainwright (1927) have been mentioned previously (Chap. 1). Georgiades (1956) reports refractive index measurements for Aegean source. material, giving one measurement of 1.500 from Giali and ranges of 1.444 -1.500 and 1.480 - 1.500 from Antiparos and Melos respectively. Mayor Island obsidian (New Zealand) is typically of a distinctive peralkaline greenish type (though brown and honey coloured varieties do occur and some peralkaline material is clear) and dreen (1952) reports an equally distinctive range of

refractive indices from 1.4970 - 1.5070 for this material. Ranges for Maraetai and Taupo are less distinct, showing respective ranges of 1.4866 -1.4940 and 1.4867 - 1.4894. Samples from Arid Islands (Rakitu) east of Great Barrier Island, showed refractive indices of 1.4857 - 1.4873 and as such could fit in with a Taupo or Maraetai origin, chemical analyses were necessary to confirm the identify of the samples with Taupo source material ( In Taylor, R.E., 1976). Cann and Renfrew (1964) on determining refractive indices of c. 55 samples from in and around the Mediterranean, concluded that a difference could be seen between the broad peralkaline and calc-alkaline groups but felt that in general, appearance was more diagnostic of provenance.

Green (1962) suggested that refractive index measurements might initially serve as a check on differences observed by macro or microscopic examination of a sample and thus if a correlation could be established between refractive index and certain more easily observeable diagnostic appearance features, then the more lengthy and laborious task of determining refractive indices could be abandoned and characterisation could be based on these features alone (1962,13). The author notes 'a fair success' in this direction between geological provinces but less succe is within a province.

As can be seen with measurements here quoted, a considerable overlap in values often exists between sources, naturally resulting in ambiguity of source attribution. The fact that refractive indices increase with increasing devitrification (Read and Watson, 1968, 388) provides a further obstacle, in necessitating the avoidance of material in different stages of devitrification.

Refractive index measurements provide useful information only in the form of a preliminary inspection, though in exceptional cases, as with peralkaline obsidians, a high refractive intex, together with appearance characteristics may be sufficiently dia mostic to subject provenance. The inadequacy of a Pantelleria - non-Pantelleria or Mayor Island - non-Payor Island discrimination

is, however, readily apparent.

'Density is a fundamental and characteristic property of a crystalline substance or solid and as such is an important determinative property' (Muller, 1967, 459). Though often assumed to be synonymous a distinction does exist between specific gravity (henceforth S.G.) and density. S.G., an abstract number having the same value in all unit systems, is defined as the ratio of the mass of a substance to that of an equal volume of a liquid (generally water taken to be 0.988 i.e. 1) at a specific temperature (i.e.  $60^{\circ}$ F) and pressure. Density is defined as the ratio of the mass of any quantity of a substance to its wolume, when expressed in C.G.S. units this becomes the mass in grams of 1 cubic centimetre of the substance, and as that volume of water at  $60^{\circ}$ F weighs one gram, density is then numerically equivalent to S.C.

In determining the density of rocks, where relatively large samples are available, any simple method of measurement may yield acceptable results. Many techniques in use necessitate the immersion of a solid in a liquid, wherein the possible adherence of small air bubbles to the surface of the solid creates a major source of possible error. Measurements on obsidian may be further disturbed by inclusions within the material in the form of gas bubbles or vesicles. As a general guide Semenov quotes the S.G. of obsidian as between 2.35 and 2.5 (1964,34)

Despite problems inherent in physical property analysis attempts have been made to use density determination as a non-destructive means of obsidian characterisation. Cann and Renfrew (1964), on the basis of their work, concluded density not to be an adequate discriminant, though in more recent years it was felt that the analysis of obsidian by way of density determination warranted re-examination. The densities of Mediterranean obsidian were measured to an accuracy of only  $\pm$  .4% whereas, Reeves and Armitage (1972) suggest that without much difficulty and with cimple equipment a precision of  $\pm$  0.01 - 0.04% is feasible and with thic improved precision might come a corresponding improvement

in the source discriminations so effected. Using two simple and reproducible methods of density determination, the free flotation method and the hydrostatic method, Reeves and Armitage (1973) undertook a study of New Zealand obsidian. The free flotation technique involves finding a liouid in which obsidian will neither sink nor float and then measuring the liouid density with a calibrated pycnometer. The obsidian can be floated in the more dense component of a liquid mixture and the less dense component added until the solid is just suspended. A temperature variation version of this method was used in which the density of the flotation medium is adjusted by temperature changes of  $\stackrel{+}{=} 0.02^{\circ}$ C. A suitable flotation liquid for use with obsidian was prepared by the addition of 7.36 gm. of 1 - pentanol to 85.55 gm. of bromoform, giving a liquid containing 92.06% bromoform by weight and having a refractive index  $(N_{p}^{20})$  of 1.5515, the density of which, at temperatures between 9°C. and 45°C. was determined using a pycnometer of Sprengel Ostwald type. A suickfit tube 20 x 25 cm., fitted with a ground glass joint and a thermometer which could be read to  $\frac{+}{-}$  0.02<sup>°</sup>C. was used, placing an unper limit of c. 1 gram on the size of obsidion sample. The tube was half-filled with the flotation liquid then immersed in a water bath and the temperature of this bath raised at a rate not exceeding 0.10°C. per minute. By this method obsidian densities were found to an accuracy of -0.004 gm. cm<sup>-3</sup>. (Reeves and Armitage, 1973, 563). The alternative method of hydrostatic weighing was found more suitable for samples in excess of 1 gram. The technique involves the weighing of the specimen, first in air, then suspended in a liquid of known density. The obsidian, suspended by a fine steel wire, was immersed in distilled water at a known temperature and the density of the obsidian, after correction for immersion of part of the steel wire. was calculated from the equation:

$$D = \frac{10 \text{ mm} - 10000}{10 \text{ m} - 100}$$

Where p, pw and pa are the respective densities of obsidian, water and air and Wa and Ww the respective weights of obsidian in air and in water. Measurements on obsidians of mass 1 gram. Or larger, using this method could be made with an accuracy of 0.0010 gm.  $\text{cm}^{-3}$  in a few minutes (Reeves and Armitage, 1973, 564).

Using whichever method was more appropriate (mainly due to size consideration) Reeves and Armitage determined the density of 61 obsidians from 6 major sources in New Zealand, together with archaeological specimens for which the sources had previously been identified by chemical analyses. The results were disappointingly inconclusive. Mayor Island sub-grouping distinguished by chemical analyses (Armitage et al., 1972) were not apparent through density differences, though the range of reported densities, from 2.375 - 2.432, allowed Mayor Island material to be separated from some other New Zealand source material. Kaeo (2.403 - 2.420) and Mayor Island obsidian show a higher density range than Huruiki (2.358 - 2.364), Whitianga (2.351 - 2.358), Taupo (2.346 - 2.354) or Great Barrier Island (2.335 - 2.354). The overlap is obvious and the discrimination achieved exclusively through density reasurements is essentially on an 'either - or' basis; Mayor Island or Kaeo (though appearance discriminates easily between the pair); Huruiki or Whitianga and Taupo or Great Barrier Island.

The within-source variability and between-source similarity of density determinations is emphasised and this reappraisal again demonstrates the preliminary nature of density in characterisation of obsidian.

## 2:3 Physical Dating Methods

Of the many geographically separate obsidian sources some may fortuitously resemble others in chemical composition, thus making difficult cheracterisation by way of analysis of elemental concentrations. Dating techniques, generally

giving indication of the time of eruption of the obsidian flow, provide a useful alternative means for identification of the geologic origins of obsidian artefacts. Various different methods have been attempted with varying success.

### 2:3:a Thermoluminescence

The phenomena of thermoluminescence (henceforth TL) has to the present day, been utilised in archaeology primarily as a dating technique applied to ceramic material. Recent research has, however, extended the possible applications to dating of other silicate materials and to studies of provenance.

It is not within the scope of this paper to describe in detail the mechanism of TL and several comprehensive review articles are available for reference (Seeley, 1975; Fleming, 1976). Briefly then, 'TL dating makes use of the fact that many crystalline materials have the ability to store energy derived from radiations of radioactive substances and from cosmic radiation and under favourable circumstances, to emit a part of this stored energy in the form of light when the material is heated to a temperature below that at which normal radiative light emission would otherwise occur' (Seeley, 1975). Siliceous material will have been subject to a radiation dosage from its time of formation at some remote geological epoch. Heating, whether intentional or accidental to above a critical temperature removes the stored TL and the process of acquisition restarts from zero, increasing linearly with time. With respect to ceramics TL is placing a date to a heating event ; the deliberate firing of the clay by man, whilst for have flows the resetting of the TL 'clock' is effected by their natural process of formation and the date applies to the time of crystallisation of the lava.

TL of lava flows or the products of these flows (unaltered by subsequent heating) way ultimately enable some degree of source characterisation by way of variations in dates of formative vulcanism, though in utilising a dating technique to suggest heterogeneity between sources, there remains the inherent possibility that two geographically separate flows may have formed during a similar time period.

TL can indicate whether heating of flint by prehistoric man (in an effort to improve the flaking properties of the raw material) has taken place (Goksu and Fremlin, 1972; Rowlett et al., 1975) and although the application may reveal aspects of lithic technology it is not of direct relevance in the present context.

Thermoluminescence of igneous rocks and minerals has not as yet been extensively studied but preliminary investigations on lava flows in the hope of age determination have so far proved discouraging (Aitken et al., 1963; Wintle, 1974). Aitken and his co-workers conducted thermoluminescent studies on lava flows of known age from Mount Etna, Hawaii and Kana-a (Sunset Crater, Arizona). The thermoluminescence as exhibited by whole rock samples from Nount Etna was lower than expected, though between the TL and the known age of the flows some relationship, albeit rough, did seem to exist. To account for the low equivalent dosage the authors suggested that perhaps the natural TL was concentrated in the phenocrysts. Mineral separates from the lava flow samples were thus investigated and the expected dose calculated, based on beta and geama rediation and on the flow age. Unhappily the eouivalent doses from the separates proved anomalously high. The study highlights the difficulties involved in dating lava flows by the nature of their TL and any future hope of iating obsidian flows must await the outcome of further research in this field.

In most ismeous rocks, fellowers are the principal source of TL

(NcDougall, 1968, 533). Feldspar-rich rocks usually exhibit fairly pronounced glow curve peaks which decrease in height with increase in the non-TL mineral content. For most igneous rocks McDougall (1968, 535) suggests that the level of TL is dependent on a number of variables; the percent of feldspar present, the composition of these feldspars and the presence of other TL minerals. Thermoluminescence of feldspars may also depend on the temperature of formation, on trace elements and on radioactive elements, though to what extent remains uncertain. Farrington Daniels (1953), Boyd and Saunders in an early review article pointed to a simple application of TL to geology in identifying stratigraphy within sedimentary deposite. 'A complicated glow curve with peaks coming at definite temperatures provides a means of "fingerprinting" rocks of the same geological history' (Daniels 1968, 15). The extension of this fingerprint technique to igneous rocks and indeed to obsidian might thus be expected to prove effective.

Provenance studies of siliceous materials by observation of their TL have in recent years, proved successful. Samples of marble from Grecian statues produced artificial TL glow curves, differing with respect to the material from different quarries (Afordakos et al., 1974), whilst distinctive glow curves were obtained from 7 known European and American sources for majolica ceramics, enabling source identification of archaeological pottery finds by comparison of their individual glow curves with those of the sources (Vaz and Cruxent, 1975).

Research on artificial glasses suggested that the TL of obsidian might be expected and work by Leach and Fankhauser (1977) demonstrated that the glow curves and the amount of artificial TL induced under controlled conditions of p irradiation were uniquely characteristic of individual sources. This current research is restricted to New Zealand obsidian <u>sources</u>, but in view of its considerable potential as an alternative, swift and inexpensive method of

characterisation, the technique employed will be described in brief. It is to be hoped that extension of TL characterisation studies to other obsidian sources will meet the commensurate success. However, the method must be viewed with cautious optimism. Saturation effects and the possible bleaching of TL in excavated material may create problems and the artificial glow curves may therefore be more diagnostic than the natural TL of specimens.

30 mg. samples from each of the sources were ground, using a kaolin pestle and mortar, then shaken in a 4 cm. column of ethanol in a test tube. 15 seconds allows the courser fraction of the sediment to sink to the bottom and the finer fraction can be poured off. The decanted fraction is then washed in acetone and dried in an oven for 10 minutes at 50°C. 3 samples in the range of 7.3 - 8.3 mg. were taken for each individual source, one being retained for estimation of the natural TL and the two remaining being annealed in an electric furnace at 400°C. for an hour. Samples were spread on silver discs then exposed to beta radiation from a 40 mCi <sup>90</sup>Sr - Y placue source for 10 minutes at 300 rads. per minute. TL was detected with an EMI - 9635 QB bi-alkaline photomultiplier tube increasing the temperature at a rate of 15°C. per second, and the glow curve was automatically recorded on an x - y plotter and scaler. A corning 5.57 colour filter with maximum transmittance of the order of 4200 Angstron was interposed between the photomultiplier tube and the sample (since the radiation of interest is in the blue region of the spectrum). The light-tight 'glow over' was evacuated for 150 seconds prior to analysis and then flushed with a current of highly purified nitrogen during the proce dure (in avoidance of spurious TL).

5 curves were obtained for each source (minimum). After obtaining the natural TL, the same sample was exposed to a known dose of beta radiation and re-run. The first run only partially somealed the natural TL, so that the second was a TL part artificial and part natural. For reproducibility of

results thus only the first glow curve was considered. The artificial TL curves were then obtained from separate samples whose natural TL had been removed by successive reheatings. Finally the normal thermal radiation component or black body curve is obtained and subtracted from the total counts recorded by the scaler to give the integrated area for all curves.

TL studies as applied to characterisation of obsidian may hold much promise for the future.

### 2:3:b Fission Track Dating

The past fifteen years have witnessed the development of the fission track dating technique, as first described by Price and Walker (1963) and originally applied to the dating of various natural crystals and glasses (Price and Walker; 1963, Fleischer and Price, 1964a and Fleischer et al., 1965a).

The method relies on the presence in trace amounts of the uranium isotope <sup>238</sup>U. in many minerals and natural glasses (obsidians, tektites, etc.). Host uranium atoms will decay by alpha-particle emission to the stable lead isotope, Pb, approximately 1 in 2 million, however, will decay by spontaneous fission, when the uranium nucleus disintegrates to form two heavy nuclei with atomic weights in the range 70 - 160 (Tite, 1972). The sponta eous fission of  $^{238}$ U impurities produces minute sub-microscopic fission tracks or damage trails of the nuclear fragments in most crystalline and glassy insulating solids. Spontareous fission of <sup>238</sup>U contained in obsidian may be considered to take place at a constant rate and if the radiation damage tracks so created are permanent over geological time, then radiometric ages can be calculated by a count of these tracks. Thermal fading of tracks can occur, though it has been empirically demonstrated that materials (obsidion included) whose fading temperatures lie above 400 - 500°C retain tracks over geological time. Thus, in the absence of track fading, fission tracks ages for obsidian indicate the tite of the original crystallisation or solidification of the flow. The track density is proportional to the uranium content of obsidian as well as to the time lapse since the formation of the flow, thus necessitating the determination of  $^{238}$ U atoms contained within the material. A track density proportional to the uranium content is induced by bombarding the obsidian in a nuclear reactor, with a known dose of thermal neutrons. The present day ratio of  $^{238}$ U to  $^{235}$ U atoms is a known constant in geological material (Fleischer, Price and Walker, 1969,59), thus the ratio of spontaneous to artificial fission enables sample age to be determined.

The submicroscopic fission tracks are rendered visible under an optical microscope by first etching with some suitable chemical reagent. For obsidian the preparation typically involves the cutting of a small piece (c. 100 mg.) from the sample which is then polished to an optical finish and etched with hydrofluoric acid for several seconds at room temperature. This treatment offers preferential dissolving of the damaged obsidian along the fission tracks, producing conical etch pits which can be counted under magnification, c. x 1000 in the field of an optical microscope. After irradiation with a controlled dose of thermal neutrons the induced fission tracks on the same sample surface can be counted.

The half-life by spontaneous fission is c.  $8 \times 10^{15}$  years, a uranium content of c. 100 ppm. being necessary to determine in a short count period ( c. 1 hour) a minimum sample age of 3000 years, whereas a more laborious count of the order of 30 to 49 hours can facilitate determinations of more recent date.

Fission track dating has been used in an attempt at characterisation of obsidian sources by their geological ages. The shortcomings of the technique as a source discriminant have already been discussed with respect to the research by Durrani et al., (1971) on Aegean, Central European and Mear Eastern material (Chapter 1, op. 16-17). The measuring of fillsion track ages and of uranium contents has been more successfully applied to characterisation of West Mediterraneen (Bigazzi and Boradonna, 1975: Bigazzi et al., 1971) and Japanese obsidiers

(Suzuki, 1969, 1970; Kaneoka and Suzuki, 1970). Bigazzi and Bonadonna examined Liparian geological material and archaeological material from sites on the Adriatic coast of Italy. Of the four main source flows on Lipari : Forgia Vecchia, Rocche Rosse, Gabellotto and Acquacalda, only the latter two proved to be af prehistoric date. The suggested date for the Gabellotto flow is c. 11,500 years in geological age and all archaeological samples analysed proved of comparable date. Small pebbles of obsidian from the Acquacalda pumices were dated to c. 21,000 years (1973, 322). The discrimination so effected by fission track is particularly interesting since similarities in the chemical composition of historic and prehistoric Liparian flows had previously been noted.

Bigazzi and his co-workers (1971) achieved a discrimination between the 4 source regions of the Vest Mediterranean, obtaining dates of  $0.021 \pm 0.004$  m.y.,  $3.1 \pm 0.3$  m.y.;  $1.7 \pm 0.3$  m.y. and  $.135 \pm 0.016$  m.y., for source material from Lipari, Sardinia, Palmarola and Pantelleria respectively.

Suzuki (1970) reports the successful application of fission track work to obsidian from workable sources in Japan, the material showing a wide range of measured values of ages and uranium contents, apparently homogeneous within and heterogeneous between sources.

The limitations are set on characterisation of obsidian by use of fission track (as with other dating methods) in that, as seems to be the case with Acigol and Aegean material studied (Durrani et al., 1971), simultaneous flow eruptions may have occurred in two or more geographically remote localities or indeed within a single source region, successive eruptions may have occurred over an extended period.

# 2:3:c. Potassium Arson Dating (X - Ar)

Potassium is one of the most abundant elements in the earths crust and is contained in proctically all linerals (Centner and Linpolt, 1969, 89). Of this

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total potassium, the radioactive isotope  ${}^{40}$ K forms a constant fraction of c. 0.012%, this  ${}^{40}$ K decays by two processes: by beta decay to  ${}^{40}$ Ca (89%) and by electron capture to  ${}^{40}$ Ar (11%). The latter decay process provides the basis for age determination.

Since argon is a gas the heating to a molten state associated with flow formation of volcanic rocks will expel any existing  ${}^{40}$ Ar present and at the time, t = 0, the mineral will contain only argon with an isotopic ratio the same as atmospheric argon. The amount of radiogenic  ${}^{40}$ Ar will increase continually with time as a result of  ${}^{40}$ K decay and from measurement of the  ${}^{40}$ K concentration and the radiogenic  ${}^{40}$ Ar content the time lapse since the formation of the volcanic deposit may be determined. In addition to radiogenic  ${}^{40}$ Ar :  ${}^{36}$ Ar = 296 : 0.19 : 1 (Gentner and Lippolt, 1969, 90). The ratio of  ${}^{40}$ Ar to  ${}^{36}$ Ar for atmospheric argon is known, thus by mass spectrometric determinations of the isotopic ratios the atmospheric  ${}^{40}$ Ar content can be measured and subtracted to give the radiogenic  ${}^{40}$ Ar content.

The long half-life of  ${}^{40}$  potassium of 1.30 x 10<sup>9</sup> y means that in geologically recent rocks the radiogenic  ${}^{40}$ Ar content will compose only a fraction (less than 10<sup>5</sup>) of the total  ${}^{40}$ Ar present. Very real problems exist in the accurate mass spectrometric determination of small amounts of argon and in normal circumstances contamination by atmospheric argon limits the applicability of the K - Ar dating method to rocks older than 100,000 years (Tite, 1972, 92).

From obsidian blocks embedded in a perlite matrix from the vicinity of Uras in the Monte Arci area of Eardinia a K - Ar date of  $3.0 \pm 0.2$  m.y. has been obtained (Belluomini et al., 1970) whilst from Monte Tramontano obsidian on Falmarola a K - Ar are of  $1.6 \pm 0.2$  m.y. has been determined (Barberi et al., 1967). Both these dates are in good agreement with fission track determinations for Sardinian and Pontine Island material of  $3.1 \pm 0.3$  m.y. and  $1.7 \pm 0.3$  m.y. (Bigazzi et al., 1971), and suggest that obsidian does retain argon and ages obtained are therefore justifiable.

If a dating technique is to be used in obsidian characterisation by way of the contrast in ages between different sources, then difficulties inherent in K - Ar dating of geologically young samples (i.e. Lipari and Pantelleria obsidian) suggest fission track dating as more readily applicable to the problem.

#### 2:3:d. Obsidian Hydration Dating

The potential of obsidian hydration as an archaeological dating technique was brought to the fore by Friedman and Smith (1960). They recognised that freshly fractured obsidian over geological time absorbed water from the ground surface environment ultimately forming its hydration product, perlite. Moreover they noted a seeming regularity in the extent of hydration (in the form of a measureable layer or rim) with respect to time.

Early studies encountered discrepant hydration rates, and it became rapidly apparent that the hydration process could not be viewed as 'addition of water to obsidian in the manner of a permeable seive' (Ambrose, 1975, 85). The fundamental assumption that the hydration band increases in thickness with time, nevertheless remained unchallenged.

Since the original paper discussing the technique, advances in this field have aimed mainly at establishing the relative importance of the many variables contributing to and effecting the rate of hydration.

Friedman and Smith originally determined variant hydration rates for different climatic zones using the expression x = dt to describe the relationship between hydration and time, where x is the thickness of the hydrated layer in micrometers, K is the hydration constant for a fixed temperature and t, the time lapse in years. Other workers in the field found it necessary to suggest alternative numerical variables, for the exponent of time. Thus Clark (1961, 1964) suggested  $x = Xt^{\frac{3}{2}}$  for Central Californian material, Meighan and colleagues suggest linear hydration equations to satisfy data from the Morret site in West Mexico, whilst Kimberlin found  $x = Kt^{\frac{3}{2}}$  a suitable equation for this same site. Ericson et al., (1975 and 1976) suggest that the discordance in reported hydration equations reflects a disregard of systematic variables (other than time and temperature) which may be operative in the hydration mechanism, thus they give consideration to the alumina and alkali concentration in obsidian, the initial water concentration, the specific volume, the silicon-oxygen ratio and the reaction energies of individual water species in perlite (1976, 43). These writers in no way imagine these to be the only other operative variables and on this account suggest an empirical approach as essential in definition of hydration rates for individual obsidiens. Cn theoretical grounds therefore, they predict different hydration rates for different obsidian sources.

Although primarily obsidion hydration is valuable as a chronological technique the concept of source specific hydration rates holds interesting implications with respect to characterisation of the material. Ericson and Berger (1976) demonstrated the source specific nature of obsidian hydration with reference to obsidian artefacts from Oregon, California and Vest México. Analysis of Central and Northern Californian source obsidians by NAA allowed a division into 9 chemically distinct groupings representative of 6 source areas (Ericson and Berger, 1976, 47 - 48). To put their theory to the test Ericson and Berger chose samples from buriel contexts on Central Californian sites, making the assumption that obsidion associated with the burials would have been manufactured contemporaneously. Any discontinuities in the hydration band with would taux indicate measurement error or indeed the exploitation of tore that the obsidien astifacts from two Sectral Californian buriel contexts, Godard and Elosson, on which reviewsly obtained hydration

measurements had shown unexplained internal discontinuity, (Clark, 1961; Friedman, Smith and Clark, 1969) were selected for MAA. Source attribution by NAA confirmed the dual-nature of the Goddard hydration data, whilst discontinuities observed within the Blossom site data suggested interval variation in the trace element characteristics of the St. Helena source area.2 samples from the Peterson-2 site (Central California) showing consistent hydration values were analysed and attributed both to one source in the St. Helena region. Supported by further data from Oregon and West Mexico, (Friedman et al., 1976 and Kimberlin, 1976) the argument for the correlation between chemical grouping and hydration values is convincing.

In view of the recent findings, attempts at stratigraphic analysis (Michels, 1969, Michels, 1973 and Neighan, 1976) by measurement of hydration rims on artefacts from each level should be considered with due caution. Heterogeneity in band width of obsidian from a single cultural level has previously necessitated explanation in terms of stratigraphic mixing, exposure to fire or direct sunlight, spalling, reuse or measurement error.

The present state of knowledge sets limits to the widespread application of the technique, its refinement will depend on determination of sourcespecific hydration rates for individual sources within a given region and on identification of the artefact source prior to dating (Ericson, 1975). Unce established, the hydration phenomenon can be utilised to date the exposure of a new surface (either the date of formation of the flow or manufacture of the obsidion artefact) or perhaps where artefacts closely dated by typological or physical methods are available source attribution of artefacts may be a future possibility.

Preparation of the obsidion samples for measurement involves the cutting of sections from each specimen with a diamond-charged brass saw blade. The section is ground optically flat with silicon carbide and aluminum oxide crits

to a thickness of 0.003 inch and covered with a glass cover slide using canada balsam. An optical petrographic microscope with a Leitz micrometer eyepiece was used to make measurements of the rim at 3 or 4 different points with 5 readings per point (Ericson, 1975). Precision of measurements depends on hydration rim variability, instrument and operator error and readings are reproducible within 0.2 micron (Ericson and Berger, 1976, 52). By means of photographic enlargement Findlow and de Atley (1976, 165) report a reduction in error to less than 0.05 micron.

#### 2:3:e. Palaeomagnetism and Archaeomagnetism

Igneous rocks, on cooling from the molten state and baked earths on firing, acquire a magnetism (due to the small percentage of magnetic minerals within the material), thermoremanent in origin. The fundamental basis of palaeo-and archaeomagnetism is that the direction of this remanent magnetism, as preserved in rocks and baked clays, is in accordance with that of the ambient geomagnetic field at the time of formation or manufacture and that the intensity of remanent magnetism is proportional to this field.

An objective of palaeo- and archaeomagnetism is to develop a complete record of the arcient geomagnetic field, once established this 'record may serve as a space and time reference system' recorded by volcanic rocks and baked clays (Clark, 1974). The earth's magnetic field is changing continually in both its direction and intensity and on establishing the pattern of variation with time it should, in theory, be possible to correlate new direction and intensity values as recorded by rocks and clay with thic pattern and to assign a date to the heating event. In practise, where the magnetic elements (intensity and direction, as defined by declination and inclination) for a specific geographical area are known over a sufficiently long period (as in London after c. 1540) then archaeomagnetic dating is possible, but more often the magnetic elements are
inadequately known and measurements of stable and reliable directions and intensities from dated rocks, kilns and the like serve to further supplement the incomplete magnetic record.

Direction and intensity of the geomagnetic field both differ with respect to latitude and are subject to regional disturbances in addition to exhibiting long term or secular variation. Declination and inclination of the field vary by only one or two degrees in c. twenty years, whilst the secular variation in intensity, apparently unrelated to direction changes, is markedly less. Latitudinal variations in present day intensity values range from 0.40 oersted at the equator to c. 0.61 oersted at the magnetic poles.

The earliest records of geomagnetic field direction measurements are to be found in Paris and London dating back to the 16th Century, whilst field intensity measurements were initiated in the last century by Gauss, working on lavas and baked earths.

Much data for secular variation in declination (D) inclination (I) and field intensity (F) derives from fired structures and objects of baked earth. Results are available from France (Thellier, 1966), Japan (Matanabe, 1958; Kawai et al., 1965); Britain (Aitken and Meaver, 1962; Aitken and Hawley, 1967); Russia (Burlatskaya, 1962) and Greece (Belshe et al., 1963), elucidating the field direction in the separate areas over specific time periods. Field intensity date exists for Europe stretching back to c. 7000 B.C. (Bucha, 1967, Bucha et al., 1970), for Central America back to c. 2000 B.C. (Bucha et al., 1970) and for Japan (Magata et al., 1963; Basejina, 1965) back to c. 3000 B.C.

From c. 10,000 B.C. onwards remarent magnetic data from fired archaeological structures and objects are used to trace ascular variations in the seomasmetic field, prior to this suitable archaeological samples are lacking and the record of field variations as preserved in rocks suitable obsidied. Obsidien suitable

for working by prehistoric man (i.e. exhibiting conchoidal fracture) is predominantly the product of Tertiary or Quaternery Volcanism (Cann and Renfrew, 1964, 113), thus it is evidence on the geological time scale which assumes importance. Dating of obsidian flows by palaeomagnetic means will depend on the establishment of secular variation curves, as derived from rocks. Age determination of obsidian artefacts derived from the flows (in an attempt to attribute artefact to source by comparison of their magnetic dates) will necessitate the use of intensity measurements, since the original direction of magnetisation as preserved in the in situ source material is lost on removal of material from the flow.

The first systematic balaeomagnetic study of secular variation of the geomagnetic field direction, using data from the well dated historic volcanic flows of Mount Etna, was conducted by Chevalier (1925). The favourable nature of the material for such a study encouraged Tanguy (1970) to continue this research and results make possible the determination of the geomagnetic field direction in Sicily subsequent to the 12th century. Doell and Cox (1961, 1963) have carried out intensive palaeomagnetic studies on prehistoric and historic Hawaiian lavas, whilst the historic lavas of Huzi, Sakarjuna and Ozima in Japan have also focused attention (Kato and Nagata, 1953; Yukutake, 1961). On the geological time-scale, however, palaeomagnetic research suggested the occurrence of reversely magnetised rocks. Brunhes (1906) reported a direction of magnetisation, as recorded in lava flows in France, practically opposite to that of the present day geomagnetic field and Matsuyama (1929) basing his conclusions on data from post-Termary basalts of Korea and Japan, suggested periodic reversals of the geomagnetic field. Brymjolfsson (1957) from his study of Tertiary Icelandic basalts estimated the transition interval for reversal of the field as approximately  $10^{7} - 10^{4}$  years and taking c. 3000 years to complete.

The available data on geomagnetic field intensity show a tendency towards a continuous decrease during the past 2000 years. Japanese and Russian research suggests a cyclic variation of field intensity with a periodicity of c. 10,000 years and data points to an increase in intensity prior to 2000 B.C. Bucha, reporting on measurements from Czechoslovakia, postulates a maximum geomagnetic field intensity occurring at around 400 B.C. when the field was 1.6 times its present value, and a minimum value occurring between 4000 - 3500 B.C. when the field drops to .6 times its current intensity. Thellier and Thellier (1959) working in France, found that c. 0AD the field was almost twoce its 1959 value.

Although advantageous in showing effectively simultaneous variation over a region several hundred miles across, direction values may recur with time. It has been suggested (Weaver, 1966) that the slow variation in field intensity may allow discrimination between in situ material for which the field directions are similar. Naturally global or regional variations in field strength present an advantage in not requiring in situ material, but age determinations based on intensity values are far less accurate than direction determinations, since the overall variation in intensity is  $\frac{1}{2}$  50% of the present value and since the precision of measurements is reported as c. 10% as compared with 1<sup>0</sup> for direction values in favourable conditions.

As mentioned, if applied to obsidian artefacts, age determination would necessarily be based on field intensity values, the estimation of which involves comparison of the intensity of natural remanent magnetism (primary and secondary components combined) with that of thermoremanent magnetism (magnetism after removal of secondary components) produced on heating and cooling in a controlled laboratory field. The most satisfactory method is the double-heating method as described by Thellior and Thellior (1959).

Two main procedures are in use for extraction of rock samples from outcrops and exposures: the block method, involving the use of an aluminium frame placed on the upper portion of the sample and wedged so that the upper surface defined by its sides is exactly horizontal, then filled with plaster of paris; and the core method, involving the drilling of a long core. The sample, before removal, is oriented, so that its direction of magnetisation may be related to present day geographic coordinates.

The absence of any regular pattern of variation in the geomagnetic components means that a magnetic date can be no more reliable than the chronology used in establishing the magnetic reference curve. (Aitken, 1974). There is as yet much research necessary on securely dated geological flows, in developing a time scale for palaeomagnetic studies. At present the status of studies is not sufficiently advanced to facilitate age determination of obsidian source and artefactual material, in an attempt at characterisation.

#### 2:4 Mössbauer Analysis

The Mössbauer effect refers to the recoil-free emission (Mertheim, 1964) of nuclear gamma rays from excited nuclei, formed in a radioactive source and their resonant absorption by nuclei of the same isotope in the solid under examination.

Iron is widely distributed in nature so that solid materials of the earth will normally contain iron in small quantities. Obsidian containing a few per cent weight of iron disseminated throughout the matrix of the material, is thus amenable to examination by <sup>57</sup>Pe Nössbauer spectroscopy and information may be obtained concerning the distribution of the iron in its different oxidation states. The several nor cont of iron in a rook specimen may be distributed through a number of different ineral phases, with certage only a fraction of 1 in any one phase. Approximately 2.19% of the iron nuclei in a natural

sample are the resonant isotope  ${}^{57}$ Fe (Herzenberg, 1970, 211) and the Wössbauer spectra associated with this isotope have frequently been used to study the iron-containing mineral phases in archaeological materials. The gamma ray source is provided by  ${}^{57}$ Co. The radioactive cobalt isotope,  ${}^{57}$ Co, decays to an excited state of the iron isotope,  ${}^{57}$ Fe, which then decays to its ground state by emission of recoil free gamma rays with an energy of 14.4 KeV (Tite, 1972, 293). A sample, typically of c. 100 mgs. in weight is exposed to gamma rays from the source and the intensity of radiation detected with a scintillation or semiconductor counter, after absorption by the radioactive nuclide  ${}^{57}$ Fe in the specimen. By varying the incident gamma ray energy over a range of c.  $10^{-5}$ ev and moving the source relative to the specimen (i.e. by mounting the gamma ray source on an electromechanical vibrator) the Mössbauer spectral pattern is obtained (i.e. the  $\beta$ transmission of gamma rays by the specimen versus the velocity of the gamma ray source).

The hyperfine interaction (the tiny perturbations of the nuclear energy levels by surrounding electrons) composes three basic parameters, namely the isomer shift, the nuclear electric quadrupole splitting and the nuclear magnetic dipole oplitting (Mertheim, 1964, 94). The isomer shift measuring the charge density of atomic electrons around the nucleus results in a displacement of the main absorption peak with respect to zero source velocity. The quadrupole splitting of the main absorption peak into two components is dependent on the electric field gradient at the nuclei and is related to the point symmetry of the lattice surrounding the atoms. The magnetic field splitting refers to the tresence of subsidiary absorption peaks at each side of the main ceak and is the result of the interaction of nuclear magnetic dipole moments and the magnetic field bie to the atoms own electrons. Tarictions in isomer shift and in values of cuadrupole splittings will provide information for distinguishing between the ferric and fermous iron states in obsidian and presumably reflect the differing conditions of flow formation (temperature, pressure, cooling rate etc), whereas the splitting of the spectra into 6 peaks is an indication of the presence of magnetic minerals (e.g. magnetite, haematite).

Herzenberg, (1970, 223) discussed the use of the Mössbauer effect as an analytical tool in determinative mineralogy and mentioned its possible potential in obsidian source characterisation - Mössbauer spectra of synthetic glasses have proven to differ with respect to compositional variations, thus the absorption spectra of obsidian from any geological source is compositiondependent + might be expected to show unique spectral forms.

A recent analysis of West Hediterranean obsidian by Mossbauer effect study, in an attempt at differentiation of source material, has been conducted by G. Longworth in collaboration with S.E. Warren at Bradford University (Longworth, G. and Warren, S.E., Archaeometry Conference Payer, 1978). Much of the material (both geological and archaeological) under examination had previously been subject to analysis by NAA therefore allowing comparison of the preliminary results of Mössbauer spectrometry with the data available from chemical analyses. Geological material was presented for analysis in powdered form, whereas artefactual material was presented in its original form (the possibility of non-destructive analysis should be appreciated). Counting periods were of the order of 1 day.

Preliminary results on the Mossbauer spectra of Mest Mediterranean obsidians are available (S.A. Marren, Private Communication). The spectre for Pantellerian obsidiar escharical its different structure and facilitated its distinction from other Mediterranean source starial. On the basis of this research effort obschamer analysis follow to establish a clear different-

iation between Pontine Island and Liparian material, though a plot of the magnitude of quadrupole splitting of ferric ions versus that of ferrous ions shows reasonably distinct clusters for Pantelleria, Sardinia and for Pontine Island and Liparian material together. The total absorption would probably sort out Liparian from Pontine Island <u>source</u> material, but would not enable the non-destructive analysis of artefactual pieces. Source material from the prehistoric Liparian flow of G-bellotto (locality R - see Fig. 5) showed a sextuplet form of spectra indicative of the presence of magnetite smaller amounts of magnetite were detected within other samples, notably in the one Sardinia group C specimen included and in two samples from Vulcano. Fössbauer work at Bradford has also been carried out on Aegean obsidian and though analysis is not yet complete, the data holds promise.

Further work in this field is necessary to evaluate the possible contribution of Mössbauer spectra in colving obsidien source discrimination problems.

#### PART 2.

#### CHAPTER 3.

# PRINCIPLES OF MAGNETISM AND AIMS OF RESEARCH

#### 3:1 <u>Magnetism in Igneous Rocks</u>

The magnetic properties of different materials will vary according to thermal and chemical history, composition and grain size of the material. Igneous rocks are formed by cooling of a solution of oxides, silicates and various volatiles (magma). The mineral composition of igneous rocks depends on the chemical composition of the parent magma and on the geological conditions under which they formed. Crystallisation may proceed at varying temperatures, deep in the earth's crust or, as with obsidian, upon extrusion at the surface.

The magnetic properties, as exhibited by igneous rocks are generally to be attributed to the various iron oxides and sulphides (i.e. magnetite, titanomagnetite, pyrrohotite etc.), comprising perhaps 3 to 4% of the total and causing the rock to respond to the magnetic field in which it is situated. The present study relies on the presence within the obsidian of a small percentage of magnetic minerals disseminated throughout the predominantly non-magnetic matrix of the material. Crystallisation of magnetic minerals occurs above the Curie point, often between 1,100° and 860° (Irving, 1964), and obsidian will acquire most of its magnetism (Thermo-memanent magnetism) on cooling through the Curie temperature. The resulting grain size may be expected to depend on the rate of cooling during crystallisation and as such is very variable.

#### 3:2 Accuisition of Thermoremanent magnetism

Of prime importance in palaeomagnetism is the two-fold phenomenon of magnetisation of igneous rocks on cooling in the earth's field and acquisition

of a stable thermoremanent magnetism (henceforth TRM) in a direction parallel to and of magnitude proportional to the earth's field in which they cooled.

Natural remanent magnetisation (henceforth NRM) comprises a <u>primary stable</u> <u>component</u> (TRM) and a <u>secondary viscous component</u> (viscous remanent magnetism, VRM, **p** 83.)The 'primary magnetisation' is acquired as the rock cools down from its molton state and in obsidian this may be considered as largely thermoremanent in origin. A brief exposition of the theory of TRM will be given here, though for greater detail reference should be made to 'Neel's (1955) standard work, and to later works discussing the subject (Stacey 1963, Strangway 1970, Tarling 1971, McElhinny 1972 and Stacey and Banerjee 1974).

The phenomenon of TRM can be explained adequately with reference to single domain theory. Neel (1955) defines a critical grain diameter (the blocking volume,  $V_{\rm R}$ ) above which magnetic grains on removal of the applied field can 'block' the direction of the magnetic moments as dictated by the ambient field (H) and exhibit a remanence measureable in the laboratory. Related to this is the blocking temperature  $(T_B)$ , above which magnetic domains can realign with the applied field and below which the thermal agitation energy is insufficient to cause domain reversal within the time interval of observation. The theory of acquisition states that on cooling from a high temperature spontaneous magnetism appears at the Curie point  $(T_{C})$ . On cooling below the blocking temperature the magnetisation acquired at this temperature is 'frozen in' and subsequent changes in field direction are ineffectual in altering the direction of magnetisation. This TRM is essentially stable through geological time. The magnitude of the TRM is dependent not only on the ambient field in which the rock cooled (generally that due to the earth: i.e. 0.5 oersted) but also on the concentration and mineralogy of magnetic oxides within the material.

1. The figure quoted refers to the approximate field strength at the present day.

#### 3:3 <u>Mineralogy of Magnetic Oxides</u>

The term 'ferromagnetic' is often used when referring to iron oxide and sulphide minerals but in sensu stricto these minerals exhibit ferrimagnetic or imperfect antiferromagnetic properties and can retain a magnetisation even in the absence of an applied field. (This spontaneous magnetisation is the result of interaction between spins of unpaired electrons in neighbouring orbits). The composition of magnetic minerals in igneous rocks is governed by the composition and the physical conditions operative during cooling (Irving, 1964).

The primary chemical units of ferrimagnetic oxide minerals are  $Fe_{3}O_{4}$ (magnetite);  $Fe_{2}O_{3}$  (haematime and maghaemite);  $Fe_{2}Tio_{4}$  (ulvospinel) and Fe Tio\_{3} (ilmenite). Since the oxide minerals in rocks rarely conform to pure compositions, their magnetic properties can generally be well explained in terms of solid solution series between the above minerals within the Ternary System (FeO - Tio\_{2} - Fe\_{2}O\_{3} - Fig.9.), whilst it is convenient to consider the physical theory in relation to the two most important accessory minerals, magnetite and haematite. The mineralogy of magnetic oxides has been reviewed in detail (Nicholls, 1953; Akimoto, 1957; Gorter, 1957; Nagata and Akimoto, 1961; Akimoto, 1961).

In basic igneous rocks the iron-titanium oxides are generally of a composition between ulvospinel and magnetite which together form a solid solution the titanomagnetite series. In acid igneous rocks, however, the ferrimagnetic constituent may have a composition lying between the titanomagnetite and ilmenohaematite series.

Iron-titanium oxides in rocks have proven variable in composition and have shown a wide range of magnetic properties, differing with respect to these variations. The intrinsic magnetic properties of intensity of saturation magnetisation depend to a large extent on chemical composition, for example the Curie Temperature of magnetite is reported as c.  $578^{\circ}$ C. with a fairly high saturation magnetization of 480 emu/cm<sup>-3</sup> and that of haematite as  $680^{\circ}$ C. with a

1. Nagata, T., 1961, Rock Magnetism, Tokyo, Maruzen.





Fig. 9 After Tarling, 1971

The average chemical composition of the iron-titanium oxides found in most igneous rocks is shown dotted.

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small saturation magnetisation of 2.2  $emu/cm^{-3}$  (McElhinry, 1972 and others) (Kittel, 1946 and 1949).

The grain size of ferrimagnetic minerals in natural rocks can range from c. .01 to 1 cm. (Nagata and Ozima, 1967,115) though a range lying between .05 mm. and 1 mm. in diameter is more usual in volcanic rocks (Irving, 1964,16). Unlike the properties of Curie temperature and intensity of spontaneous magnetisation which are indeed independent of grain size, the magnetic properties of susceptibility, coercive force and remanent magnetisation are sensitive to structure and grain size of the material (Nicholls, 1955,113). Chevallier and Nathieu, (1937) and Akimoto, (1951) demonstrated the dependence of magnetic susceptibility on grain size respectively for haematite and for ferromagnetics close in composition to magnetite. Gottschalk (1935) and Nagata (1953) have both shown a general increase in coercive force as grain size decreases.

#### 3:4: Aims of Research

The primary component of magnetisation (TRM) or indeed the primary and secondary components together (NRM) may be of value in discriminating between obsidian flows. Measurement of intensity of remanent magnetism, together with measurements of susceptibility, saturation magnetisation and backfield coercivity may be expected to vary from one obsidian flow to another with differences in mode and occurrance of ferrimagnetic oxides.

Early work on the remanent magnetism of Italian volcanic rocks (Meloni, 1953; Folgheraiter, 1899), suggested a connection between this remanence and the geomagnetic field at the time of production of the rock. Since that time studies have gradually developed, making use of the remanent magnetism of baked earths and natural rocks to study the direction and more recently, the intensity of the geomagnetic field in archaeological and geological time. By building up a secular variation curve of the ancient intensity and direction of the field, determinations of the 'age' of rocks and baked earths can be made. This is the

basis of magnetic dating.

The present research is an attempt at magnetic characterisation of obsidian particularly by measurement of magnetic intensities. Theory suggests that magnetic properties of obsidian may be used as discriminating variables, the examination of which might illustrate homogeneity within geological sources and heterogeneity between sources. If successful in practice then valid conclusions could be drawn from the magnetic analysis of archaeological obsidian artefacts suggestive of provenance and hence allow inferences to be made on the nature and extent of the prehistoric obsidian trade.

Of prime consideration in the present magnetic work is the speed and economy with which such analyses can be conducted, together with the nondestructive nature of the technique.

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#### CHAPTER 4.

#### PROCEDURE OF MAGNETIC ANALYSIS

#### 4:1 Measurement of NRM

The NRM of obsidian is measured by rotating the specimen and noting the magnitude and phase of the alternating voltage induced in nearby pick-up coils. The magnitude of the signal is dependent on the intensity of the component of magnetisation in a plane at right angles to the axis of spin and parallel to the axes of the coils, while the phase of the direction is measured relative to a fiducial mark on the rotating platform.

The instrument used is a balanced fluxgate rock magnetometer, developed at the University of Newcastle by Dr. Lindsay Molyneux (Molyneux, 1971) and now available commercially. The unit comprises magnetometer measuring head to hold samples, electronics unit, computer and teletype (Fig. 10).

#### 4:1:a. Balanced Fluxgate Spinner

The sample is placed in position on the measuring head; a special platform mounted at the top of a metre long shaft and surrounded by the balanced fluxgate, then lowered below the mu-metal shielding (which effectively precludes any ambient magnetic disturbances). The cabinet housing the rotating mechanism and the platform itself are manufactured from non-magnetic materials. The one metre shaft is turned by direct motor drive at approximately 7 revolutions per second. A reference signal is generated by means of light emitting diodes and photodiodes and the phase of the alternating voltage is measured with respect to this signal by a phase-sensitive detector.

#### 4:1:b. Magnetometer Electronics Unit

The unit provides a 5 KHz. signal to drive the fluxgate and detects the magnetic disturbances created by rotation of the sample. The amplifier



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BALANCED FLUXGATE SPINNER

sensitivity can be altered to cover a range of intensities.

#### 4:1:c. Micro 16V + ADC Computer

The magnetometer uses a Digico Micro 16V minicomputer with a 4K. of store and a 12 bit ADC. for signal analysis. The results are printed out on the Console Teletype.

#### 4:2 <u>Sample Preparation</u>

All samples to be measured are weighed on an analytical balance.

The Digico balanced fluxgate rock spinner magnetometer is designed to measure the remanent magnetisation of rock samples which have been machined to a cylinder of specific dimensions and quotes an intensity in emu/cc x  $10^{-6}$  (microgauss) assuming a sample of the set dimensions. A hollow wooden cylinder was machined to fit within a length of plastic drainpipe (cylindrical), of dimensions dictated by the geometry of the measuring head and within the whole is placed a cylindrical plastic container holding the obsidian. The obsidian is held firmly in position by embedding in polystyrene. Wood, polystyrene and plastic are magnetically inert and will not contribute to the resultant intensity. Measurements are made relative to an arbitrary fiducial mark drawn on the plastic container (see Fig. 11). The samples were presented for measurement in this form and the intensity values so obtained, corrected to give a result in emu/cc x  $10^{-6}$ .

#### 4:3 Measurement of a sample

Calibration, using a test sample containing a strip of magnetic material of known intensity, is carried out as a preliminary to measurement of obsidian samples and due to drifting of intensity is repeated approximately every half-

A procedure involving 6 spins is used (Fig. 11). With the computer integrating over 2<sup>4</sup> spins (i.e. 16 spins over 2.3 secs.), it is possible to measure approximately 30 samples per hour. For each of the 6 spins of a

# Measurement of

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Sample

Not to Scale

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SPIN No 2

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SPIN No 3

FIG.11



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complete measurement the magnetic vectors in two directions are measured; x is the component along the fiducial, y at right angles to it and z along the axis of the sample cylinder. At each spin the two components perpendicular to the axis of rotation are measured. The platform is raised and the sample placed in position (1) with fiducial mark on the sample aligning with fiducial mark on the sample holder (Fig. 11). The sample is then spun for the preset number of rotations and the declination for the first position printed out and stored within memory. The rock sample is rotated through 90° and results are obtained in this plane (spin 2). Readings corresponding to spins 1 and 2 are taken with the sample rotated through 180° (spins 3 and 4). The individual results for each of the four orientations are stored and combined to give the magnetisation along the three orthogonal directions. After measurement of 4 positions the three orthogonal components are combined and the complete result is printed out : the total intensity in terms of emu/cc x  $10^{-6}$  (to be corrected), the declination and inclination.

Two further measurements are made (spins 5 and 6) in different orientations, thus completing an equal number of measurements of all axes. The results are again printed out founded this time on 4 measurements of 3 axes rather than 2. The latter two spins act as a check on the original results.

#### 4:4 Step Demagnetisation of samples by alternating fields

The systematic use of alternating field demagnetisation in palaeomagnetic work was introduced by Thellier and Rimbert (1954 and 1955) and further established by As and Zijderzeld (1958), Creer (1959) and others.

The secondary components of magnetisation (VRM), particles with relatively short relaxation times characterised by a low coercive force, are eliminated by alternating field demagnetisation, leaving behind the high coercive force original fossil magnetisation (TRM).

After measurement on the spinner magnetometer of the initial direction and intensity of remanence, the obsidian samples still oriented in the plastic containers are placed within a coil and subjected to an alternating current of peak intensity  $(H_p)$ . This field is then reduced slowly and smoothly to zero by decreasing the current of the field coil. The magnetisation of the 'larger' grains (magnetically softer) with coercive force less than the magnitude of the peak field is randomised and effectively removed. The magnetisation of the sample is then remeasured and the process repeated at progressively higher alternating field strength.

For the procedure the full symmetry of the field is necessary. Even harmonics of the alternating field are precluded by tuning the demagnetising coil and steady (dc) field effects by cancelling the geomagnetic field at the demagnetising coil. Demagnetisation is carried out in field-free space to prevent acquisition of anhysteretic remanent magnetisation (ARM). Spurious components comprise less than 1% of the total current. The apparatus used is of the general type described by Creer (1959).

Within the demagnetising coil the specimen is 'tumbled' about three mutually perpendicular axes. The grains within the obsidian are thus presented to the field in all possible orientations. Imperfect annulment of the earth's field, assymetry of the alternating field and the polarising effect of the alternating field are effectively reduced or counteracted by sample rotation.

The alternating current for the solenoid is obtained from the normal mains supply of frequency 50 cycles per second (Creer, 1959; Irving et al., 1961) and controlled by a potential divider to avoid abrupt jumps in the current.

An empirical approach is employed since prior to demagnetisation the optimum a.c. field treatment to effect magnetic 'cleaning' is unknown. A number of pilot samples are subject to a.c. demagnetisation at propressively increasing field values. 'Cleaning' intensities used for these specimens are 25, 50, 75, 100, 150, 200, 250, 300, 400, 500, and 750 oersted with measurement of remanent

magnetism between each step.

The remaining samples are subject to a.c. demagnetisation at two successive field values (200 and 500 oe.) as dictated by visual examination of the demagnetisation curves, reinforced by the less subjective method of computation of the stability index of remanence (section 4.5) for the pilot specimen.

As a general guide, optimum field treatment in the range of 150 - 300 oe. for igneous titanomagnetite bearing samples (though higher peak fields for haematite-bearing samples) has been suggested (Stacey and Banerjee, 1974).

# 4:5 Computation of the Stability Index of Remanence

Objective choice of the optimum field treatment for magnetic 'cleaning' is based on computation of a Stability Index (SI) for the pilot specimens (Tarling and Symons, 1967), a property related to the remanent magnetisation and changing during alternating field demagnetisation.

The Stability Index is a function of the direction of remanence (irrespective of intensity) over two or more successive increases in field expressed in spherical statistics and the range of field over which the directional change is least (Tarling and Symons, 1967,443).

SI = max (Range ½/circular standard deviation) of three or more successive directions for each progressively demagnetised pilot specimen. The range of field which yields the stability index is the range of the most suitable 'cleaning' field for isolating the stable component of magnetisation. SI exists as a dimensionless figure allowing comparison of stability of remanence within and between source material.

#### 4:6 Low Field Suscentibility of Samples

Susceptibility measurements were made on all samples after completion of a.c. field treatment. Apparatus used to measure initial susceptibility of

magnetic technique has much to recommend it as an alternative method of characterisation. Magnetic analysis is essentially swift and inexpensive and its' non-destructive nature is a major advantage over OES, which necessitates destructive sampling.

With very small samples a real difficulty in the present study was that of integrating a weak signal above the noise level of the magnetometer system in use. On this account a sample mass limit of c. 0.7 - 1 gm was introduced,( pl46 ) below which results were considered less reliable. This is an obvious disadvantage of the technique over OES and NAA, both of which are capable of analysing samples less than a milligram in total mass.

Although further evaluation of the magnetic distinction of obsidian sources is yet required, the present study confirms the general validity of this approach and demonstrates that it may, on occasion, be used successfully as an alternative to trace element analysis. The extent of overlap in magnetic properties of obsidian observed from the Aegean, West Mediterranean, Near East and Central Europe suggests that the magnetic approach will never supplant characterisation by quantitative determination of elemental concentrations, either by OES or NAA. Essentially its' current importance lies in its potential as a swift and economic means of preliminary examination, giving a sound basis for source discrimination, which may be later confirmed by detailed trace element analysis.

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obsidian samples is of the type described by Collinson et al. (1963). The transformer susceptibility bridge consists of a balanced circuit of coils wound on two ferrite rings, in both of which a gap is cut. Each ring has primary windings or exciting coils which carry a low frequency alternating field of approximately 10 cersted. The secondary windings or pick up coils on either side of the core gaps are connected in series opposition. Initial balancing of the circuit is achieved by controlled adjustment of a small ferrite slug lying close to one of the core gaps and is calibrated by measuring the deflection produced by standard discs containing ferrous sulphate and adjusting the sensitivity accordingly.

The sample is placed between the gap faces of one of the core rings giving rise to imbalance of the circuit. The amplified out-of-balance signal from the cores produces a direct current proportional to its magnitude and phase (shown in the deflection produced on the output microammeter) - i.e. in proportion to the mass of the material and its susceptibility. The attenuater setting can be altered to cover the range of susceptibilities apparent in the obsidians measured. By this method a hundred or more specimens can be measured in one hour.

The deflection in microamps produced on the output microammeter is corrected to give the total susceptibility of a 1" cylindrical sample. This figure is then divided by the mass of the obsidian to give the <u>mass</u> susceptibility in  $emu/gm \ge 10^{-6}$ .

# 4:7 Measurement of Saturation Magnetisation and Coercivity of Remanence

Experimentally 'ferromagnetics' are characterised by hysteresis or irreversibility of magnetisation (Stacey and Banerjee, 1974).

Saturation magnetisation  $(\mathbb{N}_{SAT})$  and coercivity of remanence (Hcr) are measured by means of an iron-cored electromagnet producing a high field in a

Collinson, D.W., Molyneux, L., Stone, D.B., 1963. A Total and Anisotropic Magnetic Susceptibility Meter

3 cm. gap. The apparatus consists principally of an iron yoke, iron-alloy pole pieces and two coils carrying electric current to build up and maintain the flux in the yoke. Only a few kilowatts of electric power are required.

The sample, initially in a demagnetised state is introduced into the pole gap and the field applied in the direction of the fiducial mark (i.e. along the direction of the x component) effectively magnetising in this direction. On applying a field (H) the magnetisation changes slowly at first and reversibly, with increase in the strength of the field (H) the magnetisation changes more rapidly and irreversibly and on reducing the field to zero the magnetisation does not fall to zero but to a remanence value. ( $N_{TRN}$ ).

The field values used for the pilot specimens are 200, 500, 1,000, 2,000, 3,500 and 4,500 oersted. Between each step the intensity of magnetisation of the x component is measured on the spinner magnetometer (spin positions 5 and 6). The intensity of this component should be approximately equal for both spins (within  $\frac{+}{2}$ %), the best value being obtained by averaging the data from these spins.

The material is driven into saturation by a field of appropriate strength in one direction, then the field direction is reversed by turning the sample through  $180^{\circ}$  and placing in the pole gap. Fields of increasing strength are applied in this direction until the magnetisation falls below zero (indicated by a negative x component on the magnetometer printout). A reverse field of 100 oe. is produced, increasing in 100 oe. steps as necessary.

Magnetic hysteresis curves of igneous rocks generally show saturation of magnetisation to be attained at magnetic fields of c. 3,000 - 4,000 oe., and coercive force of only a few hundred oersted (though 1,000 oe. and over if haematite present). (Nagata and Uyeda, 1961,135). Data from the obsidian pilots specimens generally conform to these maxime and the remaining samples

are only treated in saturating fields of 1,000, 2,000 and 3,500 oersted. Graphical presentation of saturation magnetisation curves shows the saturation magnetisation (M<sub>SAT</sub>) the field required to saturate (H<sub>SAT</sub>).

## 4:8 Precision, Accuracy and Estimation of Errors

#### Precision

Precision of remanent magnetisation measurement using the 6 spin procedure is dependent on the noise level of the instrument together with any operational errors. Instrument noise of a mechanical type produced by the rotating mechanism is kept to a minimum by the use of carefully made synthetic materials in manufacture. A greater source of error is that due to electronic noise. In principle, since the magnetometer employs linear integration to calculate a result, all information is weighted equally and reduction in noise level is inversely proportional to the square-root of the observational time (Molyneux, 1971). With the computer integrating over  $2^7$  spins (i.e. 18 seconds per spin), giving a total measurement time of under 4 minutes, the noise level of the machine has been quoted as  $25 \times 10^{-9}$  emu/cc. In theory a spin-time of  $2^{10}$  should reduce the noise level to 9 x  $10^{-9}$  emu/cc.

Checks on the noise level of the instrument using a time-constant of  $2^4$  (the spin time generally used throughout the present work) were made by taking a set of measurements with no obsidian sample present. The noise level indicated by the printout of the three orthogonal directions and defined as the largest of the x, y or z components, was found from a series of runs. The 'worst' component or effective noise level was determined as  $28 \times 10^{-8}$  emu/cc.

The magnetometer is capable of measuring rocks with an intensity of magnetisation as low as  $.5 \times 10^{-7}$  gauss, provided the samples are rotated for long enough spin times, allowing integration of the signal above the noise

level. Obsidian samples yielding low uncorrected intensities (either due to intrinsically low intensity or to very small sample mass) were measured first using  $2^4$  as the spin constant, then repeat measurements were made at a spin time of  $2^6$ , the respective time for 6 spins being approximately 1 minute and 15 seconds. Results obtained using a time constant of  $2^6$  were not considered sufficiently more accurate than those obtained over  $2^4$  spins to warrant the extra time spent. Intensity measurements proved comparable to within 2.5% and declination and inclination respectively to within  $.3^\circ$  and  $.35^\circ$ . A much longer spin-time would be necessary for integration of the signal above the noise-level, however, due to the restricted period of study this was not feasible.

Estimates of reproducibility of intensity and direction of remanent magnetisation have been quoted respectively as  $\frac{+}{2}$  3% and  $\frac{+}{-1}$  1%. To ensure precision of the present experimental measurements, 10 successive 6-spin measurements were made on a selected sample. The results obtained are in accordance with those quoted (see Table 1). Repeat measurements on selected samples were conducted after a time lapse of up to a month, the results are, in general, less precise though still reproducible within 5% for intensity determinations and within 4<sup>0</sup> for direction determinations.

Components of magnetism of the rock platform and the standard deviation for each orthogonal vector of the result were computed for chosen specimens. The maximum noise level of the platform over 89 full measurements is .631 emu/cc x  $10^{-6}$ , though the value is more usually of one or of two orders of magnitude lower. The fiducial mark drawn on the cylindrical container is invariably c.1 -  $2^{\circ}$  in width and can result in some loss of precision in repositioning of the sample on the rock holder after each spin. The standard deviation on the x, y and z components of a measurement shows the operator error in positioning the samples and on average the error observed over the 89 measurements was .094 emu/cc x  $10^{-6}$ . Occasionally very small specimens appeared to be adversely affected by exposure to a.c. field, exhibiting large and erratic directional changes and acquiring a spurious magnetisation. Such results are naturally viewed with extreme caution and where possible duplicate or similar specimens of larger mass were obtained for measurement.

Error due to intensity drift was avoided by regular calibration. Precision of susceptibility measurements is dependent on the ability of the operator to determine correctly the deflection produced on the microammeter. The a.c. susceptibility bridge microammeter used in the present research can be read to 1 micro amp with some degree of certainty, further interpolation of the microammeter scale is impossible. Repeat susceptibility measurements were conducted on selected samples about 1 month after the initial measurements, the results so obtained showed reproducibility within 1 micro amp.

#### Accuracy

The accuracy of both spinner magnetometer and a.c. susceptibility bridge measurement are assured by regular calibration. Specimen shape and magnetic inhomogeneity have little effect on spinner magnetometer accuracy, being largely counteracted by specimen rotation in the 6 spin positions. For accurate determinations of susceptibility with the rock in bulk form, the magnetic material must be uniformly distributed through the predominantly non-magnetic matrix of the sample and errors may occur, with increasing anisotropy. Samples in powdered form should be effectively isotropic and as such are suggested as giving more reliable susceptibility i terminations as measured by the transformer susceptibility bridge. Time shortage precluded the powdering of selected samples, in order to deduce the statistical significance of the error introduced by sample inhomogeneity.

In several instances, with samples of very small mass, no deflection was observed on the microammeter. This did not necessarily reflect the intrinsic 'zero' susceptibility of the material, but gave an indication of the practicable sensitivity limits of the apparatus in use. An empirical check was made on this by observing the deflection produced by comparable or duplicate specimens of larger mass. The practicable mass limit, below which accurate determinations cannot be made on the apparatus in use, depends on the intrinsic susceptibility of the material, the present analyses, however, suggest that erroneous results may derive from low susceptibility obsidian where less than a gram of material is present.

TABLE 1 A TEST ON PRECISION OF MEASUREMENT

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Results of 10 successive 6-spin measurements on a selected sample (MA 185)

Declination	Inclination	Intensity of NRM ( $emu/ccx10^{-6}$ )
47.9	-56.9	253.0
47.2	-55.8	254.1
44.6	-55.2	251.9
46.7	<del>-</del> 55 <b>.</b> 5	256.1
48.0	-56.7	246.7
47.3	-56.9	249.3
45.8	-56.0	248.6
45.0	-56.6	251.3
50.5	-57.8	249.9
45.9	-55.3	248.7

# CHAPTER 5.

#### MATERIAL ANALYSED AND RESULTS OF AMALYSIS

# 5:1:a. <u>Material Analysed</u>

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A total of 216 samples of obsidian were analysed. Table 5 documents the provenance of the material and Table 6, the results of the present analysis together with details of appearance for each piece.

Geological samples comprised material from Aegean, West Mediterranean, Central European and Near Eastern sources. (Figs. 1 - 8), in all 108 samples were analysed and included:-

32 fragments from Melos

22	17	"	Giali
1	H	n	Nisyros
1	11	11	Karpathos
17	11	n	Lipari
2	11	11	Vulcano
1	17	11	Italy
1	H	и	South France
4	11	11	Sardinia
1	11	11	S. Antioco
2	11	11	Pantelleria
4	11	"	Pontine Islands
7	n	"	Sunzary
1	"	"	Slovakia
1 ?	**	IT	Acigol-Topada

108 archaeological obsidian samples included:-

9	fragments	from	Greece
7	11	11	Giali
3	17	n	Karpathos
2	"	**	Lipari
1	н	n	North Africa
4	n	"	South France
27	12	Ħ	Sardinia
12	11	"	Corsica
6	"	11	Pantelleria
10	н	11	Pontine Islands
4	11	n	Italy .
5	11	*1	Hungary
3	11	11	Slovakia
12	11	n	Syria
3	II.	11	Cyprus

The choice of samples was influenced to a large extent by the objectives of the analysis, i.e. to establish the validity and usefulness of the technique. Many of the samples chosen had been previously analysed at the Bradford laboratories by the successful discriminatory technique of Neutron Activation Analysis. The data from NAA provided an independent reference for comparison with results of magnetic analysis.

A distinction is effected in the tables between analyses of irradiated and unirradiated obsidian pieces. When a sample formerly irradiated and analysed (at Bradford by STA) is included the SAA run number is prefixed by an asterisk. If, however, a duplicate unirradiated giece is included, then the SAA run number for the parent irradiated sample is given for reference.

Choice of material was influenced to some extent by availability of samples and in several instances where few or no peological hand specimens were accessible, archaeological material, previously analysed and attributed to source by NAA has been taken as representative of that particular source (i.e. Tell Abu Hureyra and Cyprus archaeological obsidian pieces, attributed a Ciftlik origin by NAA are taken as characterising the Central Anatolian Ciftlik source).

For the purpose of the present analysis samples have been allocated magnetic analysis reference numbers which will be used throughout discussion and interpretation of results (i.e. M.A. Nos. 1 - 210).

Drawings of selected artefactual material are presented in Figure 12.

At a late stage in the present research, after completion of analysis of 212 samples and compilation of Tables 5 and 6, several Pontine Island samples were received from A. Ammerman of Parma University. It was considered of value to include some in the analysis and for this reason the four samples chosen appear at the end of Tables 5 and 6 rather than with the other Pontine Island material analysed.

#### 5:1:b. Tests of Homogeneity

Five large geological hand samples from five geological source localities on Lipari were each broken into 2 or 3 pieces and analysed separately. Samples initially from one geological hand sample are given a single magnetic analysis number but identified by a suffix (a, b or c) and shown bracketed together in Tables 5 and 6. Theoretically, sample homogeneity should ensure identical results from the magnetic analysis. The error observed, due mainly to magnetic enisotropy effects, suggests limits within which discrepancies may be considered as statistically insignificent. (Poble 2). FIG. 12. TYPICAL ARTEFACTUAL MATERIAL ANALYSED

SCALE 1:1





MA 30

MA 31





MA 37







→ MA 38



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MA 33

MA 32



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MA 40

MA 39



MA 41



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District	Sample No.	M <sub>init</sub>	<sup>M</sup> 2000e	<sup>M</sup> 5000e	M sat35000e	Susc.
Roceba Rosse	MA 76a	100	100	100	100	100
	b	72.1	62.2	58.3	74.5	102.4
	с	62.8	62.8	53.9	64.9	98.5
Po $r_{\rm S}$ ia Vecchia	MA 77a	100	100	100	100	100
	Ъ	84.4	86.3	87.1	127.5	149.3
Porgia Vecchia	• • • • • • • • • • • • • • • • • • •	100	100	100	100	100
	Ъ	130.6	134.3	148.8	83.7	78.3
Acqueenlate	NA 91a	100	100	100	100	100
	b	94.0	97.8	97.0	115.0	108.0
dabellol.to	hA 93a	100	100	100	100	100
	b	62.7	62.0	60.3	94.5	79.4

# TABLE 2 PERCENTAGE DIFFERENCE BETWEEN INTENSITY VALUES FOR SUB-SAMPLES FROM LIPARI PARENT SAMPLES.

Note : To effect a comparison in each case values for sub-sample - a - are corrected to 100%.

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5:1:c. Tests of Internal Consistency

As an essential preliminary, representative sample batches (of c. 30 pieces) from the Adhamas flow on Melos and(of c. 20 pieces) from Giali were analysed to demonstrate the degree of internal consistency within a single flow. (MA 1 - 29 and 42 - 63 in table 6)

#### 5:2 Abbreviations used in Tables 5 and 6

Source attribution by both NAA and Magnetic analysis is included in the tables under the heading 'group'. Melos 'A' indicates Melos Adhamas; Melos 'D', Melos Dhemenegaki; Gi, Giali; Li A. Li B. Li C, Lipari A.B and C, three magnetically distinct groups on Lipari; SA,SB,SC,SD, Sardinia A,B,C, and D, four magnetically distinct groups on Sardinia; Pa, Pantelleria; PI, Pontine Islands; Ac A (Wright's localities 2 and 6), Ac B (Wright's locality 3) and Ac C (Wright's locality 5),Acig01 A,B and C, three magnetically distinct groups in the Acig01-Topada region; Ci, Ciftlik; and Carp A,B,C,D, four magnetically distinct groups within Slovakian and Hungarian obsidian. Several entirely new groupings are represented. Where group membership remains unaltered but where the revised literal terminology is used, these individual groupings are equated with the former numerical groupings of Renfrew et al (1964, 1965, 1966, 1968.) in table 3 and the terminology here employed will be further explained in section 6:1.

Where attribution is based exclusively on the results of magnetic analysis the tentative source grouping is preceded by an asterisk in the group column. There attributions by the techniques do not seem to be in agreement. the source grouping is preceded by NAA (suggesting that the group is based on 2 A results) and the implications are discussed in the text. (Chapter 6) It can otherwise be assumed that the two techniques independently suggest similar groupings.

In table 6 the prefix PL before the analysic number indicates a pilot specimen. The abbreviations used by Cann or PRonfrow (1964 ) and Hallam
et al (1976) are retained. Colour of specimens in transmitted light are; R: red; G: grey or smoky; B: black; M: clear (white); E: green; Br: brown. A cross in the column headed Suitability (Suit) indicates irregular or pitchy fracture, otherwise conchoidal fracture can be assumed.

The transparency/translucency scale (T/T) is after Cann and Renfrew (1964):-

0 : not transparent/opaque

1	:	11	11	/almost opaque
2	:	17	17	/fairly translucent
3	:	fairly	"	/almost opaque
4	:	11	н	/fairly translucent
5	:	11	**	/translucent
6	:	tra	nspare	ent/ "

In the 'Remarks column , P indicates pearly lustre; S: striations in transmitted light; V: white spots (vesicles); M: mottled in direct light; C: opaque clouds; G: gritty and Pt: pitchstone.

In table 5 G.H.S. indicates geological hand specimen. This term includes both primary source material and secondary source material, the latter occurring as scatters of obsidian lumps which are either volcanic ejecta or the products of weathering and fragmentation of flows.

## 5:3 Results of Analyses

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### 5:3:a Estimation of Reliability

A problem raised in the context of the present study is to decide on en index of reliability for sample results. The Stability Index(SI) exists es an abstract number computed by observation of changes in remanence direction from step to step with a.c. demagnetisation. (see 4:5). Changes in remanence direction can be have and erratic when very small samples or samples of intrinsically low stability are exposed to a.c. fields. SI thus incorporates both variables and as such should give a true indication of reliability of results. In the first instance computation of the stability index for pilot specimens was used to suggest the optimum field treatment for 'magnetic cleaning' and it seemed that this dimensionless figure could be used as the foundation on which to gauge reliability of resultant discriminations. (table 4). It was therefore decided to compute SI for all remaining samples, but based only on the change in direction of remanence over two increases in alternating field (at 2000e. and 5000e.). The stability index for these samples, however, proved incorparable with that computed for pilot specimens over eleven directional changes and figures are not included in the SI column of table 6. Where an indication of semple stability is useful therefore, pilot specimens from a particular source are often assumed to be typical of samples of similar mass from the like source.

## 5:3:b Homogeneity of Semples

As can be seen in table 2, tests on fragment samples from Lipari (3:1:b) show large variations in intensity values within the whole. The percentage difference in initial intensities (M<sub>init</sub>) in fragments from the same parent sample ranges from 65 (2 fragments from Acquacelda locality k, X.A.Nos. 91 a & b) to 37% (for 2 Gabellotto locality r fragments, N.A.Nos. 93 a & b). Variations on measurements of intensity after a.c. demagnetisation at 2000e. range from prom 6% to 35% 2% - 39%, in measurements of saturation magnetisation (M<sub>sat7500</sub>) wfrom 2% - 49% in low field susceptibility measurements. The variability observed is in cases, greater than could be expected from experimental error and reveals magnetic inhomogeneity of obsidies.

Considered in isolation the apparent magnetic inhomogeneity exhibited by certain sub-samples from Lipari parent samples assumes some importance. Two explanations are postulated to account for the non-equivalence of magnetic values from Lipari sub-samples. Firstly, close examination of appearance characteristics reveal the presence of spherulitic inclusions and vesicles within certain of the pieces. Prehistoric man would naturally have a preference for good quality obsidian, fracturing conchoidally and wherever possible this would preclude the use of material of a spherulitic variety. The non-equivalence of geological Lipari material analysed in the present study with archaeological pieces analysed (having been previously activated and assigned a Lipari origin by NAA ) has been suggested in the text.(p158) Therefore the sample inhomogeneity may reflect the unsuitable spherulitic nature of the obsidian and if such be the case then close agreement of magnetic intensities and susceptibilities from these pieces might not be expected. Indeed the apparent magnetic inhomogeneity might be an indication that the very nature of these pieces precluded their use in prehistory.

A second suggestion to account for the diversity in magnetic values is the use of sub-samples whose total mass falls below the limit suggested on page 146.

It should be strongly emphasised, however, that representative sample batches from the Adhamas flow on Melos and from Giali (totalling some 50 pieces) were analysed as a preliminary test on internal consistency of magnetic properties within a single flow and results showed a relatively good degree of within-source consistency.

It is suggested therefore that the discrepancies observed between certain duplicate pieces of Lipari geological obsidian are atypical and should not invalidate the magnetic approach to obsidian characterisation.

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# TABLE 3.

Present Terminology	Source	Renfrew's Grouping
Melos 'A'	Melos Adhamas	1c
Melos 'D'	Melos Dhemenegaki	1c
Gi	Giali	1a
Li A	Lipari A	4a.
Li B	Lipari B	
Li C	Lipari C	
SA	Sardinia A (Conca Cannas)	2a
SB	Sardinia B	
SC	Sardinia C	6
SD	Sardinia D	
PI	Pontine Islands (Palmarola)	4ª2
Pa	Pantelleria	4b
Ac.A	Acigöl - Topada A	1e - f
Ac.B	Acigol - Topada B	1e - f
Ac.C	Acigöl - Topada C	
LV .	Lake Van area	1g
Ci ·	Çiftlik	26
Carp 1	Erdöbenye	
Carp 2	Tolcsva	1a
Carp 3	Erdöbenye and Csepegö Forras	
Carp 4	Viničky	

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ojective Classification bility Index	:- :-	Unstable 0-0.5	Metastable 0.5-1-5	Poorly Stable 1.5-2.5	Stable 2.5-5	Very Stable 5-10	Very Stable (cont)	Extreme C	ly Stable Over 10	
		MA 203 Abu Hureyra	MA 160 Pantelleria	MA 14* Melos 'A'	MA 16* Nelos 'A'	MA 1*Melos 'A'	MA 99 Tour Tour	MA 2*Me	los 'A'	
					MA 52* Ciali	MA 3* "	MA 104 Tanca Tamis	MA 7* .		
					MA 64 Giali	MA 4* "	MA 109 Monte Arci	MA 8*	"	103
					NA 72* Kerpathos	MA 5* "	MA 131*S.M.Zuarbara	MA 15*	"	•
						MA 6* "	MA 145*Pontine Is.	MA 20*	11	
						1.A 9* "	MA 153 Molise	MA 28*	11	
						HA 10* "	MA 164*Erdöbénye	MA 916*	Acquecalda	
						isa 11* "	MA 168*Tolcsva	MA 936*	Gabellotto	
						MA 12* "	MA 173*Csepego F.	MA 766*	Rocche Ross	se
						Ma 13* "	MA 181*Acig01	MA 95*	Conca Cannas	ទ
						MA 36*Melos 'D'	MA 189 <sup>™</sup> "	MA 112*	Sonnixeddu	
						NA 42%Giali	MA 205 Dhali Agridhi	MA 117	Basi	
						MA 55*Giali		MA 123	Grotta Sa Ud	cca
						HA 77b*Forgia V.		NA 133	Monte Gross	o

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STABILITY INDEX FOR PILOT SPECIMENS

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TABLE 4

N.B. \* indicates a geological hand sample.

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5:3:c. Choice of Discriminating variables.

The data was scanned to determine which of the magnetic variables were likely to prove the betters discriminators. Of the range of magnetic variables considered in the current research some prove better discriminators than others. Examination of results suggested that sources could be best distinguished on the basis of two variables; intensity of effective saturation magnetisation and intensity of natural remanent magnetisation. A third variable, low-field mass susceptibility, also proved on occasion a useful discriminator.

Saturation magnetisation  $(M_{sat})$  is assumed as having been attained on application of a magnetic field of 35000e, this figure  $(M_{sat35000e})$  is quoted as the effective intensity of saturation, thus avoiding subjective estimation of the intensity value by visual examination of the magnetisation curves. In this choice the assumption is implicit that saturating field  $(H_{sat})$  is not diagnostic, an assumption suggested by literature references (page 87) and supported by the present analyses.

Backfield coercivity (Hcr) for the bulk of pilot specimens from all individual areas fell in the range of 150-2500e, a very few showed higher coercive force in the region of 4000e and only one gave a value in excess of 9000e (MA 173) suggestive of the presence of heematite grains within the material. Coercive force is reliant on variability in the structure and grain size of the obsidian and although source-dependent are not sufficiently marked to be source-discriminant.

The strength of remanence in a specimen relative to the quantity of magnetic lineral is expressed in terms of a parameter Q.(the Koenigsberger ratio, after loanigscencer 1938) The ratio of remanent megnetication to induced magnetization is here defined as:

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where MIM is the remanence of a specime: in the earth's field (either the initial intensity or that after step demagnetisation at 200 or 5000e.) and  $\chi^{\rm H}$  is the magnetisation induced by a low field in the laboratory (100e.) Q values, like coercive force are dependent on grain size of the sample, spinel minerals (i.e. magnetite) giving values of one order of magnitude lower than those for hexagonal minerals (i.e. haematite). The ratio can thus give information aiding identification of magnetic minerals within the material. Comparison of Q values for the three intensity values (M<sub>init</sub>, M<sub>2000e</sub>. M<sub>5000e</sub>.) with respect to susceptibility of individual samples can be a valuable indication of whether or not the natural remanence is thermoremanent in origin.

Percentage change from one intensity value to the next with a.c. demagnetisation can also give an indication of magnetic minerelogy. Minerals of spinel form will generally be demagnetised to less than one half of their initial value by 'magnetic cleaning' in fields of up to several hundred oersteds whereas ilmeno-haematite is demagnetised only a little even on exposure to fields in excess of 10000e. The above can only five qualitative information on magnetic minerplogy, in itself this is not sufficient to effect source discrimination.

Independent consideration of each of the major variables permits certain divisions between source materials and demagnetisation and magnetisation curves of selected samples (Figs. 13, 14, 16 and 18) and histograms of susceptibility values (Fig. 20) are included for comparison within and between sources. Discussion of the magnetic data is based on consideration of these three main variables (viz. intensity of natural remanence, intensity of the saturation moment and low field mass susceptibility). There are four separate ways to look at the jata in an attempt at characterisation: firstly two variables may be selected at one time for display on a two dimensional

plot (simultaneous consideration of the two parameters of intensity of natural remanence and saturation magnetisation appears to provide the best discrimination). Secondly, mean and standard deviation on individual measurements of the 5 variables ( $M_{init}$ ,  $M_{200}$ ,  $M_{500}$ , Susc. and  $M_{sat}$ ) may be calculated and plotted graphically. Thirdly a non-statistical approach (i.e. cluster analysis) and fourthly a discriminant function analysis may be attempted. A discriminant function analysis programme was newly available at Bradford but was still being tested on alternative data.

#### 5:3:d. Treatment of Results

It is proposed therefore to display the data in three different ways. In the first instance, where a statistically significant number of geological samples (5 or over) or archaeological NAA source-attributed pieces (weighing over 0.7 gram) from a single source were available the mean and standard deviation on individual measurements of the five variables (M<sub>init</sub>; M<sub>2000e.</sub>; M<sub>5000e.</sub>; M<sub>sat35000e.</sub>; Susc.) were calculated. The mean values of intensity together with appropriate standard deviation values are given in table 7. As mentioned, the coercivity and saturation field values do not vary significantly from source to source and therefore these results are not included here. This treatment suggested the extent of within source variation to be expected and also showed certain patterns emerging within the data.

In an attempt to emphasise differences among sources all other groups of data were compared with that from Melos Adhamas (M.A. 1-29) which was selected as a 'standard' source. The choice of Melos 'A' was not purely arbitrary but rested upon the wealth of data available for that source. Intensity values are shown in graphical form relative to trone of chos 'A' (Fig. 24) and as an aid in source attribution of orchaeological samples of unknown provenance, the spread from unity of intensity values from celos 'A' are also shown. Standard deviations for other source material are plotted, assuming Melos 'A' to be standard.

Intensity of remanent magnetisation for all samples was measured prior to any treatment  $(M_{init})$  then after exposure to a.c. peak fields of 200 and 500 oe. ( $M_{200}$  and  $M_{500}$ ). Calculation of the standard deviation on a measurement for each of the three treatments indicates the group of measurements giving the closest statistical spread. In the alternative data display method, on the basis of this information it was decided to use the values of initial magnetisation  $(M_{init})$  as one of the discriminating variables. The initial intensity (NRM) is composed of primary and secondary components, the presence of an unstable secondary component need not preclude use of the initial magnetisation as a discriminator since the magnitude of TRM and VRM together will reflect the material composition, grain size and the like. Secondary magnetisation acquired by archaeological materials after removal from the flow will be negligible compared to that accumulated over the interval from the time of formation of the flow to the time of deliberate removal of obsidian by man. Thus the secondary components of artefactual material taken from any particular flow should not be very different from secondary components of the source material itself.

In this second form, the results are displayed on a two-dimensional plot with saturation magnetisation (M<sub>35000e</sub>.) as the ordinate and intensity of remanent magnetisation as the abscissa : for convenience a log-log scale is adopted (Figs. 15, 17, 19, 21 and 22). From this treatment certain clear discriminations and groupings within the data are apparent. The second presentation enables incorporation of archaeological material as well as geological data previously excluded (on grounds of insufficient sample numbers). Hence all evailable data is disclayed, if in a correspond subjective manner. Cluster Analysis of selected Aegean and West Mediterranean samples is attempted in an effort to verify or clarify the discriminations effected by subjective visual examination of the magnetic data presented in table 6, and moreover provides a means of displaying, in dendogram form, the data for more than two variables. Clustering procedure and results of Cluster Analysis are discussed in Chapter 7.

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Group	M.A. No.	Di stri ct	Site	Cultural Context	Object	Collected by	From	NAA Run No.	Reference
helos 'A	r 1	Melos	Sta Nychia Nr. Adhamas	(Source)Loc.No.1 Horizon No.1.	G.H.S.	P.H. Shelford	Prof.C.A. Renfrew	584/11	†I
n	2		11	(Source)Loc.No1 Horison No.IV		n	n	584/5	1IV
u	3	11	11	(Source)Loc.No.2 Horizon No.I	11	N	n	584/10	<b>2</b> IA
.,	4	n	"	(Source)Loc.No.2 Horizon NO.III	u	u	u	584/3	2IIIB
11	5	u	u	(Source)Loc.No.2 Horizon No.VI	11	"	11	584/16	2VIB
и	6	н	u	(Source)Loc.No.3 Horizon No.II	"	11	11	584/24	3114
"	7	n	u	(Source)Loc.No.3 Horizon No.II	"	· II	n	584/25	3110
"	8	u	"	(Source)Loc.No.3 Horizon No.VIII	u	11	U	584/26	3VIIIA
"	9	n		(Source)Loc.No.4 Horizon No.I	n	11	u	584/9	4IA
11	10	11	12	(Source)Loc.No.4 Horizon No.II	n	n	u	584/90	4IIB
11	11	n	11	(Source)Loc.No.4 Horizon No.VI	"	n	u	584/2	4VID
"	12	u	11	(Source)Loc.No.4 Horizon No.X	11	n	n	584/6	4XA

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Group	H.A.NO.	District	Site	Cultural Context	Object	Collected by	From	NAA Run No.	Reference
Melos 'A'	13	Melos	Sta Nychia Nr. Adhamas	(Source)Loc.No.4 Horizon No.XII	G.H.S.	P.H. Shelford	Prof.C.A. Renfrew	584/4	4XIIA
11	14	"	11	(Source)Loc.No.4 Horizon No.XV	Ð	11	11	584/14	4XVA
11	15	H		(Source)LocNo.4 Horizon No.XV	10	11	11	584/15	4XVC
11	16	11	"	(Source)Loc.No.4 Horizon No.XVII	11	n	u	584/13	4XVIIB
11	17	u		(Source)Loc.No.5 Horizon No.II	11		11		5IIA
11	18	11	"	(Source)Loc.No.5 Horizon No.III	11	u	11	584/23	5111A
*1	19	n	"	(Source)Loc.No.5 Horizon No.V	11	11	n	584/8	5VA
11	20	n	11	(Source)Loc.No.5 Horizon No.VI	"	n	n	584/19	5VIA
"	21	11	n	(Source)Loc.No.5 Horizon No.VII		11	n	584/21	5VIIB
11	22	11	II	(Source)Loc.No.5 Horizon No.VIII		n	u	584/28	5VIIIC
11	23	IT	11	(Source)Loc.No.5 Horizon No.X	"	u	11	584/29	5XA
11	24	11	v	(Source)Loc.No.5 Horison No. X	11	"	11	584/22	5xd

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Group	M.A. No.	District	Site	Cultural Context	Object	Collected by	From	NAA Run No.	Reference
Melos 'A'	25	Melos	Sta Nychia Nr. Adhamas	(Source)Loc.Nob Horizon No.I	G.H.S.	P.H. Shelford	Prof.C.A.Renf	rew 584/17	61
11	26	11	u	(Source)Loc.No.6 Horizon No.III	IJ	"	11		6111
**	27	11	11	(Source)Loc.No.6 Horizon No.IV	11	11	18	584/1	6IVD
н	28	n	n :	(Source)Loc.No.6 Horizon No.V	**	11	17	584/12	6V
11	29	11	II	(Source)Loc.No.6 Horizon No.VI	u	"	11	584/27	641
"	Ň	Sacedonia, Greece.	Servia	Late Meolithic	Flake	Cressida Ridle	y Cressida Ridle	ey *583/1	E10/D-F 10/D Baulk H 3732
**	31	"	11	и	Blade	11	н	*583/3	EO/C
11	32	11	11	Early Neolithic Varytimidnes V	Flake .	11	11	<b>*5</b> 8 <u>3</u> /5	3601(SF 952)
ж. Н	33	Thessaly, Greece	Lagonissi	Unstratified	17		Dr. J. Nandris	5	
Helos 'b'	34	Melos	Dhenengaki	(Source)Loc.No.7 Horizon No.I	G.H.S.	P.H. Shelford	Prof.C.A.Renfi	rew 584/7	71
11	35	u		(Source)Loc.No.7 Horizon No.II	11	88	11	584/20	711

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Group	N.A. No.	Distri <b>ct</b>	Site	Cultural Context	Object	Collected by	From .	NAA Run No.	Reference
Melos 'D'	36	Melos	Dhemenegaki	(Source)Loc.No.7 Horizon No. III	G.H.S.	P.H. Shelford	Prof.C.A. Renfrew	584/18	7111
NAA Melos 'b'	37	Macedonia, Greece.	Servia	Late Neolithic	Flake	Crestida Ridley	Cressida Ridley	*583/2	E10/A 3737
11	38	11	11	Middle Neolithic/ Late Neolithic	Blade	H	11	*583/4	F10 <b>/d</b> 3014
11	39	11	11	Early Bronze Age or Late Neolithic	Flake	H	u	*583/6	F20/A 7 H20
<b>≁</b> II	40	Thessaly, Greece.	Lagonissi	Unstratified	Blade		Dr. J. Nandris		_
- 11	41		**	"	ıt		u		12.
Gi	42	Giali	Area A (see map)	(Source)1st 'Fransect O.m. Bottom	G.H.S.	R. Torrence & J. Cherry	R. Torrence & J. Cherry	623/16	A1 1
11	43	"	u	(Source) 1st Transect 12.m. Bottom.	18	n	11	623/20	Δ5 5
11	44	n	u	(Source) 1st 'fransect 24.m. from Bottom.	11	u	11	623/24	A9 9
II	45	"	41	(Source) 2nd Transect 34.m. a.s.l.	"	u	n	623/27	A10 10

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NAA RUn Collected by M.A. No. District Cultural Contemt Object From Reference Group Si te No. (Source) 2nd R. Torrence & 623/27 G.H.S. R. Torrence & A12 12 46 Ciali Area A Gi J. Cherry Transect 54.m.a.s.l. J. Cherry (see map) 11 (Source) 3rd 11 11 A13 15 47 ... 11 " Transect Bottom, Sea Level (Source) 3rd 11 11 A15 17 48 11 11 11 11 Transect Top of Cliff (Source) 1st n 11 11 623/31 B16 1 Area B 49 11 11 Transect 20.m. a.s.1. B18 3 💀 (Source) 1st .. ... 623/33 n 50 11 11 .. Transect . 623/35 (Source) 1st n \*\* \*\* B20 5 51 11 11 11 Transect 623/36 (Source) S. end of " 11 B21 11 52 11 u 11 B, Sea Level 624/1 (Source) N. end of 11 \*\* 11 B22 53 11 н 11 B, Cliff Top (Source) N. end of 624/2 B23 \*\* 11 et 17 11 11 54 area B. from outcrop

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Group	H.A. No.	Distri <b>ct</b>	Site	Cultural Context	Object	Collected by	From	NAA Run No.	Reference
Gi	55	Giali	Area C	(Source) 1st Transect at S. end samples taken Horizontally from S. to N.	G.H.S.	R. Torrence & J. Cherry	R. Torrence & J. Cherry	624/4	C25 1
u	56	u	11	(Source) 1st Transect 12.m. along.	"	11	11	624/8	C29 5
11	57	u	"	(Source) 1st Transect 24.m. along	"	11	11	624/12	<b>C</b> 33 9
<b>11</b>	53	"	H	(Source) 2nd Transect at N. end from N. to S.	"	11	11	624/14	C35 1
11	59	н	Area D	(Source) 1st Transect. Middle.	u	n	11	624/20	D41
"	60	n	Area E	(Source) S. Wall of Valley	n	n	11	624/22	E43
11	ю <b>1</b>	н	u	(Source) N. Cliff of Valley at Head	u	n	11	624/23	E44
"	62	11	Area G	(Source) Eop of Tallest Hill. Eastern Side.	u	n	11	624/24	G45
12	63	H	Area C	(Source) 2nd Transect at N. End from N.to S.	11	n	11	624/17	C38 4

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Group	M.A. No.	District	Site	Cultural Context	Object	Collected by	From	NAA Run No.	Reference
* 0i ?	64	Giali	Beach at N.E. end of Giali Bay	Unstratified	Rolled Pebble	R. Torrence & J. Cherry	R. Torrence & J. Cherry	626/2	46/2
* " ?	65	11	"	11	11	H	11	626/9	46/10
* " ?	66	"	"	n	"	н	"	626/15	46/17
* " ?	67	11	n	н	н	"	u		46/26
* " ?	68	11	n	n	u	"	n		46/61
* " ?	69	11	n	н		11	"		46/68
* " ?	<b>7</b> 0	"	".	н		u	"		46/76
-	71	Nisyros (Greece)	n	G.H.S.	G.H.S.	u	"	624/25	
-	72	Karpathos (Greece)	Vrontounta	G.H.S. Flint	n	Christos Doumes	Prof.C.A. Renfrew	*460/4	A 226
-	73	11	n	Unstratified Flint.	Flake	11	n	*460/3	A 225
-	74	"	11	H	Lump	19	11	*461/1	A 220
-	75	11	11	11		88	11	*461/3	A 222
★ I,i A	$(^{76} a)$	Lipari	Rocche Rosse	C.H.S. (see map)	G.H.S.	0. Williams	0. Williams	467/1	
·* II	76 ъ	11		n		11	"	11	
* "	( <sub>76 c</sub>	"	n :			y	п	"	

From M.A. No. Site Cultural Context Object Collected by Group District NAA Run Reference No. ۰. Forgia Vecchia (Source) Loc. h. 467/9 O. Williams 0. Williams \* Gi Lipari G.H.S. 77a Top of Forgia Vecchia n 11 11 11 п 11 77b 11 \* 11 467/8 11 (Source) Loc. i. 11 11 11 # 11 78a n Bottom of Forgia Vecchia 11 11 . 11 н 11 11 11 ¥ 11 78b (Source) Loc. j. 11 н # 11 79 11 Acquacalda 11 in situ. but 116. redeposited bed W. end of Acquacalda 60 н (Source) Loc. 1. 11 Ħ 11 467/4 <del>x</del> 11 11 Boulder on Acquacalda beach E. end. G.H.S. BM93466 11 п 81 11 <del>\*</del> 11 11 11 B.M. Nat.Hist. 236/2 \* 11 82 11 Rocche B.M. Nat.Hist. BM50540 Rosse 236/3 83 11 Campi n 11 11 IJ BNi50482 \* 11 Bianco 467/6 11 **Vulcano** 11 11 0. Williams O. Williams Vii 84 ★ II

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Group	M.A. No.	District	Site	Cultural Context	Object	Collected by	From	NAA Run No.	Reference	•
* Gi	85	South France	Font-Marthe	Neolithic (Chasseen)	Blade	M.Jean Courtin	M.Jean Courtin	188/4		
n	86	Lipari		Capri (Neolithic)	Lump	M. Cavalier	M. Cavalier	194/5		
¥ 11	87	Italy	Biferno Valley Molise	Appenine Bronze Age	Flake	G. Barker	G. Barker		G1 VII 12 A2	
* " ?	ક્ષ	Italy	Biferno Valley Molise	11	"	"	11		G VII 3 D1	
NAA Li	89	Lipari	11	Capri (Neolithic)	Ħ	M. Cavalier	M. Cavalier	195/6		
NAA Li	90	North Africa	Bechater		Chip	M.Jean Courtin	0. Williams			117.
* Li B	91a	Lipari	Acquacalda	(Source) Loc. k. Acquacalda Beach E. end.	G.H.S.	O. Williams	O. Williams			
* "	91Ъ	11	u	u	"	11	п			
* 11	92	u	N	(Source) Loc. m. Acquacalda Beach E. End.		u	11			
* Li C	93a	11	Gabellotto	(Source) Loc. r.	11	28	u	467 <b>/7</b>		
* "	93Ъ	11	11		11	"		19		
-	94	n	Volcano, Della Fossa	G.H.S.		Dr. P. Baker	Dr. F. Baker	230/6	474/1T	

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Group	M.A. No.	No. District Site		Cultural Context	xt Object Collected by		From	NAA Run No.	Reference
SA	95	Sardinia	Conca Cannas	(Source) 1st Flow	G.H.S.	B. Hallam	B. Hallam	572/6	
"	96	11	n	(Source) 2nd Flow		11		<b>572/1</b> 0	
"	97	11	Ile Monica Nr. Str. of Bonifacio	Unstratified Neolithic	Flake	M.Jean Courtin 1960's	n M.Jean Courtin	185/7	
11	Ģð	South France	Marres, Rematuelle	Southern Chasseen	Blade	M.Jean Courtin Excavs. 1967.	n M.Jean Courtin	188/2	
11	Ģà	11	Tour Tour (Var)	u	14	M.Jean Courtin 1960's	n M.Jean Courtin	188/5	
* "	100	Sardinia	Tanca Tamis	Unstratified	Lump	B. Hallam	B. Hallam	572/3	13.
<del>х</del> и	101	<b>H</b> .	Grotta Sa Ucca (30 Km. S.S.E. of Sassari)		Chip	Dr.D.H. Trump	Dr.D.H. Trump	558/6	т/10
* 11 ?	102	n	Grotta Del Inferno (4 Km. S.E. of Sassari)		u	u	n		T/14
* SA? or SC?	103	"	Perdas Urias	Unstratified	Lump	B. Hallam	B. Hallam	572/4	
* SA?	104	11	Tanca Tamis	n	Scraper		n	572/3	
* SA?	105	Corsica	Monte Grosso	Level IVb Late Neolithic	Flake	M.F. de Ianfian	dhi Dr.P.Philips		M.G.3047
* SA?	106	"	12	Test. Pit-Sondage Late Neolithic	11	u	11		M.G. 673

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Group	M.A. No.	District	Site	Cultural Context	Object	Collected by	From	NAA Run No.	Reference
SB	107	Sardinia	Monte Arci	Unstratified	Flake	M.Jean Courtin 1960's	M.Jean Courtin	185/2	
11	108	"	11	n				185/3	
"	109	н	11	п	17	11		186/1	
II	110	Corsica	Currachiaghiu Nr. Levie.	Level V Late Neolithic c. 2980 b.c.	u	M.F. de Ianfiancia Excavs. 1968	i M.F. de Lanfrancthi	201/5	С5ъ 173
"	111	Sardinia	Grotta Sa Ucca		Chip	Dr. D.H. Trump	Dr. D.H. Trump	558/1	т/б 🚍
* 11	112		Sonnixeddu	Unstratified	Lump	B. Hallam	B. Hallan	572/7	0
* "	113	n	Santa Maria Zuarbara	11	"	u	n	5 <b>72/</b> 2	
* " ?	114	17	11	11	11	13	11	11	
* "	115	11	Tanca Tamis	"		11	n		
SC	116	u	Ile Monica Nr. Str. of Bonifacio	Neolithic	Flake	M.Jean Courtin	M.Jean Courtin	185/6	
H I	117	Corsica	Basi (Coffres De)	Upper Neolithic	n	н	11	189/1	
n	118	11	Vascolaccio	18	Lump	M.F. de Lenfrancthi	11	200/3	C 3a
H	119	n	Coffres de Tivolaggio	Upper Neolithic	11	n	t	200/7	C 4a

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Group	M.A. No.	District	Site	Cultural Context		Collected by	From	NAA Run No.	Reference
SC	120	South France	Marres	Neolithic (Chasseen)	Chip	M.Jean Courtin	M.Jean Courtin	211/9	
"	121	Italy	Servirola a San Polo (Emilia)	,	11		Dr. D. Evett	229/6	
	122	Sardinia	Grotta Sa Ucca		n ·	Dr. D.H. Trump	Dr. D.H. Trump	558/2	т/3
*"	123	11	11			11	n	558/3	т/4
*"	124	11	**		Scraper	"	n	584/33	т/5
*"	125	11	11		Flake	11	n	558/4	т/7
*"	126	u	11		Scraper	"	n	558/5	т/9
*"	127	**	11		Chip	11	n		'T/11
*"	128	n	u		Flake	n	"	584/32	т/12
*"?	129	11	Grotta Del Inferno		Сһір	u	11	584/31	T/13
*"	130	11	11		Flake	"	11	558/8	т/15
*"	1,31	11	Antioco Porcu E. of Santa Maria Zuarbara	G.H.S.	G.H.S.	B. Hallam	B. Hallam	572/1	
*"	132	13	11	Unstratified	Lump	"	11	572/2	

Group M.A. No. District Site Cultural Context Object Collected by From NAA Run Reference No. \*SA 133 Corsica Monte Grosso Level IVb Late M.F. de Lanfrancthi Dr. P. Philips Flake M.G.3029 Neolithic **\***11 134 11 IF. 11 11 11 Level II Late M.G.3165 Neolithic ¥ 11 135 11 11 11 Level IV Late Blade н M.G. 660 Neolithic ¥Ⅱ 136 11 11 11 Scaffa Piana Flake S.P.1525 \*11 137 11 n Level XXB Ħ 11 Blade S.P.3346 138 н жn Dr. D.H. Trump Dr. D.H. Trump Ariguina Middle Neolithic No. 2467 Laver XVb 1970. 572/5 \* SD 139 Sardinia Perdas Urias G.H.S. G.H.S. B. Hallam B. Hallam 11 11 11 572/4 \*11 140 Unstratified Lump 11 11 Summit, Monte н Flake Dr. P. Philips ¥11 141 Arci. G.H.S. (Rhyolite Dept. of Mineral-Dept. of Miner- 198/7 142 Nr. S. Antioco G.H.S. Sardinia Pitchstone) ogy & Petrology, alogy & Petrology Cambridge. Cambridge. G.H.S. н ? 143 Italy Marostica Dr. C.Cornaggia 189/7 Castiglioni 11 ti -Harvard 144 South ~ University France M.Jean Courtin 189/2 11 M.Jean Courtin Ч 145 Palmarola n Pontine

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Group	M.A. No.	District	Site	Cultural Context	Object	Collected by	From	NAA Run No	Reference
<b>b1</b>	146	Pontine Islands	Palmarola	G.H.S.	G.H.S.	M.Jean Courtin	M.Jean Courtin	189/3	
NAA PT	147	11	Ponza	Unstratified	Blade	Dr.G. Buchner	Dr.G. Buchner	189/4	0ES. 18
11	148	Italy	Palidoro (Latium)	Lower Neolithic	Core		Dr. D. Evett	211/2	
11	149	n	Grotta Sant'angelo (Calabria)	Lower-Middle Neolithic	Flake		u	211/3	
11	150	11	Grotta Delle Felci (Capri)	Middle-Late Neolithic	Blade		"	211/6	
13	151	11	Monte Circeo (Latium)		Chip		u	229/1	
11	152	u	Campo Mezzomonte (Latium)	Unstratified	Blade		11	229 <b>/2</b>	
* 1-1	153	n	Molise	Neolithic Probably Early	11	G. Barker	G. Barker		C186 II 1
-	154	Pontine Islands	Ponza, Chiaja Di Luna	G.H.S. (Pitchstone)	G.H.S.	B.M. Nat.Hist.	B.M. Nat.Hist.	232/8	BM56612
-	155	17	Procida Island.	11	"	н	"	235/5	BM456
Рз	156	Pantelleri	8	Unstratified	17		Mrs.P. Guido	193/1	
	157	17		11	n		"	193/2	
11	158	"		11	n		*1	193/3	
n	159	11 ·			11		11	193/4	

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Group	M.A. No.	District	Site	Cultural Context	Object	Collected by	From	NAA Run No.	Reference	
Ра	160	Pantell <b>eria</b>	Citta	Unstratified	Flake		Dr.C. Cornaggia Çastiglioni	193/5		
H	161	11	11	"	11		11	193/6		
?	162	11	Salto La Vecchia	G.H.S.	G.H.S.	Dr.De Michele Geol.Mus. Milan				
dAA -	163	tt	Mida, E. of Cudda	G.H.S. (Pitchstone)	н	B.M. Nat.Hist.	B.M. Nat.Hist.	236/7		
*Carp A	164	N.E. Hungary	Erdöbenye	G.H.S.	11	O. Williams	0. Williams	615/7	3	123.
*Carp A	165	S.Hungary	Zeng <b>ov</b> arkony Nr. Pecs.	Lengyel	Blade		Janu <b>a</b> Pannonius Museum, Pecs.	587/6	1936.14.6/ 3d.b./936	
<del>⊼</del> 11	166	N.Hungary	Tizsacsege	E. Linear Bandkeramik	Blade			589/4	3	
¥ 11	167	S.E. Slovakia	Bohdanovce	Bukk	II		Vychodoslovenste Museum Kosice CSSR	593		
*Carp B	168	N.E. Hungary	Tolcsva	G.H.S.	G.H.S.	0. Williams	0. Williams	614/7	4	
* "?	169	S.E. Slovakia	Bohdanovce	Bukk	Blade		Vychodoslovenste Museum Kosice CSSR	593		
*Carp B or C	170	N.Hungary	Tizsacsege	E. Linear Bandkeramik	11			589/5		

Group	M.A. No.	District	Site	Cultural Context	Object	Collected by	From	NAA Run No.	Reference
*Carp В or C?	171 ??	S.E. Slovakia	Kasov	Neolithic? Surface Find.	Blade		Slovenske Narodne Museum Martin CSSR	593	
*Carp C	172	N.E. Hungary	Csepegö Forras	G.H.S.	G.H.S.	0. Williams	O. Williams		
* 11	173	17	"	u	17	n	11	612/3	3
* "	174	n	Erdöbenye	n	n	и	11	615/6	2
<del>*</del> "	11/5	н	11	11	u		12		
¥ "	176	S.Hungary	Zengovarkony Nr. Becs	Lengyel	Blade		Janus Pannonius Museum, Pecs.	587/6	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
	177	N.E. Hungary	Lebuj Tokaj	G.H.S.	G.H.S.	O. Williams	0. Williams		
*Carp D	) 1 <b>7</b> 8	Slovakia	Viničky	G.H.S.	11	11		611/1	
-	179	S.Hungary	Babarc. Nr.Pecs.	Lengyel	Core	Dr. Eva Harf	Janus Pannonius Museum, Pecs.		
* A <b>C</b> A	180	Cappadocia	E. of Acigöl, Acigöl-Topada	(Source) Loc. 2.	G.H.S.	Peter Benedict	G.A. Wright	355/1	A 200 OB 676
<del>*</del> 11	181	U1	. "	11	11	n	u	355/2	a 201 Ob 677
<del>*</del> 11	182	n	**	u	u	n	n	355/3	A 203 OB 673

Group	M.A. No.	District	Site	Cultural Context		Collected by	From	NAA Run No.	Reference
*Ac A	183	Cappadocia	E.of Acigöl, Acigöl-Topada	(Source) Loc. 2.	G.H.S.	Peter Benedict	G.A. Wright	355/4	A 204 OB 674
* 11	184	"	11	n	11	11	11	355/5	A 205 OB 675
<del>*</del> 11	185	11	11	11	11	11	11	355/6	A 206 OB 678
≠ H	186	n	30Km. S. of Acigöl	(Source) Loc. 6.	n n		n	356/3	A 210 OB 559
<del>*</del> 11	137	n	11	11	11	11		356/4	A 211 OB 660
* 11	188	11	11	II	11	n	u	356/5	A 212 OB 661
*AC B	189	11	E.of Acigöl, Acigöl—Topada	(Source) Loc. 3.	H	11	n	355/7	a 20 <b>7</b> Ob 666
*AC C	190	11	n	(Source) Loc. 5.	88	u	"	356/2	a 209 UB 654
¥ 11	191	11	n	<b>H</b>	11	n	n	356/2	A 209 OB 654
L.V.	192	Syria	Tell Abu Hureyra	eyra Late Aceramic Exca <b>v.</b> Level 23.		Andrew Moore 1973 Excavs.	Andrew Moore 1973 Excavs.	445/4	B23 F150 1
"	193	17	n	Late Aceramic Excav. Level 53.	31	18	0	449/13	B53 F95 2
n	194	93	11	Ceramic Neolithic Excav. Level 30	<b>Blade</b>	17	n	459/6	B30 F47

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Group	M.A. No.	District	Site	Cultural Context	Object	Collected by	From	NAA Run No.	Reference
L <b>.V.</b>	195	Syria	Tell Abu Hureyra	Ceramic Neolithic Excav. Level 30	Bladelet	AndreW Moore 1973 Excavs.	Andrew Moore	459/11	B30 F54
11	196	n	11	Late Aceramic. Excav. Level 10	u	11	II	*449/11	B10 F15
MAA"	197	0	H	Ceramic Neolithic Excav. Level 30.	Blade	*	11	*459/6	B30 F47
Çi	198	n	11	Early Aceramic Excav. Level 147.	Bladelet	n	n	445/11	B147 F228
11	199	u	н	Ceramic Neolithic Excav. Level 30.	Tang of Projectil Point	" e	н	459/4	B30 F44
"	200	"	U	Ceramic Neolithic Excav. Level 32.	Flake	Andrew Moore 1972 Excavs.	11	466/3	72–B30 F68
n	201	11	n	Ceramic Neolithic Excav. Level 40.	H	n	n	466/10	72B40 F89 3
u	202	н	11	Ceramic Neolithic Excav. Level 30.	Blade	Andrew Moore 1973 Excavs.	"	*459/12	B30 F55
11	203	n	11	Ceramic Neolithic Excav. Level 28.	Badelet	Andrew Moore 1972 Excavs.	11 11	*468/2	72 B28 F4
18	20 <b>4</b>	Cyprus	Dhali Agridhi	Aceramic Neolithic Area 2.76 Locus 015 S.W.	Chip	Yechiel.M.Lehavy	Yechiel M.Lehavy	610/21	732

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Group	M.A. No.	District	Site	Cultural Context	Object	Collected by	From	NAA Run No.	Reference
Çi	205	Cyprus	Dhali Agridhi	Aceramic Neolithic Area 31.76 Locus 003 N.E.	Blade Fægment	Yechiel M.Lehavy	Yechiel M.Lehavy	610/22	777
11	206	11	11	11	Chilp	11	11	610/23	855
PI	207	Pontine Is.	Pedel Freno		Scraper	A. Ammerman	A. Ammerman		
11	208	Italy	Fondi nr		Flake	12	33		02-1
11	209	Ponza	Sperlonga Punta del		Chip	11	n		PP3
11	210	**	rapa II		Flake	11	11		PP2

					(In	emu/cc x	10 <sup>-0</sup> )	emu/oe	1			emu/cc				
9eight (⊕n)	: M.A.NO.	Nat. Source	Origin	Group	M <sub>init</sub>	M <sub>2000e</sub> .	M5000e.	Susc.	QO	Q <sub>200</sub>	Q <sub>500</sub>	M sat35000e.	SI	Colour S	uit T/T	Remark
n <b>.</b> 549	PL 1	*	Adhamas	Melos 'A'	842.4	<b>7</b> 94•5	545.3	63.48	13.3	12.5	8.6	26364.2	7.85	B–G	0	Р
2.040	PL 2	*	u	"	615.3	684.9	464.3	41.16	15.0	16.6	11.3	25026.6	24.78	B-G	0	P
0.465	PI. 3	*	v	"	1392.4	1302.2	559 <b>.</b> 8	70.54	19.7	18.5	7.9	41087.5	7.57	B-G	0	P
0 <b>.</b> 96 <b>7</b> .	PI 4	*	**	"	1099.0	1005.3	345.7	67.84	16.2	14.8	5.1	30434.4	14.22	B-G	0	PS
2.6::2	Pi. 4	*	**	11	1213.3	1308.9	615.7	51.97	23.3	25.2	11.9	21427.2	7.81	BG	0	PS
0.7	Pi ℓ	×	"	"	403 <b>.7</b>	483.6	261.4	28,12	14.4	17.2	9.3	26 <b>09</b> 8.5	7.44	G	0	Р
1.3%	PL 7	*	11	"	681.4	760.8	496.4	63.33	10.9	12.0	<b>7.</b> 8	241 <b>33.</b> 8	20.78	B-G	0	PS
1.101	<u>91. –</u>	*	н	17	735.6	648.5	386.0	44.69	16.5	14.5	8 <b>.</b> ń	32910.3	16.21	B-G	0	P
1.50%	PL 9	×	18	11	546.3	616.4	370.6	49.10	11.1	12.6	7.6	30616.2	11.84	EG	0	Р
1.131	PL10	*	"		376.0	492.8	<b>290.</b> 8	64.23	5.9	7.7	4.5	28 <b>7</b> 35 <b>.8</b>	11.01	C	0	Р
5.176	PL11	*	11	"	631.5	758.0	383.0	33.27	19.0	22.8	11.5	29339.0	5.78	E-G	0	PS
0.612	PL12	*	11	11	538.5	644.6	349.3	50.25	10.7	12.8	7.0	22525.6	7.38	BC	0	PS
4.299	PL13	*	11	83	592.2	741.0	405.1	43.87	13.5	16.9	9.2	28872.9	13.32	B-G	0	Ρ
1.503	PI.14	*	11	11	439.8	592.7	332.2	64.11	6.9	9.3	5 <b>.2</b>	23315.3	2.34	G	0	Р
1.049	PL15	*	11		456.2	609.5	361.6	58.63	7.8	10.4	6.2	31880.6	25,28	B-G	0	Ρ
0.528	PL16	*	**	11	1088.5	569.6	291.5	77.65	14.0	7.3	3.8	33212.4	4.66	G	0	PS

TABLE 6. RESULTS OF ANALYSES

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Veight (gm)	М.А.ИО.	Nat. Source	Origin	Group	<sup>M</sup> init	<sup>M</sup> 2000e.	<sup>M</sup> 5000e.	Susc.	۵ <sub>0</sub>	Q <sub>200</sub>	<sup>ର୍</sup> 500	<sup>M</sup> sat3500oe.	SI	Colour	Suit	т/т 1	lemarks
5.425	17	*	Adhamas	Melos 'A'	1038.0	896.9	484.1	53.10	19.6	16.9	9.1	30486.6		B–G		0	PS
2.466	18	*	v	**	1074.0	1065.2	806.0	5 <b>5.7</b> 0	19.3	19.1	14.5	33012.8		G		0	PS
6.944	19	*	"	u	2384.2	1986.9	1207.2	<b>49.</b> 68	4 <b>と</b> ₊0	40.0	24.3	19990.6		G		Û	PS
1.407	FF50	*	11	"	1115.1	965.4	617.5	68.93	16.2	14.0	9.0	30337.6	27.85	G		0	PS
4.650	21	*	н	18	1731.9	1465.4	1005.9	11.90	145.5	123.1	84.5	31938.4		G		0	PS
1.928	22	*	"	u	988.5	1388.8	466.4	71.24	13.9	19.5	6.6	32227.2		B–G		0	PS
5.9%	23	*	"		997.6	841.8	584.7	34.86	28.6	24.2	16.8	18038.9		B–G		0	P 10
1.329	24	*	u		1310.0	1089.5	711.3	70.96	18.5	15.4	10.0	26919.4		B-G		Ģ	ъ .
6.517	25	A	"	"	536 <b>.</b> 3	344.5	194.5	49.08	10.9	7.0	4.0	22073.5		G		U	Р
5.505	26	*	n	"	H0 <b>7.</b> 0	638.6	365.0	24.7	24.7	19.6	11.2	18671.0		G		U	Ρ
5.221	27	*		**	548.6	499.0	247.6	30.84	17.8	16.2	8.0	20641.5		B–G		υ	PSM
1.756	PL23	*	u	**	596.9	446.6	267.0	80.55	7.4	5.5	3.3	22494.6	18 <b>.7</b> 8	G		0	PS
1.358	29	*	н	11	1198.6	1021.7	517.8	66.42	18.1	15.4	7.8	27151.2		BG		0	₽M
2.401	30		Servia	"	841.5	570 <b>.</b> 0	375.7	38.42	21.9	14.8	9.8	18996.4		G		0	S
0.672	31		11		544.9	457.6	169.1	57.96	9.1	7.9	2.9	26013.3		G		0	s
1.855	32			n	526.3	424.2	263.0	40.89	12.9	10.4	6.4	25298.2		G		0	PM
0.411	33		Lagonissi	* "	1222.1	954.3	410.8	64.84	18.9	14.7	6.3	34412.2		B-G		0	

leight (gm)	N.A.No.	Nat. Source	Origin	Group	<sup>M</sup> init	<sup>M</sup> 2000e.	<sup>M</sup> 500oe.	Susc.	ବ	Q <sub>200</sub>	Q <sub>500</sub>	<sup>M</sup> sat3500oe.	SI	Colour Suit	т/т	Remarks
.874	34	*	Dhemenegaki	Melos 'D'	2 <b>38.</b> 8	236.3	165.5	5 <b>3.</b> 95	4.4	4.4	3.1	14652.5		G	0	PS
.228	35.	*		"	493.8	409.9	267.7	50.08	9.9	8.2	5.4	15008.3		G	0	PS
) <b>,</b> 890	PL <b>3</b> 6	*	n	10	267.4	216.9	152.7	80,62	3.3	2.7	1.9	15098.7		G	0	PS
) <b>.1</b> 91	37		Servia	NAA Melos 'D'	539.9	386.3	235.4	75.13	7.2	5.1	3.1	30057.6		G	2	S
341	33		н	"	125.8	141.4	82.8	66.13	1.9	2.1	1.3	23400.6		G(E)	0	Р
.023	39		11	11	251.8	210.5	87.5	70.14	3.6	3.0	1.3	10324.4		G (E)	0	P
.186	40		Lagonissi	* " ?	501.1	374.7	220.2	33.06	15.2	11.3	6.7	16045.0		G	1	C 130.
.206	41		11	* " ?	431.2	226.5	201.8	19.90	21.7	11.4	10.1	18352.9		B-G	0	-
P.110	PL42	*	Ciali	Gi	100.3	67.0	51.7	29.15	3.4	2.3	1.8	4251.9	5.07	G(Br)	5	VC
0 <b>.7</b> 84	43	*	11	"	62.9	82.1	54.3	13.07	4.8	6.3	4.2	3829.4		G (Pr)	5	VC
.967	44	*	n	"	98.7	85.7	70.8	25.44	3.9	3.4	2.8	2849.9		G	5	VC
•516	45	*	n	11	206.2	121.3	91.2	51.39	4.0	2.4	1.8	4186.4		G(Pr)	4	VC
3.300	46	*	u	"	101.0	80.5	54.2	26.09	3.9	3.1	2.1	3848.4		G (Br)	5	VC
.237	47	*	11	. "	117.7	48.3	42.2	23.20	5.1	2.1	1.8	3213.3		2 <b>6</b> (Br)	6	VS
•423	48	*	n	u	41.2	73.8	54.2	24.49	1.7	3.0	2.2	4467.6		G(Br)	5	VC
.229	49	*		u	101.9	89.6	66.8	40.03	2.6	2.2	1.7	4376.9		G(Br)	4	VC

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Veight (gm)	M.A.No.	Nat. Source	Origin	Group	<sup>M</sup> init	<sup>M</sup> 2000e.	<sup>M</sup> 5000e.	Susc.	QO	Q <sub>200</sub>	Q <sub>500</sub>	<sup>M</sup> sat3500oe.	SI	Colour	Suit T/T	Rema <b>rks</b>
0.960	50	*	Giali	Gi	. 97.4	73.2	58.1	17.08	5.7	4.3	3.4	4800.0		G	4	VC
1.231	51	*	11	n	207.8	168.7	147.2	69.94	3.0	2.4	2.1	8779.0		G(Br)	5	VC
1.948	$PL^{t, r}$	×	11	11	113.9	41.9	51.8	28.41	4.0	1.5	1.8	4434.8	3.43	G	4	VC
1.661	53	*	11	11	321 <b>.9</b>	61.5	31.1	34.56	9.3	1.8	0.9	3243.6		G	3	VC
1.946	54	*	11	11	141.1	103.3	71.2	17.91	7.9	5.8	4.0	4943.5		G	4	VC
1.434	56JA	*	11	Ц	261.1	213.7	137.7	32.88	7.9	6.5	4.2	6688.3	12.32	G	5	v
1.563	55	*	11	11	392.5	338.7	236.3	48.53	8.1	7.0	4.9	16119.1		G	4	VC
1.226	57	*	n	11	128.0	102.9	73.6	11.70	10.9	8.8	6.3	4377.7		G	3	VC
1.047	53	*	11	11	300.9	235.0	143.2	25.45	11.8	9.2	12.1	12614.8		G(Br)	3	vc
0.947	59	*	11	11	62.9	53.8	39.8	54.12	1.2	1.0	0.7	3143.8		G(Br)	4	v
1.202	60	*	11	11	341.1	294.9	223.9	17.05	20.0	17.3	13.1	4893.8		B-G	2	v
1.827	61	*	11	11	300.2	264.5	186.4	61.71	4.9	4.3	3.0	9444.3		G	3	v
1.172	62	*	n	11	38.7	38.2	29.5	12.24	3.2	3.1	2.4	2747.4		G <b>(</b> Br)	4	vc
0.808	63	*	11	11	32.3	50.1	46.8	12,69	2.6	4.0	3.7	1957.1		WG	6	VS
4.937	1-1.64		H	*" ?	16.0	17.2	<b>9</b> •8	3.32	4.8	5.2	3.0	1230.4	4.18	BG	0	
0.835	65		"	*"?	18 <b>.</b> 7	36.4	20.1	4.62	4.1	7.9	4.4	1341.7		G	5	S
6.963	66		0	* " ?	3.1	3.3	4.2	1.47	2.1	2.2	2.9	306.2		G	4	
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Weight (pm)	: M.A.No.	Nat. Source	Origin	Group	Minit	<sup>M</sup> 200 <b>0</b> e.	<sup>M</sup> 5000e.	Susc.	QO	Q <sub>200</sub>	Q <sub>500</sub>	<sup>M</sup> sat35000e.	SI	Colour	Suit	т/т	Remai	rks
0 <sup>.</sup> .799	67		Giäli	*Gi ?	45.5	41.2	30.6	12.83	3.6	3.2	2.4	2001.4		G(E)		6	٧s	
0.864	68		11	*"?	19.5	25.4	26.4	4.75	4.1	5.4	5.6	991.1		G(Br)		6	С	
•957	69		11	*"?	8.2	12.9	10.8	1.05	7.8	12.3	10,3	674.6		G		6	S	
3.146	<b>7</b> 0		n	* " ?	2.9	8.1	8.3	3.26	0.9	2.5	2.6	758.5		G(Br)		6	CS	
1.927	71	*	Nisyros	-	25.3	24.2	23.3	11 <b>.7</b> 0	2.2	2.1	2.0	1127.5		G(Br)		4	٧S	
3.251	PL72	*	Karpathos	-	16.9	7.5	7.5	-	-	-	-	70.7	2.90	Br.	Х	0	Flint	tΡ
2.153	73		u		20.4	0.8	9.2	-	-	-	-	111.9		В	Х	0	**	P
1.535	74		11	-	27.2	9.4	14.4	-		-	-	270.1		Br	Х	1	11	$\mathcal{F}$
6.159	75		97	-	9.1	4.2	3.2	-	-	-	-	36.9		В	X	0	11	P
3.699	765	*	Rocche Rocse	*Li A	386 <b>.7</b>	330.8	258.1	13.86	27.9	23.9	18.6	9078.1		G		1	F	
3.755	PL76b	*	11 11	<del>*</del> "	265.8	205.9	150.5	14.19	18.7	11.0	10.6	6767.5	23.47	G		2		
1.502	76e	*	11 11	* "	242.8	207.9	139.0	13.65	17.8	15.2	10.2	5893.3		G		4	С	
1.233	PL774	*	Forgia Vecchia	<del>⊀</del> 11	216.1	177.9	134.0	8.31	26.0	21.4	16.0	3014.7	10.62	G		3	C	
0.661	<b>7</b> 7b	*	u	* II	182.3	153.5	115.9	12.41	14.7	12.4	9.3	3842.8		G(Br)		4	C	
3.085	<b>7</b> ta	*	11	* "	415.8	344 <b>.7</b>	260.6	15.95	26.1	21.6	16.3	8563.0		G		1	VCM	
1.969	76b	×	н	* "	543.2	462.9	387.8	12.49	43.5	37.1	31.1	7164.7		G		1	VM	132.

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Weight (gm)	M.A.No.	Nat. Source	Origin	Group	M init	<sup>M</sup> 2000e.	<sup>M</sup> 5000e.	Susc.	QO	Q <sub>200</sub>	Q <sub>500</sub>	Msat35000e.	SI	Colour S	buit	т/т	Remark	9
6.543	79	*	Acguacelda	# 11	299.8	238.8	173.8	14.41	20.8	16.6	12.1	7235.2		B–G		3	С	
0.789	80	*	11	¥ 11	223.0	195.2	124.3	2.60	85.8	75.1	47.8	5372.7		G		4	VC	
2.721	81	*	Lipari Is.	<del>×</del> II	287.1	242.4	180.7	11.30	25.4	21.5	16.0	7564•3		G(Br)		3	VC	
0.926	62	*	Kocche Kosse	<del>×</del> 11	251.9	228.6	166.5	4.43	56.9	51.6	37.6	6572.4		B–G		5	v	
1.198	83	*	Campi Bianco	<del>*</del> 11	544.3	477.5	365 <b>.1</b>	10.27	53.1	46.5	35.6	12712.6		B-G	х	2	v	
1.954	ö4	*	Vulcano	<b>₩</b> II	336.7	173.5	66.9	31.47	10.7	5.5	2.1	8811.5		B-G		2	C	
0.280	65		Font-Harthe	"?	120.8	152.4	152.8	-	-		-	3762.6		G		4	GV	-
0.221	cit		Lipari		252.3	289.6	233.6	9.28	27.2	31.2	25.2	4285.2		G		6		
0.143	ô7		Molise	<del>×</del> 11	291.6	255.1	315 <b>. 3</b>	14.34	20.3	17.8	23.5	6760.5		B-G		3	CM	
0.500	88		11	* " ?	97.7	70.8	102.5	8.20	11.9	8.6	12.5	5383.6	•	W-G		5	C	
0.136	89		Lipari	NAA Li	153.3	212.1	253.1	-	-	-	-	803.4		G		6		
0.095	90		<b>Bechater</b>	u 11	597.1	186.3	128.9	21.58	27.7	8.6	6 <b>.</b> 0 <sup>.</sup>	259.6		Е		1		
1.113	91a	*	Acquacalda	* Li B	8655.8	7316.4	<b>3655.</b> 8	138.14	62.7	58.9	26.5	98740.0		B-G		0	Р	
2.466	PL91b	*		* 11	8133 <b>.</b> 2	71534	3547.2	<b>149.23</b>	53.5	47.9	23.8	113575.2	16.25	B–G		0	Ρ	
2.665	92	*	11	* 11	12353.1	10747.1	7831.6	107.88	114.5	99.6	72.6	119788.1		B–G	x	0	GPt.	
3.360	93a	*	Gabellotto	* Li C	9602.6	8450.4	3245 <b>.7</b>	444.94	21.6	19.0		171727.6		B-C	X	0	GV	
9.159	Р1.93Ъ	×	<b>n</b> ,	¥ 11	6024.1	5239.3	1955 <b>.7</b>	<b>353.4</b> 0	17.1	14.8	5.5	162347.1	20.08	B–G	X	0	G	

Vei <sub>E</sub> ht (ლი)	M.A.No.	Nat. Source	Origin	Group	<sup>M</sup> init	<sup>M</sup> 2000e.	<sup>M</sup> 5000e.	Susc.	QO	Q <sub>200</sub>	Q <sub>500</sub>	Msat35000e.	SI	Colour	Sui t	т/т	Remarks
2.839	94	*	Vulcano Della Fossa	-	20 <b>7</b> 0•3	1 <b>7</b> 92.6	1315 <b>.</b> 9	52,66	39.3	34 <b>,</b> 0	25.0	43404,9		G		2	V
3.496	PL95	*	Conca Cannas	SA	511 <b>.7</b>	456.5	364.8	17.59	29.1	26.0	20.7	8051.0	45.31	G		4	CS
10.915	96	*	11 11	"	282.8	229.2	151.7	14.65	19.3	15.7	10.4	5514.6		G		4	CS
0.721	97		Ile Monica	11	533.5	.454•4	425.6	28.43	18.7	16.0	15.0	10451.0		G		4	SGC
0.196	9B		Marres		978.3	1123.0	951.1	20,92	46.8	53.7	45.5	13211.8		G		4	SG
0.216	PL99		Tour Tour		828.0	648.5	635.6	9.49	87.3	68.3	67.0	12319.6	6.20	G		4	
17.000	100		Tanca Tamis	* SA	195.2	166.3	119.7	14.88	13.1	11.2	8.0	6575.1		BG		0	
3.113	101		Grotta Sa Ucca	* SA??	159.6	144.1	107.2	11.19	14.3	12.9	9.6	4566.8		G(Br)		4	S
0.735	102		Grotta Del Inferno	* SA?	58.4	51.7	40.5	33.56	1.7	1.5	1.2	10731.9		G(Br)		4	C
1.419	103		Perdas Urias	* SA? o SC?	r 3069.5	<b>26</b> 8 <b>3.</b> 3	2456 <b>.</b> 8	21.67	141.7	123B	113.4	11630.6		В		1	
1.121	I <b>L 1</b> 04		'Tanca Tamis	* SA?	285.0	225.6	169.9	20.12	14.2	11.2	8.4	2896.8		G		5	SGC
0.403	105		Monte Grosso	* SA?	589 <b>.1</b>	493.4	421.6	25.43	23.2	19.4	16.6	14402.6		G		4	GC
0.385	106		n n	* SA?	1124.5	1025.6	862.2	15.97	70.4	64.2	54.0	12860.1		G		5	SG
0.852	107 `		Monte Arci	SB	152.9	157.8	103.2	43.31	3.5	3.6	2.4	18557.1		G		4	S
Weight (gn)	M.A.110.	Nat. Source	Origin e	Group	M init	<sup>M</sup> 2000e.	<sup>M</sup> 5000e	Susc.	QO	g200	Q <sub>500</sub>	<sup>M</sup> sat3500oe.	SI	Colour	Suit	т/т	Remarks
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<b>9.</b> 967	108		Monte Arci	SB	394.3	<b>322.9</b>	228.8	65.11	6.1	5.0	3.5	24331•4		G		4	SGC
0.521	<b>5</b> 109		18 13	u	440.3	350.5	246.1	59.02	7.5	5.9	4.2	24701.3		G		4	SG
0.070	110		Curacchia- chiu V	"	1021.5	1026.7	948.8	58 <b>.</b> 57	17.4	17.5	16.2	17845.5		BG		1	
2.475	111		Grotta Sa Ucca	H	380.0	314 <b>.1</b>	282 <b>.9</b>	48 <b>.</b> 04	7.9	6.5	5.9	18823.0		B–G			CS
3.428	PL112		Sonni xeddu	* SB	721.7	607.9	533.1	20.93	34.5	29.0	23.3	17625.7	30.21	В		1	С
4.728	113		Santa Maria Zuarbara	* 11	180 <b>.</b> 6	<b>213.</b> 5	123.5	55.94	3.2	3.8	2.2	17944.3		B–G		0	s _
2.603	114		11	* " ?	1243.8	1095.6	1014.6	34.65	35.9	31.6	29.3	23317.0		BG		0	35. S
4.075	115		Tanca Tamis	* "	861.2	741.3	616.2	39.24	22.0	18.9	15.7	17584.8		В		0	
1.124	116		Ile Monica	SC	<b>43680 b</b>	29370.1	7695.0	76.60	5 <b>7</b> 0.2	383.4	100.5	104412.1		B-Br		0	
0.326	117		Basi	**	24296,8	20671.7	14573.4	81.75	297.2	252.9	178.3	66292.1	15.17	G		0	
0.100	118		Vascolaccio	n	2445.8	2154.9	1698.0	82.00	29.8	26.3	20.7	46116.0		В		0	
0.244	119		Tivolaggiu	11	43811.4	36006.3	21722.7	75.61	579.4	476.2	287.3	107225.4		В		0	
0.112	120		Marres	*1	6500.2	5582.6	3303.7	54.91	118.4	101.7	60.2	49220.4		BG		1	S
0.060	121		Servirola A San Polo	II	1460.5	1432.2	440.4	170.83	8.6	8.4	2.6	57289.2		B-Br		0	
0.813	122		Grotta Sa Ucca	11	11396.1	10646.5	8149.0	113.47	100.4	93.8	71.8	50397.6		B–G	x	0	SPt

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Weight (gm)	M.A.No.	Nat. Source	Origin	Group	<sup>M</sup> init	<sup>M</sup> 2000e.	<sup>M</sup> 5000e.	Susc.	QO	9 <sub>200</sub> 9500	<sup>M</sup> sat3500oe	. <sup>SI</sup>	Colour	Suit	Т/Т	Remarks
1.092	PL123		Grotta Sa Ucca	* SC	6502.8	5965.5	3985.9	90.11	72.2	66.2 44.2	66292.1	20.68	BG	X	0	Pt
2,863	124		u	<del>*</del> 11	13404 <b>.7</b>	11018.7	4361.1	100,42	133.5	109.7 43.4	71489.3		B-G		0	
0 <b>.87</b> 2	125		"	* "	7883.5	7402.0	6830.7	98 <b>.</b> 74	79.8	75.0 69.2	65899.1		B-G		0	
1.508	12.		u	* II	5568.2	2517.9	871.0	36.70	151.7	68 <b>.6 23.7</b>	30258.5		G-Br		3	S
1.371	127		"	* "	12 <b>32</b> .9	901.1	555.2	<b>95.7</b> 0	12.9	9.4 5.8	29304.2		BG		0	V
0.302	12:		"	* "	10030.6	<b>9</b> 3 <b>7</b> 8.2	8568.1	97.13	103.3	101.7 88.2	46333.7		B-C		1	GPt
0.955	12.5		Grotta Del	* "?	2034.8	1859 <b>.8</b>	1461.3	52.94	38.4	35.1 27.6	31156.1		G		4	S
0.839	130		Interno "	* "	15253.8	11119.7	5994.6	58.64	260.1	189.6102.2	55558.3		B–G		0	S
1.100	PL131	*	S.M.Zuarbara	* "	6359.5	5483.4	2367.1	138.64	45.9	39.6 17.1	86067.8	9.07	B–G		0	S
0.049	132		11	* "	8592.1	7724.0	4924.8	128.49	66.9	60 <b>.1 3</b> 8 <b>.</b> 3	171252.2		G		0	PVS
0.470	HL 133		Monte Grosso	* "	12719.4	12200.7	7583.3	52.34	243.0	233.1144.9	40465.4	18.16	BG		0	SPt
0.323	1/54		"	* 11	12789.4	10995.2	7589.9	88.85	143.9	123.8 85.4	53368.4		B–G		0	Pt
0.177	135		11	* "	4411.5	4376.6	4017.1	69.49	63.5	63.0 57.8	78087.0		BG		2	Pt
0.415	136		Scaffa Piana	* "	10636.4	9581.1	6979.1	74.10	143.5	129.3 94.2	87699.7		В		0	Pt
0.253	137		11	* "	1645.7	1233.2	537.6	89.13	18.5	13.8 6.0	29042.3		В		0	Pt

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Voight (gm)	N.A.NO.	Nat. Source.	Origin	Group	M init	<sup>M</sup> 2000e.	<sup>M</sup> 500 <b>o</b> e.	Susc.	Q <sub>O</sub>	0 <sub>200</sub>	Q <sub>500</sub>	<sup>M</sup> sat3500oe.	SI	Colour	Sui t	т/т	Remark	cs
1.175	PL153		Molise	* PI	134.8	107.0	97.6	40.13	3.4	2 <b>.7</b>	2.4	29088.5		B-G		1	vs	
1.696	154	*	Ponza	-	10.7	20.7	11.6	2.42	4.4	8.6	4.8	192.7		B-E	X	0	Pt	
1.778	115	-	Procida Is.	-	182.4	119.7	51.6	1578.60	0.1	0.1	0.03	17103.9		В	Х	0	Pt	
6.273	150		Pantelleria	Ра	8.9	82.6	119.0	7.51	1.2	11.0	15.9	155.4		E		1	3	
0.271	1-1		11	"	71.6	57.7	83.6	-	-	-	-	164.8		Е		0		
õ <b>.</b> 115	153		11	u	99.1	201.3	211.8	35.65	2.8	5 <b>.7</b>	5.9	402.6		E		4	С	
0.319	159		11	"	35.3	8 <b>7.</b> 0	75.2	6.43	5.5	13.5	11.7	218.6		E		1	S	
<b>0.</b> 199	PL160		Citta	"	41.4	71.3	43.8	20,60	2.0	3.5	2.1	158.6	0.79	Е		0		13
0.158	161		"	"	65.2	162.6	182.6	-	-	-	-	273.1		E		0		7.
6. 199	162	*	Selto la Vecchia	?	0.69	6.5	2.4	11.72	0.1	0.6	0.2	20.0		B–G		0		
0.743	163	*	Pantelleria	NAA -	9.1	26.3	28.9	5.52	1.7	4.8	5.2	320.6		B-E		0	Pt	
0.748	EL164	*	Erdöbenye	*Carp A	1800.3	1171.6	110.8	16.44	109.5	71.3	6.7	21897.5	9.59	G		1	S	
0.209	165		Zengovan-	<del>*</del> "	4127.1	490.6	129.9	39.23	105.2	12.5	3.3	15524.5		W		5	S	
0.311	160		Tizsacsege	* "	2029.6	205.8	165.6	46.14	44.0	4.5	3.6	12863.6		W		5	S	
1.627	167		Bohdanovce	<del>*</del> "	4429.3	1450.4	164.3	32.76	135.2	44.3	5.0	12776.5		W		5	S	
5.609	PL16H	*	Tolcsva	*Carp B	281.3	273.5	226.3	13.52	20.8	20.2	16.7	8486.4	13.47	B-G		1		
0.981	169		Bohdanovce	* "?	76.0	47.3	38.5	29 <b>.2</b> 6	2.6	1.6	1.3	8239.5		₩–G		5	S	
0.557	170		Tizsacsege	* " B or C	270.3	114.7	35.5	25 <b>.7</b> 6	10.5	4.5	1.4	12021.4		W-G		5		

Weight (gm)	A.No.	Nat. Source	Origin	Group	<sup>M</sup> init	M <sub>2000e</sub> .	<sup>M</sup> 5000e.	Susc.	Q <sub>O</sub>	Q <sub>200</sub>	Q 500	Msat35000e.	SI	Colou	r Suit	т/т	Remarks
2.004	1,38		Ariguina	* SC	1 <b>5</b> 550 <b>.</b> 4	13708.3	10582.8	90.02	172.7	152.3	117.6	69420 <b>.7</b>	•	B–G		0	Pt
4.067	139	*	Perdas Ūrias	* SD	3.9	0.9	3.6	4.03	1.0	0.2	0.9	225.5		Br		4	VC
1.106	140		11 11	<del>*</del> 11	7.6	18.5	17.3	3.71	2.1	5.0	4.7	302.6		G(E)		3	VCS
0.546	141		Monte Arci	<del>*</del> 11	28.2	43.5	43.3	-	-	-	-	117.0		G		5	VC
2.076	142	*	S. Antioco	-	5560.3	950.3	579.6	254.82	21.8	3.7	2.3	22 <b>7</b> 540 <b>.1</b>		G	x	0	SPt
0 <b>•7</b> 20	<b>1</b> 43	*	Marostica	?	86 <b>.</b> 5	61.9	50 <b>.</b> 0	8.54	10.1	7.2	5.9	5059.2		G		5	
3.232	144	*	South France	?	<b>7</b> 3.5	67.7	. 30.3	448.33	0.2	0.2	0 <b>.1</b>	2927.4		BG	x	0	Pt
1.612	PL145	*	Palmarola	PI	267.3	243.3	188.2	66.13	4.0	3.7	2.9	31904.4	8.46	G		0	138.
0.797	146	*	11	11	184.0	145.3	94.0	59.16	3.1	2.5	1.6	35562.6		G		4	
0.133	147		Ponza	NAA PI	83.8	205.0	185.0	30.83	2.7	6.7	6.0	12928.6		G		4	
0.020	148		Palidoro	NAA "	733.3	1 399.9	1278.7	205.00	3.6	6.8	6.2	27194.3		G		2	С
0.296	149		Grotta Sant 'Angelo	NAA "	111.4	49.5	123.3	13,85	8.0	3.6	8.9	10559.2		B-G		1	
0.267	150		Grotta Delle Pelci	NAA "	81.7	90.8	76.7	15,36	5.3	5.9	5.0	9867.3		G		2	- 20
0.0%5	151		Wonle Circeo	NAA "	340.8	<b>355.</b> 0	319.4	24.12	14.1	14.7	13.2	40692.3		<b>B</b> C		1	С
0.148	152		Campo Mezzomonte	NAA "	1625.5	1457.6	1687.8	27.7	58 <b>.7</b>	<u>5</u> 2.6	60,9	20961.0		BG		1	C

0ri<sub>l</sub> in Q<sub>200</sub> Jeight M.A. ho. Nat. Q<sub>500</sub> Group <sup>M</sup>sat3500oe. SI <sup>M</sup>init <sup>M</sup>2000e. <sup>M</sup>5000e. Susc. Q Colour Suit T/T Remarks ( 178) Source 0.312 137 × Acigöl 195.8 196.2 82.4 13.14 6.3 7115.2 5 \*Ac A 14.9 14.9 W-G 0.374 11 153 ¥ II 35.4 50.6 9.38 4.5 3.8 5394.2 \* 42.3 5.4 ₩--G 4 М 0.927 PL1:0 ¥ 11 \*Ac B? 899.0 808.1 602.0 37.59 23.9 21.5 16.0 34694.4 5.69 B-G 3 S 11 1.211 190 ¥ \*Ac C 165.3 161.0 113.7 18.62 8.9 8.7 6.1 15652.4 G 3 СМ 0.637 191 × 11 \* 11 247.8 187.3 145.2 19.31 12.8 9.7 7.5 21596.4 G 3 М LV 274.7 298.5 202.5 1626.0 W-G(E)0.829 192 Tell Abu С 129. 4 -Hureyra ш 11 1.059 122.6 131.8 59.6 2179.0 G-Br 193 1-3 S --2.639 11 11 423.6 461.5 360.1 194 4175.3 B-G --1-3 S 0.703 11 57.8 45.2 710.6 ₩-E(Br) 11 49.7 195 ---2-4 C \_ 0.273 11 140.7 115.0 127.4 11 1951.8 Br196 1-3 -\_ 0.147 197 11 742.9 730.5 262.2 5276.8 NAA" B-G 1-3 CS --340.9 0.925 Ħ Gi 292.1 272.0 2.20 155.0 132.8 123.6 4814.3 5 198 G 4.174 Ħ 11 2049.6 1987.9 1397.0 5.40 379.6 368.1 258.7 21490.9 В 0 199 11 u. 688.2 633.3 266.7 7939.6 724.9 2.58 245.5 5 S 2.181 200 281.0 G 876.0 321.1 9282.6 11 905.4 223.0 2-3 7.939 201 11 628.8 2.82 310.6 G 561.7 7626.9 5 0.093 11 n 285.4 181.1 202 W-G

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₩e (	ight gm)	M.A.No.	Nat. Source	Origin	Group	M init	<sup>M</sup> 2000e.	<sup>M</sup> 500 <b>0</b> e.	Susc.	QO	Q <sub>200</sub>	Q <sub>500</sub>	Msat3500oe.	SI	Colour Suit	т/т	Remarks
1.	683	171		Kasov	*Carp B	? 213.8	96.0	<b>3</b> 8.7	36.54	5.9	2.6	1.1	12696.5		W-G	4	S
, 0 <b>.</b>	310	172	*	Csepegö	*Carp C	639.3	656.9	601.0	19.84	32.2	33.1	30.3	10767.7		B-G	2	S
0.	30:5	PL 173	*	HOTTAS	* "	544.7	481.6	454.5	6.66	66.8	72.3	68.2	12094.0	10.63	B-G	1	
0.	408	174	*	Erdöbénye	* 11	781.1	664.9	563.6	15.07	51.8	44.1	37.4	9721.9	•	B-G	1	S
0.	533	175	*		H 11	631 <b>.7</b>	580.6	452.5	19.23	32.9	30.2	23.5	12906.0		B-G	0	
0.	427	176		Zengovar-	<del>*</del> 11	561.9	92.0	110.1	28.81	6.1	3.2	3.8	10921.5		W	5	
0.	326	177	*	Tokaj		<b>9</b> 56.6	<b>903.</b> 5	724.3	25.15	38.1	35.9	20.2	18900.8		В	0	140.
с.	600	178	*	Viničky	*Carp D	? 263.2	25 <b>5.</b> 0	191 <b>.1</b>	6.63	39 <b>•7</b>	38.5	28,8	4616.1		G	4	S
6.	714	179		Babarc	?	15.9	14.8	6.8	20 <b>.7</b> 6	0.8	0.7	0.3	7205.3		B-G	2	С
1.	54 <b>1</b>	180	*	Aci <i>µ</i> öl	*Ac A	373.4	343.1	269.1	14,63	25.5	23.5	18.4	10832.3		G	4	VC
1.	518	PL 181	*	н	<del>*</del> 11	260.9	233.7	179.8	8.10	32.2	28.9	22.2	6261.2	5.12	G	4	CS
2.	149	182	*	н	¥ 11	299.5	267.3	213.3	17.17	17.4	15.6	12.4	8200.3		G	4	
7.	013	183	*	U .	* 11	167.3	140.7	108.9	17.54	9.5	8.0	6.2	6293.2		BG	3	С
0.	437	184	*	**	* "	230 <u>.</u> 4	136.2	161.4	14.07	16.4	9 <b>.</b> 7	11.5	5205.1		W-G	5	
1.	913	185	*	**	# 11	253.0	237•9	185.4	9.64	26.2	24.7	19.2	7519.3		G	2	CS
6.	<b>77</b> 3	186	*		* 11	336.1	328.4	146.0	15 <b>.81</b>	21.3	20.8	9.2	11945.7		W-G	5	

					The second s														
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Weight (gn)	M.A.No.	Nat. Source	Origin	Group	M init	<sup>M</sup> 2000e.	<sup>M</sup> 5000e.	Susc.	QO	Q <sub>200</sub>	Q <sub>500</sub>	Msat3500oe.	SI	Colour Suit	т/т	Remarks
0.092	PL203		Tell Abu Hurevra	Çi	656.1	328.0	318.8	-	-	-	-	6614.7	0.36	W-G	6	
1.285	204		Dhali Agridhi	11	767.8	732.3	573.0	36.69	20.9	20.0	15.6	17039.1		G	4	
0.602	PL205		u	n	636.9	627.7	564.4	27.24	23.4	23.0	20.7	24996.8	9.08	G	4	C
0.318	206		11	11	546.9	556.4	494 <b>.7</b>	12.89	42.4	43.2	38.4	20352.6		G	4	C
15.483	20 <b>7</b>		Pedel Freno	PI	40.3	37.9	23.5	23.82	1.7	1.6	1.0	23834.3		BG	0	Pt
1.111	208		Fondi	н	36.5	26.5	73.1	38.76	0.9	0.7	1.9	27525.2		B-G	0	SPt
1.327	209		Punta del	. 11	18.6	56.1	49.9	91.34	0.2	0.6	0.5	20291.3		В	0	
1.586	210		rapa "	u	54.6	60.9	13.3	76.45	0.7	0.8	0.2	9358.5		BG	1	SPt -

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#### CHAPTER 6.

## DISCUSSION AND INTERPRETATION OF RESULTS

#### 6:1 Introduction

Comparison of the magnetic data from the four regions under consideration; the Aegean, the West Mediterranean, Central Europe and the Near East, shows a degree of overlap. This does not invalidate use of magnetic analysis as a discriminant technique provided certain a priori assumptions are made. For the purpose of the present attempt at characterisation it is supposed, for example that little or no interaction exists between the West Mediterranean and Aegean, or indeed the West Mediterranean and Mear East, and that in general obsidian from a geological source locality will have been predominantly utilized in the immediate environs. Indeed all archaeological material to date analysed by NAA from Sardinia and Corsica has been attributed to a Sardinian source and therefore with respect to the magnetic analysis of Sardinian and Corsican material (where MAA results are not available) the assumption of a Sardinian origin is immilicit.

Evidence to date from Çiftlik, Melos and Giali.does, however, suggest the reciprocal traffic of obsidian between South Anatolia and the Aegean area and it is thus important to attempt distinction between the three sources. Carpathian obsidian has been identified by NAA as occurring, together with Pontine Island and Lipari obsidian, on the North East Adriatic coast. This situation most probably reflects the bounds of distribution rather than the overlapping distribution of the sources involved, thus in this case, source separation though raturally lesirable is of lass importance than in the situation of reciprocal traffic in cheldian between tractors.

Discussion of the anomatic iste all progressively reveal limits and nerits of the method as a discriminatory technicye.

In accordance with the revised group terminology set up by Hallam et al., (1976) for West Mediterranean obsidian, I have adopted a literal terminology, equated with Renfrew's original numerical classification in Table 3. Subdivisions suggested in the course of discussion (designated A, B, C etc.) are essentially hypothetical and tentative and should be viewed in the manner of a provisional explanation of the observed data.

## 6:2 Implications of the Magnetic Data

#### 6:2:a. Aegean Geological and Archaeological Material

Tabular and graphical presentation of geological Aegean obsidian data (table 6, Fig. 15) suggests a generally clear discrimination between Melian and Gialian material. A distinction between the Velian flows of Adhamas and Dhemenegaki appears also to emerge from magnetic analysis of the geological material, though it must be noted that only three Melos 'D' (Dhemenegaki) samples were available for analysis.

Magnetic results from three archaeological pieces (M.A. 33, 35, 37) previously irradiated and ascribed a Melcs 'A' (Adhanes) source, fall well within the range of variability observed within Melos 'A' geological material. This is highly satisfactory, unfortunately the simple discrimination is confused when source ascription by NAA of further irradiated artefactual material is compared with that suggested by magnetic results. Thus, notwithstanding the fact that three Melos 'D' geological samples showed intensity values (as a result of identical treatment) strikingly homogeneous within themselves yet distinct from Adhemas material some explanation must be postulated to account for discrepancies in source crouping of erchaeolo ical external by the two technicues. Several elternatives spearer themselves; firstly that irradiation of semples for UAA mi bt in some way effect the councils pro-rties of the material, speardly that semple means of the be of importance, and thirdly the



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possible anomalistic magnetic nature of the samples. On the basis of additional analyses the first suggestion can be riled out and the last, though feasible, seens unlikely. The second alternative is supported by the material analysis; of three samples attributed a Melos 'D' source by NAA, only one falls remotely within the expected range of variability and this sample weighs in the region of 1 gm. (A.A. 39) in contrast to the two remaining pieces weighing respectively, c. 0.2 and 0.3 gm. (N.a. 37 and 38). Magnetic analysis of the three archaeological Melos 'A' pieces (M.A. 33, 35, 37), weighing from c. 0.7 to 2.4 gm: harmonize well with the available source analyses. With very small samples a genuine problem appears to be that of integrating a very weak signal above the noise level of the magnetometer system in use. It is impossible to place a strict limit on size since intrinsic sample magnetisation must be taken into account but in avoidance of erroneous group attributions, a sample mass limit in the range of 0.7 - 1 gm. is suggested below which results though included in the tables must be treated with reserve. Clearly there is a need for further investigation of the magnetic properties of geological Dhemenegaki obsidian.

Results of analyses of Gialian geological material from a range of sampling localities on the island show in general a high degree of internal consistency supporting the suggestion that areas A.B.C and D (see Fig. 2) are all part of the same flow (Torrence and Cherry, personal communication). Material from area C exhibits a greater range of mognetic variability than that from the other locations : two pieces (N.A. 56 and 58) gave notably higher initial intensity and saturation values than the bulk of Gialian material. Unhapping these two pieces destroy the complete distinction between welow 'D' and Giali obsidian as based exclusively on the results of exempted analysis without recourse to separance cliteria one contal modpress (Fig. 15).



Interesting implications emerge from consideration of the Giali beach data (N.A. 64-70). Seven samples (probably representative of artefactual material, though altered by water action) for analysis were chosen from 80 collected on the beach at the north-east end of Giali bay. Selection of samples for analysis was not completely arbitrary: based on detailed appearance criteria Torrence and Cherry (personal communication) suggested the presence within this batch of two visually distinct groups of obsidian; the one containing inclusions typical of the geological specimens and the other containing few or no inclusions, choing dark clouds, blotches, streaks and striations and appearing more transparent than in situ geological samples. Samples were selected with a view to covering the range of appearance characteristics reported. Magnetic data from these pieces proved internally homogeneous (contra Torrence and Cherry) yet distinct from the bulk of Gialian geological material. A non-Giali origin for pieces found in such close proximity to an abundant source seems inherently unlikely and it may be supposed either that the true range of variability of Giali geological material is not represented or that water action has altered the magnetic mineralogy of the beach samples. Since haematite may form from decomposition of paramagnetic ironbearing minerals (i.e. olivines, amphiboles, pyroxenes) often associated with weathering the latter suggestion seems pleusible and could account for the low saturation intensity exhibited by the beach samples.

Based solely on close visual inspection of the present analytical data two possible source candidates might be provisionally proposed. Two geological hand samples (area C, N.A. 63 and area G, H.A. 62) from Giali provide magnetic data in accordance with that from the beach samples and though little can be assumed on the basis of two samples it would be interesting to see if further samples from these localities of at prove compatible with intensities and suscectibilities of the beach data. The second alternative of a non-Giali origin,

suggested itself on exa instion of a simple reological sample from Nisyros (M.A. 71) which provided intensity values in very close agreement with the beach data. Indeed Giali lies between the islands of Misyros and Kos, only a few kilometres distant from Misyros itself. If, however, either attribution is to be accepted then it must be assumed that marine action has radically altered the macroscopic characteristics of some of the beach specimens analysed. Confirmation or refutation of any of the above suggestions must await the results of elemental analyses.

Four samples from the site of Vrontounta, Karpathos (M.A. 72, 73, 74, 75) reputedly one geological sample and three archaeological pieces, were included in the enalysis. The pieces proved internally consistent yet distinguishable from the glassy obsidian of the nearby islet of Ginli by virtue of their very low intensity of saturation magnetisation and their 'zero' susceptibility values. Reservations previously mentioned (4:8) regarding the practicable sensitivity limits of the a.c. susceptibility bridge should be ineffectual since cample mass is in the range of c. 1.5 - 6 gm. and an intrinsic'zero' susceptibility can be accepted as meaningful. Dubsequent elemental analysis of samples from Karpathos by MAA has, however, proven the material to be other than obsidian and perhaps flint. The pitchy and irregular nature of the fracture of the material from Karpathos would in general have precluded its une for artefact manufacture when an inherently more attractive material was available close at hand.

Soturation and designatisation curves of Aerean material have been plotted (Figs. 15 and 14) and show clearly the different respondes of the obsidian to saturating and alternating fields. The discrimination effected amongst the Aerean island courses on the casis of intensity of extension moment and intensity of natural represent to matination is well likelaged in Fig. 15.

6:2:b. <u>Mest Mediterranean Geological and Archaeological Material</u>

Detailed inspection of the magnetic data from the West Mediterranean suggests that some meaningful source discrimination and sub-division is possible.

The distinctive nature of Pantelleritic obsidian, well known for its peralkaline properties has long been recognised in its characteristic ereenish colour in transmitted light, high refractive index and more recently, in the presence of high concentrations of sodium and iron and low concentrations of scandium and cobalt as detected by NAA. Magnetic analysis of <u>Pantellerian</u> samples, both archaeological and geological, once more emphasises the distinctive nature of this obsidian as exemplified in the very low intensity of remanent magnetisation and saturation magnetisation values (Fig. 17).

Only two geological Pantellerian samples, one of pitchstone variety and the other of glassy type, were presented for analysis. The two appear distinguishable on the basis of analysis, the glassy fragment showing noticeably lower initial and saturation intensity values. Artefactual material of a glassy type (M.A. 156 - 161) was found to compare more closely with the pitchstone variety of geological origin (M.A. 163) than with the glassy geological piece (M.A. 162). Neutron activation analyses (Hallam et al., 1976) had proposed the elemental equivalence of the bulk of Pantellerian artefactual material (the majority of which were included in the present analysis) with one geological sample of glassy type. This particular geological piece was not included in the present analysis and so comparison was not possible.

The number of potential sources of works is obsidian on Pantelleria is not at present clear, though the various different localities mentioned in literature are a parently spread around the island (Dixon, 1975) and imply the emistence of several individual flows. The difference in values for the glassy geological fragment and the glassy archaeological pieces would support





Fig. 17 Attribution to source groups by means of Magnetic Analysis

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this proposition. The metastable nature of the Pantellerian pilot specimen (N.A. 160) should, however, be noted and if typical of Pantellerian samples then this may account for the slight divergences in intensity values.

The three elementally distinct groupings identified within <u>Sardinian</u> obsidian by NAA (Hallam et al., 1976) emerged also as magnetically distinct. A fourth subdivision (here design ted SD) previously unreported in the literature though recently recognised by NAA (S.E. Warren, personal communication) emerged within the Sardinian magnetic data.

Conca Cannas, in the Monte Arci region of Sardinia (See Fig. 4) has been identified by NAA as the source for SA material. Magnetic analysis of Conca Cannas flow material and archaeological pieces perviously activated and assigned to an SA grouping provides results, internally homogeneous, confirming the equivalence of the SA subgroup with the ConcaCannas source, but moreover emphasising the practicable relevance of magnetic analysis to the problem of source characterisation and ultimately perhaps to interpretation of patterns of trade and contact.

The sources for the SB, SC and SD subgroups are not as yet identified with any certainty. On the basis of the present analyses of geological samples (collected by B.R. Hallam and occurring as secondary source material) from the Nonte Arci region, two sources reported by Puxeddu (1957) are tentatively suggested as potential candidates for SC and SD material. A single geological fragment (N.A. 131) from Santa Faria Zuarbara (located approximately 14 Kms. west of the source area masted by Puxeddu, 1957, R.Hallam, private communication) compares well with existing archeeological SC places showing high intensity of natural research memotisation and saturation moments, whilst a fragment of geolo icel origin from Parties Unies shows low velves in accordance with two probabilities for SC and SD restores the source of Fardes Unies and the other of vorte errowalance 'from the sourcit of 'once Vroi'.

Fuxeddu (1957, 24) refers to the proliferation of geological material at Sonnixeddu, south-east of Conca Cannas: 'coperto da frammenti di ossidiana nera in modo che si crederebbe di comminare su i resti di una grande fabbrica di bottiglie nere'. Sonnixeddu,therefore, seemed a likely source for SB obsidian. Most of the material from Sardinia is in the form of artefacts and waste flakes from chipping floors. Pieces collected from Tænca Tamis, at the confluence of the valleys from Sonnixeddu and Conca Cannas appear attributable to an SA or SB grouping whilst one specimen from Sonnixeddu itself and two from Santa Maria Zuarbara showed values consistent with an SB grouping. Analytical data is not inconsistent with an SB source at Sonnixeddu although the scarcity of material noted by Brian Hallam in a recent survey and the presence of SB material at Santa Maria Zuarbara suggests that a source locality north of Conca Cannas cannot be ruled out.

SC and SD material are easily distinguished by their respectively high and low remanent intensities, saturation moments and low-field susceptibility. Although readily separable from SC and SD, the distinction between SA and SB is not so pronounced (Fig. 19), SB obsidian exhibited values of saturation magnetisation and susceptibilities only slightly higher than those characterising SA. Definitive attribution of archaeological samples to either SA or SB is on occassion difficult and magnetic analysis of further material previously assigned to either grouping by an independent technique should prove valuable in defining more accurately the range of magnetic variability.

Of artefactual material from Grotta Sa Ucca, 30 Kms. south-south-east of Sassari (see Fig. 4) seven out of nine pieces, analysed fell with group SC whilst from Grotta del Infermo (4 Ems. south-east of Sassari) two out of three pièces were of SC origin. If Corsical successful pieces mine out of twelve, mainly from Labe F olithic contexts, is word to be at SC type, with the remaining pieces follier successful and SP. Of these mine SC fragments



Fig. 19 Attribution to source groupings by means of Magnetic Analysis.

three from the sites of Basi, Tivolaggio and Vascolaccio had been previously activated and attributed to an SC grouping, while six, three from Monte Grosso two from Scaffa Piana and one from Ariguina were assigned an SC origin exclusively on magnetic results. Two further Monte Grosso samples were provisionally attributed to the SA group and one piece, previously irradiated, from Late Neolithic Currachiaghiu, fell in with SB material. The current sample would strongly support the suggestion by Hallam et al., (1976, 97), that SC obsidian occurs more frequently in Corsica than does the SA variety.

Of all the analysed finds from Sardinia and Corsica, only two, and both of these from Sardinia itself, showed properties consistent with the single geological SD piece from Perdas Urias (M.A. 139). The scarcity of SD material within Sardinia and its absence in Corsica might imply that this source was inherently less attractive than SA, SB or SC source material and for this reason was not extensively worked by prehistoric man. Appearance criteria would support this view : the three pieces analysed contained spherulitic inclusions not generally seen in material of SA, SB and SC type and perhaps rendering the obsidian less desirable for artefact menufacture. Curecchiaghiu in Corsica is notable for the predominance of SB material. Of Sardinian and Corsican obsidian analysed by magnetic means, only one sample, and that from Curacchiaghiu, previously activated and attributed to source by NAA, fell in group SB. Based on present analyses the occurrence of SB obsidian appears restricted. NAA has documented the presence of SA and SC obsidien on sites in southern France and Northern Italy, the current sample only included four replicate pieces (M.A. 99, 99, 120, 121) and offers no new evidence in distribution of Sardinian material outside Sardinia and Corsica.

A single onworkable fragment of pitchstone variety from South Antioco (I.A., 142), so intend types off the south-west coast of Cardinia, proved of distinguishable from the south quality classy obsidious of Honte Arci by

virtue of its extraordinarily high saturation moment.

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The results of magnetic analysis of <u>Liberian material</u> document three distinct groups, here designated Li A, Li B and Li C and the implications of the data are particularly interesting. :

Geological material from the historic flows of Forgia Vecchia and Rocche Rosse (see map: Fig. 5) together with material, apparently redeposited (0. Williams, personal communication) from Acquacalda (locality j, N.A.No. 79) and a lump, presumably of geological origin, found on Acquacalda beach (locality 1, M.A.No. 80) all fall within the group here termed Li A (Fig. 17). Two archaeological pieces (N.A. Nos. 85 and 86) analyzed by magnetic means fall also within the range of variability of Li A, whereas the in situ Gabellotto (locality r, M.A. No. 93 - Li C) and Accuacalda (localities m and k, M.A. Mos. 91, 92 - Li B) prehistoric flow material show intensity values convincingly separable from one another and markedly higher than those of Li A (Fig. 17). Analysis by Cann and Renfrew (1964), Belluomini and Taddeucci (1971) and Hallam et al., (1976) established the mecchenical similarity of Gabellotto obsidian and Liparian artefactual material with that of the two younger flows, though the non-identity of these flows is now apparent in differences in lanthanom content detected by HAA (S.E. Marren, personal communication). Present magnetic analytical results suggest then the similar magnetic minaralogy of historic flow material and some prehistoric archaeological pieces. Two further archaeological fragments (M.A. Nos. 89 and 90) again having been irradiated at an earlier time and assigned a Linari Origin, provided magnetic values inconsistent with any geological material so far arelysed. Both mieces were very bing (0.095 am. and 0.136 gm.) and reservations concerning the practiceblo sensitivity limits of the magnetometer must again he b rne in mind. Woretheless all evidence spints to the non-empiralence of archaeolo fical autorial with the in situ prehistoric Galellotto and Acovacalda

source samples included in the present study. If archaeological material is to have derived ultimately from these flows then some explanation must be put forward to account for their vastly different magnetic characteristics. This apparently anomalous situation might be resolved if a change in the magnetic properties of the original in situ Gabellotto and acouacalda material over time, could be demonstrated. The possibility remains that this obsidian may have been effected by heating, perhaps that associated with the formation of the historic flows. The heating process might result in oxidation of titanomagnetites tending to alter the magnetic composition of the obsidian towards haematite, yet the high intensities, suscertibilities and saturation moments of in situ Gebellotto and Acquacalda pieces typically indicate the presence of magnetite (and indeed Hössbauer work has confirmed the presence of magnetite inclusions forming c. 60% of absorption in the coefficient in the Gabellotto locality r material). A change in the magnetic oxides present within the obsidian resulting in formation of magnetite, though remotely possible, retains unlikely. To test the hypothesis it may prove useful to heat Livarian archaeological samples, the intensities and suscentibilities of which are known, in different experimental conditions (oxidising, reducing etc). Remeasurement of the magnetic parameters subsequent to heat treatment would reflect any chemical changes.

In the light of present evidence, supported by Mössbauer effect studies, it seems likely that geological material analysed from Acauacalda (k and m) and Gabellotto (r) is not representative of the flows from which archaeological material was ultimately derived and that forther flows must be involved.

One geological sample collected from the nearby leolien island of Vulcano gave values of entrum-tion momentisation and intendity of response magnetisation in accorn with the Ii 1 cluster distinguished by the present study (fig. 17) but emerged as separate on the basis of low field suscertibility (dir. 23). Interthem Values couple ( . . c. 11) convided value distinct

from the remaining Lipari material (the anomalous nature of this sample was previously demonstrated by NAA).

Three archaeological samples from the Biferno valley in Holise, southern Italy were included in the enalysis. of these, two (M.A.Nos. 67 & 68), exhibit properties in accordance with a Lipari origin (Li A) whilst the other (M.A.No. 153) compares more closely with Fontine Island data. These source attributions are based exclusively on the magnetic data and as such are naturally tenuous. A Lipari source for some Holise artefacts is not inconsistent with the evidence to date: although Palmarola is the closer source, Liparian obsidian crops out in larger blocks and is thus a more attractive commodity. Lipari obsidian has therefore, a for wider distribution, appearing north of Palmarola though the source itself is to the south. It is particularly interesting that the two possible pieces of Liparian obsidian come from an Appenine Bronze Age context, whilst the possible Fontine Island specimen belongs to a late Heolithic horizon. These facts may be without significance but may, on the other hand, be indicative of the changing pattern of source exploitation in Molise.

Magnetic data from the <u>Pontine Island</u> material shows a wide range of variability suggestive of the presence of material from more than one flow. Subdivision within the cluster is not clear though for example samples 147, 149, 150 and 206 would appear to form a homogeneous sub-group. A comprehensive range of geological material from the Pontine Islands was unfortunately not available and analyzes are based on archaeological samples, often of microlithic type and therefore amin the problem of a low signal to noise ratio can make measurement difficult. Is batch of geological samples sent to Bradford for analysis by A. Ammerman (Parme University' access to have become lost in the Italian port!

of the Pontine Island Group : Pelmerole, Ponza, Gevi and Kannone only Pelmarola provided a variable objection source. Reploying simples from Ponza

Susceptibility

161. Values



Number of obsidian samples

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FIG. 20 Note change in scale at 100 × 10<sup>-\*</sup>emu/oe.

(N.A.No. 154) and the nearby island of Procida (M.A.No. 155), both of devitrified nature, were included in the analysis. The Procida piece was clearly different, showing a very high low field susceptibility and although the sample from Ponza fell within the range of variability of Pontellerian material, this creates no source discrimination problems since Ponza obsidian was not utilized for artefact manufacture.

#### 6:2:c Near Eastern Geological and Archaeological Material

Material from the sources of Acigöl, Çiftlik and the Lake Van area (Renfrew's 1g) was subject to analysis.

Three magnetically distinct groups emerge with the Acigol data, here termed Ac A, Ac B and Ac C. Ac A comprises source material from Wright's (1969) localities 2 and 6; Ac B, locality 3; and Ac C, locality 5 (see Fig. 21). The separation effected between pieces from locality 2 and a single pices from locality 3 is of interest: Wright could establish no clear cut elemental discrimination between his sumples from the two localities. Fission track dating (Durrani et al., 1971) however, established that locality 3 was not a single source since two specimens gave respective dates of c. 2 m.y. and of B = 9 m.y. Naturally unequivocal evidence is lacking but there exists the possibility that the variations observed in magnetic parameters are reflecting the megnetic mineralogy of two different magna types of vastly differing age.

Obsidian from Tell Abu Hureyra in Syria and Dhali Agridhi on Cyprus (previously assigned to source by NAA) is taken as representative of the Ciftlik source. The Giftlik data show results not closely convergent and again the implication is that one may be dealing with a multi-source erroup. Indeed Todd's survey of the area located two sinceble sources on the mountain of Gollu Dag. Five out of six miscos of Giftlik obsidien from Tell Ybu Hureyra show intensition of accuration magnetization reacted from c. 5000 = 9000 and  $x = 10^{-4}$  ) on  $^{-2}$  millet the receiping Syrian probabilogical pieces, in





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addition to three samples from Cyprus give higher values in the region of 20000 x  $10^{-6}$  G cm<sup>3</sup> gm<sup>-1</sup>. The two-fold division is less clear on considering natural remanent intensity and low field susceptibility figures.

On obsidian from Lake Van (Renfrew 1g - here designated LV) the five fragments analysed appear to form a relatively homogeneous cluster, particularly distinct by virtue of their intrinsic 'zero' susceptibility.

### 6:2:d Central European Geological and Archaeological Material

Information on the present state of knowledge regarding characterisation of Central European obsidian by NAA has been kindly made available (0. Williams personal communication). Within geological material from the sources of Erdöbénye, Tolcsva, Cseppegö Forrás and Vinicky, three elemental groupings were distinguished. Material from Erdöbenye was of two different types, the one forming a group together with material from Cseppego Forras and Slovakian Vinicky and the other being the single member of a distinct sub-group. Material from Tolcsva also emerged as elementally distinct. With the discriminations effected by NAA serving as guide lines examination of magnetic parameters appears, in the main to substantiate these separations (Fig. 22). In addition a single piece from the Slovakian source of Viničky does seem convincingly separable from the Hungarian sources of Cseppegö Forras and Erdöbenye, which together form a single cluster (here designated Carp. C). No archaeological Central European pieces analysed occupy a region on the natural retanent intensity/ seturation megnetisation graph (Fig. 22) corresponding to that of the Viničky semple and further analyses are necessary in confirmation of the sub-division here termed Carpathian D (Carp. D). As predicted by NA material from Erdöbénve clearly forms two separate groups, lesignated Carpathian A and C. A single geological sample from Erdövenye together with three archaeological pieces from sites in Hungary and Slowskie (F.A. Hos. 164, 165, 166, 167) display





high intensities of natural remanence, dropping by unusually large factors (of c. 10 to 30) on exposure to alternating fields of 500cc. Exposed rock outcrops can be effected magnetically by lightning strikes. The current discharge travels along the surface of an outcrop on striking the ground. In the immediate vicinity of the current the magnetic field created is large and virtually remagnetises the outcrop at these points but the effect falls off with increasing depth so that severe effects are restricted to the top few metres. The large IRM component produced by a lightning strike is readily removed by alternating field demagnetisation. The behaviour of the four samples here analysed might therefore suggest that the obsidian has been affected by lightning. If such is the case, then the sample intensity after exposure to a cleaning field of 200 or 500ce. would reflect the primary component of magnetisation on flow formation after removal of the secondary IRM and since it remains unlikely that the whole flow was affected, other pieces from Erdöbénye might be expected to show values corresponding to this stable component.

The very tentative nature of subdivisions suggested with Carpathian material must be emphasised but it is hoped that additional analyses will clarify the position.

#### 6:3 Source Discrimination

The generally convincing distinction made between material from the Melos sources and Giali has already been mentioned. It may prove less easy to identify possible incoming Carpathian obsidien since values fall completely within the range of variability of Aecean material, but at present no interaction is evident between the distributions of Belian and Carpathian material. Compathian obsidien, on the basic of the intensity saturation magnetisation and initial intensities to far ressured elonges as distinct from Dest Dediterraces Lipari and Pontine Island material.

The Near Eastern sources of Acigöl, Ciftlik and Lake Van (Renfrew's 1g) emerge as magnetically separable, by consideration of the two main discriminating variables (saturation magnetisation and intensity of natural remanence), low field susceptibility proving a valuable perameter in further substantiating the discrimination between Lake Van and Ciftlik material. On account of the evidence for reciprocal traffic it is desirable to differentiate between Melian and Central Anatolian obsidian. However, it is doubtful whether a study of the magnetic parameters considered here is sufficient to adequately characterise these sources. A single piece from Acigöl, that from locality 3, is not distinguishable from Melos 'A' obsidian, whilst four from the nine Ciftlik pieces analysed also show values similar to that of Melos 'A' (as can be seen by comparison of Figs. 15 and 21).

Fig. 17 displays the separation effected between the three West Mediterranean sources of Pantelleria, Lipari (with its three sub-divisions) and the Pontine Islands. A comparison of this plot with Fig. 19 demonstrates, however, some overlapping between Sardinian and Liparian obsidian. Very high initial intensity values and values of saturation magnetisation make differentiation between SC and Lipari B and C difficult, but since no archaeological material of Lipari origin has yet proved to be magnetically similar to that of the in situ Gabellotto (Li C) and Acquacalda (Li B) prehistoric flow material sampled there should be no problem. Excepting Li B and C, intensities for SC material far exceed those from all other material analysed and on the basis of present evidence, magnetic analysis should prove a swift and effective means of determing an SC origin for archaeological material. No close differences in the trends for the two main discriminating parameters are shown for Pantellerian material and Sardinia D pinces (Figs. 17 and 19) but differences in low field susceptibility as shown in the two dimensional plot, using the variables of seturation seguetisation and 10 field succeptibility respectively as ordinate and abscisse (Fig. 23) are apparent and this in conjunction with the distinctive





Attribution to source groupings by means of Magnetic Analysis

nature of peralkaline obsidian and the differing distribution patterns of the two sources should facilitate characterisation. Discrimination between Sardinia B obsidien and the Pontine Island variety appears adequate. only the geological samples of unworkable quality from Procida shows very similar saturation and initial intensities and even this piece emerges as distinct by virtue of its abnormally high low field susceptibility. Between the Fontine Islands and Lipari and between Lipari A and Sardinia B and C adequate separation seems possible, but the overlapping values of low field susceptibility, intensity of natural remanence and saturation moments for Lipari A and Sardinia A samples create a very real problem. Characterisation of these two sources by measurement of the magnetic parameters considered here proves therefore ineffectual. SA material has turned up at Nonte Circe (Hallam, et al., Fig. 4) but this is unusual and it has not yet been identified south of Rome. Generally Liperian and Pontine Island material predominates in this region, whilst in Southern France and Northern Italy, Sardinian obsidian is predominant. Dixon and Renfrew (1976) define an obsidian interaction zone as the region 'within which sites derive 30% or more of their obsidian from the same specific source'. The interaction zones of Gardinian and Liparian material are separate whereas the interaction zone of Pontine Island material lies totally within the Liparian zone. Although distinction between SA and Lipari A proves difficult it seems more important to discriminate between Palmarolan and Liperian Obsidian. Analysis by magnetic means allows this latter separation.

Obsidian samples from north-west and north-east Calabria are currently being analyzed at Bradford using neutron sotivation to determine provenance, in particular to ascertain whether the material is of Liperist origin. Esgnetic suclosis should prove valishly in further work on pharacterization of Liperi and Poncine Taland material to elucidate the mattern of interregional contact and computication within the last fediterrosers.

# 6:4 <u>Discussion of the mean and standard deviation pattern technique of</u> <u>data treatment (see 5:2:d)</u>.

A statistically valid number of samples were not available from all the sources included in the analysis and it was only possible, therefore, to establish the pattern of variation of intensities and susceptibilities for the sources of Melos Adhamas, Giali, Lipari A (values for Forgia Vecchia and Rocche Rosse material), Sardinia A, Sardinia B, Sardinia C, Ciftlik and Acigöl (see Table 7, Fig. 24).

The wide scatter of data for each of the five magnetic parameters is apparent in Fig. 24. The intensity of saturation magnetisation emerges clearly as the parameter showing the closest statistical spread, followed by low field susceptibility, and as such individual values for each of these variables may be treated with reasonable confidence. Intensity of natural remanent magnetisation and of magnetisation after partial demagnetisation at 200 and 500 oe. generally showed a larger data spread. The natural intensity of remanence is dependent upon the intrinsic susceptibility of the material and on its magnetic history, while the intensity after removal of any magnetisation acquired over archaeological time should reflect sample susceptibility plus the strength of the geomagnetic field at the time of cooling. Contrary to expectation in the majority of cases the NRM shows a lesser spread of data than that after partial demagnetisation. Low field susceptibility values, though exhibiting a lesser data spread than intensity of remanence, are clustered in the vicinity of the 'standard' line and as such it proves less valuable as a discrizinating variable.

In many cases results from different sources fall close to the 'standard' line, making effective characterisation, by this method, difficult. Sardinia C is a notable exception and identification should be facilitated, though there is such a large spread of data for remainent intensities that few of the individual values can be headled with assurance. Certain patterns may,

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## TABLE 7

# MEAN INTENSITY VALUES FOR SOURCE MATERIAL.

Source	No of Samples	Intensity x $10^{-6}$		- (standa		
		M <sub>init</sub>	<sup>M</sup> 2000e	<sup>M</sup> 500oe	M sat3500oe	Susc.
1/10/ 1/1	29	895 <b>.8</b> (445 <b>.</b> 1)	850.5 (368.2)	480.5 (227.3)	27241.2 (5358.4)	53.4 (16.6)
Giori	22	162.3 (110.0)	122.2 (89.2)	86.7 (64.3)	5418.2 (3441.3)	30.8 (16.8)
i i pori	10	336.6 (131.8)	283 <b>.</b> 2 (115.6)	215.7 (97.9)	7117.3 (2726.7)	11.7 (3.3)
Sartinia (2)	5	626.9 (275.8)	582.3 (336.8)	505.8 (302.8)	9909.5 (3153.4)	18.2 (7.1)
Sardinia (8)	5	477.8 (323.7)	434.4 (339.5)	424.8 (224.5)	20851.7 (3367.0)	54.8 (8.9)
Sarlinia 'C'	7	19084.5 (13477.0)	15123.5 (13763.2)	8226.0 (7639.8)	68707.5 (26204.4)	93.6 (38.2)
Aci <sub>d</sub> o)	6	264.1 (69.0)	226.5 (78.7)	186.3 (53.4)	7385.2 (1988.6)	13.5 (3.9)
Ciftlik	7	843.8 (791.6)	832.4 (543.5)	651.9 (350.9)	15130.8 (7757.2)	12 <b>.</b> 8 (13 <b>.</b> 8)

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Intensity values and standard deviations of sources relative to Melos Å





however, be extracted from Fig. 24. For instance Melos 'A' and Ciftlik samples show similar mean values and spreads for intensity of remanent magnetisation but for the latter source this is coupled with markedly lower mean values of saturation magnetisation and low field susceptibility. Melos 'A' and Giali appear distinguishable, the only overlap occurring in the spread of susceptibility values whilst for Acigöl and Ciftlik, though susceptibility and saturation values prove comparable, reasonable separation seems possible on the basis of remanent intensities.

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### CHAPTER 7

#### CLUSTER ANALYSIS

#### 7:1 Introduction

It was considered a useful exercise to perform a cluster analysis on the magnetic data of selected obsidians. The analysis was initiated with two objectives in mind. Primarily, the discrimination effected between various obsidians by the somewhat subjective method of visual examination of the data could be verified, or indeed, consequential revision of the a priori groupings could be suggested, by an independent objective data classification based on simultaneous consideration of all variables. Secondly the data could be presented in an alternative form, as a two-dimensional graphical plot.

'Clustering' or the pattern of establishment of relatively distinct groups of material related to, but distinguished from, other comparable groups can be achieved by way of cluster analysis. For the archaeologist classification and compression of data are of tremendous importance and numerical clustering of a large archaeological data set can determine patterns of covariation within the data.

### 7:2 General technique and choice of a specific clustering procedure

The data to be classified must be arranged in the form of an n x p matrix. n rows represent the individuals to be grouped, according to homogeneity between entities and p columns represent the characteristic variables on the basis of which these groupines will take place. In the present set of data the n individuals are samples of obcidian from various localities and the p variables are the magnetic parameters of initial intensity of magnetisation, intensity after step demagnetisation, ( at 200 and 500 oe ) low field mass In common with many other methods of multivariate data analysis, a preliminary procedure is the formation of a matrix of similarity coefficients calculated between each pair of units to be analysed. If n individuals are to be grouped on the basis of p measurements on each then the n x n distance matrix is the natural summarization. (Solomon, 1971)

A generally appropriate and relatively simple clustering criterion is that based on the Squared Euclidean distance or Sum Squared Error, defined as the percentage ratio of the sum of the squared distances between points and their cluster centres relative to the summed distances from the overall data mean. (Hodson, 1971, 34)

Of the range of sequential, agglomerative, heirarchic, non-overlapping (SAEN) clustering methods available within the Clustan 1A package (Bradford University Computer Centre) the similarity criteria of the nearest neighbour method was chosen as suitable. (Trasi,1975) The choice of the single linkage or nearest neighbour technique was based on rather arbitrary considerations. 9 standard methods were available within the Clustan A1 packaje. Practising taxonomists have levelled criticism against single link cluster analysis on account of the chaining effect which it often exhibits, conversely the method has been shown to be the only directly heirarchical procedure in current use possessing the formal properties required by a comprehensive theory of clustering.(Jardine and Sibson, 1968) The method has been successfully applied to archaeological problems on previous occasions (Hodson et al., 1966) and with the present relatively small data set it was thought that the chaining effect would not matter greatly. Moreover the single linkage method was economic in use of computer time.

The clustering procedure, in the first instance, treats 'n' individuals as a separate clusters each with one member. The similarity matrix is then scanned and fusion of two individuals to form one single cluster proceeds

according to distance between nearest members. Repetition of this procedure finds the next highest similarity coefficient, if one of the linked units is already a group member then the whole of that group is included in the fusion. If both units are group members then the two groups fuse, thus each fusion decreases by one the number of groupings. Fusions once made are irrevocable. The search procedure thus continues and the groups are gradually enlarged until all individuals merge sequentially into one large cluster.

The dendogram presentation of the data illustrates the fusions made at each successive level, culminating when all individuals are in one group

The cluster codes for the present data range from 1-29,(since there are 29 individuals) numbered according to the input order of the individuals. Specific identity of samples together with their cluster code numbers is presented in tabular form.(table 8)

Two separate runs were performed on the data using the nearest neighbour clustering method. The initial run made use of 8 numeric variables as a framework of reference within which to establish groups or clusters. A decision was made to mask the low field mass susceptibility and the dependent Koenisberger (Q) ratios from the coefficient calculation as 'noisy' variables, and the second cluster separation was based therefore on the remaining 4 variables: initial intensity of remanence, intensity after alternating field demagnetisation at 2000e, intensity after alternating field demagnetisation at 5000e, and intensity of saturation magnetisation. (35000e) This reduction in the number of variables resulted in some changes in the internal relationships of the classification array.

7:3 Material analysed, results of Cluster Analysis and their interpretation

Data for obsidians from the Aegean and West Mediterranean sources of Melos, Giali, Lipari, and Sardinia were selected for cluster analysis. To gain a solit visual picture of the clustering as shown by the dendograms

TABLE 8	CORRELATION	178 OF CLUSTER	CODE N	os WITH	MAGNETIC	ANALYSIS Nos.
Cluste	r Code No	MA NO	Proven	ance		
	1	<del>*</del> 1	Mel	os Adham	as	
	2	* 5	"	11		
	3	* 7	11	n		
	4	<b>*1</b> 1	11	*1		
	5	*17	"	18		
	6	*25	11	12		
	7	*34	"	Dheme	enegaki	
	8	*35	**	17		
	9	*36	11	11		
•	10	*56	Gia	li		
	11	*58	**			
	12	*42	11			
	13	<b>*</b> 43	n			
	14	<b>*</b> 49	11			
	15	*54	**	1		
	16	*57 .	11	1.		
	17	*59	11	I		
	18	64	1	beach		
	19	65	11	, ,,		
	20	6 <b>7</b>	1	1 17		
	21	68	1	1 11		
	22	*63	Gia	ali		
	23	*142	S./	Antioco		
	24	122	Gre	otta Sa	Ucca, Sar	dinia
	25	116	Ile	e Monica	, Sardini	a
••	26	117	Bas	si, Cors	sica	
	27	119	Ti	volaggio	, Corsica	1
	28	*91b	Ac	quacalda	a,locality	y k,Lipari
	29	*93D	Ga	bellotto	,locality	yr, "

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indicates geological hand sample.

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'A' source; 7-9, from Melos 'D'; 10-17, and 22, from Giali; 18-21 from Giali beach, 23 from S. Antioco, south-west of Sardinia; 24-27 from Sardinia and Corsica(SC) and finally 28 and 29 from Lipari.

Results of cluster analysis, using 8 numeric variables, as presented in dendogram form (fig.25) were disappointing. A clear discrimination is effected between individuals from Aegean sources and those from the West Mediterranean, yet, within these two broad groupings the subdivisions established are none too satisfactory. In dendogram form (fig. 25) the strikingly close relationship between all Melos and Giali obsidians seems apparent, yet this is not the case on visual inspection of the numerical data from these two source areas. The cluster analysis groups material from Melos Adhamas, Melcs Dhemenegaki and Giali in one very homogeneous cluster (cluster code nos. 6,7,8,10.) and whilst two Dhemenegaki samples (7 and 8) appear together in this cluster . the remaining Melos 'D' sample is linked on singly as an outlier to the main Aegean group. It seems then that no adequate division can be achieved between Melos material and Giali material on the basis of this first twodimensional plot. The Nelos and Giali material merge sequentially into one large cluster at a level where the distance criterion is fairly small, this would tend to suggest that the grouping is of significance, but in factpreliminary visual inspection of the measurement data does reveal differences which render possible a separation between Melos 'A', Melos 'D' and Giali.

Turning to the West Mediterranean material, the three Sardinian (SC) samples group together, but this grouping is established well down the dendogram, with the largest distance criterion. Material from the prehistoric flows: on Liperi is divided: Gabellotto obsidian (29) being erroneously grouped with mitchstone from S.Antioco, south-west of Sardinia(23) and Acquacalda obsidian (23) with archaeological material from Grotta Sa Ucca in Sardinia. (24)



FIG. 25 Cluster separation based on 8 numeric variables

The differentiation achieved on the second dendogram plot, (fig. 26) with grouping based on only 4 variables, is of a far more satisfactory nature. Several distinct clusters emerge. As before, Liparian and Sardinian material is well distinguished from that of Melos and Giali. A dichotomy emerged within Melian obsidian samples; those from Melos 'A' all clustering together and those from Melos 'D' forming part of a cluster. This was satisfactory , unfortunately a spurious relationship is shown between the three Melos 'D' samples and two from locality C on Giali. However, from prior visual examination of the magnetic data confusion between Melos 'D' and Giali locality C might have been anticipated. Source material from Giali and material found scattered on Giali beach is put in the same sub-group, and although the beach samples appear adjacent to one another, together with a single geological hand sample from locality C, forming the extreme member, whilst source material from other Giali localities appear as nearest neighbours at the other end of this group, the whole is integrated as one homogeneous cluster on the dendogram. As in figure 25, the homogeneity of Melian and Gialian obsidian appears over-emphasised but in figure 26 the small diversities shown do seem to represent genuine discriminatory groupings.

Heterogeneity within Sardinian SC material is again suggested by figure 26, the three obsidians from Sardinia appearing as nearest neighbours but only forming a cluster with all other individuals when the distance criterion is completely relaxed. The two Liparian samples (28 and 29) cluster together initially but as the similarity coefficient decreases samples from S.Antioco and Grotta Sa Ucca (23 and 24) merge into this cluster.

The dangers of misrepresentation are apparent: to quote one instance. visual inspection of the S.Antioco data shows what seems a very significant difference in respect of one variable, this, however, is not evident from the dendogram plots.



FIG. 26 Cluster separation based on 4 numeric variables

The cluster analysis demonstrates one way in which the computer can present numerical data in a simple, objective form as a foundation for discussion and interpretation. Since the procedure relies wholly on the data set to obtain a grouping of individuals, it would be, perhaps, optimistic to imagine that the subjective groupings should be greatly improved by cluster analysis. Indeed the analysis led to roughly the same clustering as that based on subjective visual data examination and as such, this means of visual display of data does allow a greater measure of confidence in the groupings recognised and discussed in the previous chapter. 184.

#### CHAPTER 8.

### CONCLUSIONS.

The principal concern in the present research is to illustrate the scope of magnetic analysis. Several concrete conclusions emerge from the data here presented:

1. Studies of obsidian from Europe and the Near East showed some magnetic parameters to be better source discriminators than others, backfield coercivity and saturating field did not vary significantly from one source to another and the best indication of provenance resulted from consideration of the intensity of natural remanent magnetisation together with the intensity of the saturation moment and where necessary low field susceptibility proved useful in substantiation of source attributions.

2. Specimens from a single source showed a restricted range of variation in the magnetic parameters of saturation magnetisation, initial intensity of remanence and low field susceptibility. Clearly it was important to establish this at the outset since wide variations in the magnetic parameters measured within a single source, would render the method impracticable. The internal magnetic homogeneity of flows was tested using geological hand samples from Melos and Giali and the within-source consistency of results obtained is well demonstrated (Fig. 15).

3. Between-source variations appeared in many cases to be greater than the magnetic parameter variations within individual specific flows, allowing adequate separation of several of the source materials studied.

4. The Melian flows of Adhamas and Dhemenewald apreared, on the basis of geological sample data, to show significant differences in magnetic properties and both were in general, easily separable from Gialian obsidian.

5. Analyses document 4 magnetically distinct proupings of obsidien from the locality of Wonte Arci in Serdinia. Of archaeological material from Corsica included in the analysis, all pieces belong to sub-groups SA, SB and SC. The SD sub-groups does not appear to be represented outside Sardinia itself. 6. Three clear sub-divisions were apparent within Liparian material. Material from the historic flows was magnetically indistinguishable from those archaeological pieces, previously activated and attributed a Liparian origin by NAA. In situ samples from localities on the prehistoric flows of Gabellotto and Acquacalda are charly separated from the remaining material and convincingly separable from one another. The remote possibility that the prehistoric flows had been radically altered, perhaps by heat action on formation of the later flows, was considered. A more plausible suggestion put forward is that the prehistoric flow material sampled is not that from which prehistoric archaeological material was derived.

7. Tentative sub-divisions are proposed within Carpathian material and that from the Cappadocian source of Acigöl.

8. Within the Pontine Island and Ciftlik source groupings, the extent of variation in magnetic parameters would support the sugrestion of the presence of more than one single flow. Clear sub-divisions were not apparent.
9. Some unfortunate source discrimination problems do exist: within the West Mediterranean no effective magnetic distinction could be achieved between sub-groups SA and Li A, whilst there existed considerable overlap between obsidian from the Aegean source of Melos and that from Ciftlik in Caupadocia.

10.The magnetic approach to the problem of obsidian characterisation has certain advantages and disadvantages as compared with the tried and tested methods of trace and minor element analysis. NAA and OES are two methods of trace element analysis most successfully applied to obsidian characterisation.

When considering the time factor and expense involved in analysis of obsidian by determining trace and minor element concentrations, the

magnetic technique has much to recommend it as an alternative method of characterisation. Magnetic analysis is essentially swift and inexpensive. Its non-destructive nature is a major advantage over OES, which necessitates destructive sampling.

With very small samples, a real difficulty in the present study was that of integrating a weak signal above the noise level of the magnetometer system in use. On this account a sample mass limit of c. 0.7 - 1.0 gm was introduced (p146), below which results were considered less reliable. This is an obvious disadvantage of the technique over OES and NAA, both of which are capable of analysing samples less than a milligram in total mass.

The extent of overlap in magnetic properties of obsidian observed from the Aegean, West Mediterranean, Near East and Central Europæ suggests that the magnetic approach will never supplant characterisation by quantitative determination of elemental concentrations, either by OES or NAA; although it <u>has</u> been demonstrated here that it may on certain occasions be used successfully as an alternative to trace element analysis. Essentially its current importance lies in its potential as a speedy and economic means of preliminary examination, giving a sound basis for source discrimination, which may be later confirmed by detailed trace element analysis. Further evaluation of the magnetic distinction of obsidian sources is yet required, the present study however, confirms the general validity of this approach.

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## SUGGESTIONS FOR FUTURE WORK

In the course of the present study of selected magnetic parameters, difficulties were encountered in measurement of the intensity of magnetisation of small samples on the magnetometer system in use - where archaeological specimens available for analysis are of microlithic type this becomes a problem. The difficulty is one of integrating a very werk signal above the noise level of the magnetometer. One solution would be to increase the spin constant from  $2^4$  (commonly used in the present study ) so that the computer integrates over, for example,  $2^8$  or  $2^{10}$  spins. (taking respectively c. 37secs. and 2mins.26secs.) This effectively increases the signal to noise ratio but, of course, makes the procedure of measurement a far 1 mphier process. Alternatively a magnetometer system with a very low noise level should facilitate measurement of small samples. Indeed magnetometer systems are commercially available with noise levels of an order of magnitude lower than that used at Newcastle.

To thoroughly investigate the potentiality of magnetic analysis as a discriminant technique, further parameters must be examined and their usefulness evaluated. It is suggested that thermal analysis might provide valuable information. Two thermal demagnetisation methods are in general use: the progressive and continuous methods. Although furnaces are built to hold 40-50 samples, the time factor involved (viz - the time for the oven to reach equilibrium at each set temperature for the continuous method and the time for the heating and cooling cycle for the progressive method ) precluded the use of thermal analysis in the present project. The demagnetisation of remanences by reheating has however, several applications of possible use. For example, the shape of the curves relating the moment remaining as a function of the temperature of heating con contribute

to a study of the magnetic composition of specimens. A specimen acquires a partial thermo-remanent magnetisation (PTRM) if it is cooled in a field through a limited temperature range and then cooled through the remaining ranges in zero field. The PTRM spectra can show the important ranges of blocking temperatures, approximate Curie points and the number of ferrimagnetic components in the rock specimen. A comparison of the stable high temperature component of natural (M<sub>PNRM</sub>) and thermal remanence (M<sub>PTRM</sub>) can give information on the intensity of the ancient geomagnetic field (comparison can also be drawn between M<sub>PNRM</sub> and M<sub>PTRM</sub> isolated by a/c demagnetisation) Further work should give consideration to these further parameters.

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