AAEC/E510

AAEC/E510

AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS

THE CHARACTERISATION OF MELANESIAN OBSIDIAN SOURCES AND ARTEFACTS USING THE PROTON INDUCED GAMMA-RAY EMISSION (PIGME) TECHNIQUE

by

J.R. BIRD
W.R. AMBROSE*
L.H. RUSSELL
M.D. SCOTT

*Department of Prehistory, Australian National University, Canberra

September 1981

ISBN 0 642 59718 9

AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS

THE CHARACTERISATION OF MELANESIAN OBSIDIAN SOURCES AND ARTEFACTS USING THE PROTON INDUCED GAMMA-RAY EMISSION (PIGME) TECHNIQUE

by

J.R. BIRD
W.R. AMBROSE*
L.H. RUSSELL
M.D. SCOTT

ABSTRACT

Proton induced gamma-ray emission (PIGME) has been used to determine F, Na and Al concentrations in obsidian from known locations in Melanesia and to relate artefacts from this region to such sources. The PIGME technique is a fast, non-destructive, and accurate method for determining these three elements with essentially no special sample preparation. The measuring technique is described and results are listed for sources, chiefly in the Papua New Guinea region. Their classification is discussed in terms of groups which are distinguishable by the PIGME method. Over 700 artefact results are listed; these show the occurrence of an additional group that is not geographically identified.

---

* Department of Prehistory, Australian National University, Canberra

National Library of Australia card number and ISBN 0 642 59718 9

The following descriptors have been selected from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA-INIS-12 (INIS: Manual for Indexing) and IAEA-INIS-13 (INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

PIGME ANALYSIS; FLUORINE; SODIUM; ALUMINIUM; ARCHAEOLOGICAL SPECIMENS; NEW GUINEA; PROTON BEAMS; GAMMA RADIATION; IGNEOUS ROCKS; OBSIDIAN

CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

1. INTRODUCTION

Obsidian is a naturally occurring volcanic glass which was used in prehistoric times to make sharp edged tools and weapons. It was a material of considerable value to prehistoric communities and hence the object of trade or exchange along with other materials. By a multiple series of transactions, some pieces were transferred over long distances from the relatively few sources of high quality obsidian. Although an obsidian artefact would have had a short life as a cutting implement and be soon discarded, it is a very durable material in an archaeological deposit and can remain comparatively unweathered for thousands of years. It therefore serves as an excellent material for the study of prehistoric trade and technology.

Volcanic glass from a particular eruption is usually uniform in both major element and trace element composition. Measurements on quite small volumes can therefore give results which are typical for the melt from that eruption. On the other hand, between different melts there is a wide range of compositions which usually can be distinguished by major or trace element analysis. The study of element ratios is subject to fewer experimental errors than individual element determinations and permits quite small changes in composition to be established at reasonably significant levels. For these reasons, the characterisation of obsidian by elemental analysis has become a very useful technique with which to trace possible sources of obsidian used in artefact manufacture and to establish distribution patterns at various periods.

Many different analytical techniques have been applied to studies of obsidian from several regions including the Americas [e.g. Stross et al. 1976], the Mediterranean [Dixon 1976], New Zealand [Reeves and Ward 1976], Melanesia [Smith et al. 1977]. Differences in composition are relatively easy to detect, particularly in trace elements, but not all elements show a range of variation within material from one source that is smaller than the change from one obsidian source to another. Likewise, only a few techniques are equally attractive from the point of view of speed, non-destructive nature and the simplicity of sample preparation. This report presents results obtained before 1979 by the prompt nuclear analysis technique [Bird and Russell 1976; Bird et al. 1978b] which has been applied to all known obsidian sources from the Melanesian region and to approximately 700 artefacts from this region. Since completion of this work, proton induced X-ray emission has been used to increase the number of elements that can be studied by proton irradiation

[Duerden et al. 1979; Duerden et al. 1980]. The new work confirms the conclusions reached in this report.

2. ANALYTICAL TECHNIQUES

The first comprehensive review of obsidian sources based on field-sampled geological specimens from Melanesia is that of Smith [1974]. The obsidian samples were processed as normal geological specimens using X-ray fluorescence analysis. Although all the known major sources could be well differentiated, the need for three or four grams of sample and the destructive nature of the technique meant that this method would not be satisfactory for the study of the thousands of small flakes in archaeological collections. Nevertheless, useful results were obtained with this method [Smith et al. 1977].

Neutron activation is well known as a sensitive, non-destructive technique and its usefulness for studies of Melanesian obsidian has been proved [Wall 1976]. Concurrent tests of the measurement of prompt gamma-rays from proton induced nuclear reactions [Coote et al. 1972] also indicated that this technique could provide a satisfactory distinction between the major Melanesian obsidian sources.

Many different types of nuclear reactions can be initiated by irradiation of a sample by positive ions, neutrons or gamma rays and all may be exploited for sample analysis [Bird et al. 1974; Bird et al. 1978a]. Prompt nuclear analysis differs from activation analysis in that radiation such as gamma-rays is detected during rather than after irradiation. It does not allow distinctions to be made on the basis of half-life but gives rise to a greater range of energies and types of radiation than is observed in activation analysis. It also offers the advantage that results are available immediately after an irradiation. Thus, in favourable cases, this method is a rapid and non-destructive technique with selective sensitivity for specific isotopes or elements. For example, charged particle induced reactions occur preferentially in light elements and the accompanying gamma-ray emission can be used to determine specific nuclides such as ^{23}Na, ^{19}F and ^{27}Al.

Coote et al. [1972] showed that when obsidian is irradiated with a 2.2 MeV beam of protons, the yield ratios of fluorine and sodium gamma-rays had characteristic values for samples from seven sites in New Zealand. The aluminium/sodium ratio also varied in a comparable way but its usefulness was not as high. This method has been developed further at the AAEC Research Establishment, Lucas Heights, for the study of Melanesian obsidian.

A typical composition for obsidian is given in Table 1. Relatively high quantities of aluminium, potassium and sodium are accompanied by relatively low amounts of iron, magnesium and calcium as well as a variety of trace elements. Major elements vary by up to a factor of two among samples from different volcanic flows and trace elements can change by several orders of magnitude. Most characterisation studies, therefore, have sought to utilise trace element variations. However, when elements such as sodium and aluminium are determined with sufficient precision, they are very useful for characterisation despite their low inherent variability and the small changes that may occur near the surface of artefacts as a result of leaching and hydration. Obsidian thin sections show that some of the artefacts from the southwest Pacific have suffered surface alteration [Ambrose 1976a]. Other surface anomalies can cause marked changes in the results observed by the prompt nuclear technique but most artefacts can be satisfactorily characterised with only the occasional measurement requiring repetition. The chief limitation of this technique is the need for access to a charged particle accelerator; however, recent development of small and relatively inexpensive accelerators may well see such techniques become more widely used.

3. MELANESIAN OBSIDIAN SOURCES

The first work aimed at using the source of a raw material in Melanesia for correlating sites on a broad regional basis was carried out by Key [1968, 1969] who employed emission spectrography to trace the sources of obsidian from archaeological sites. Since 1969, systematic geological sampling of Quaternary volcanic rock, and associated volcanic glasses, has provided a sound basis for a regional volcanic geology [Johnson et al. 1973]. At the same time it has become more feasible to sample, for archaeological purposes, obsidian from the high silica content glassy rhyolites, and tachylite from the lower silica content rocks which had glassy selvedges on rapidly chilled flows. To provide archaeologically oriented data, a field survey of the Papua New Guinea region was made in 1974 by Ambrose to locate high quality obsidian deposits which were likely to have been used prehistorically for artefact production.

TABLE 1

TYPICAL COMPOSITION OF OBSIDIAN AND SODA GLASS

Component	Concentration	
	Obsidian %	Glass %
SiO_2	76	72
Na_2O	4	14
CaO	1	9
MgO	0.2	1
Al_2O_3	13	2.5
K_2O	4	1
TiO_2	0.2	0.05
Fe_2O_3	0.5	0.05
	$\mu g\ g^{-1}$	
Zn	50	
Rb	150	
Sr	100	
Y	20	
Zr	150	
Pb	20	
Th	20	
U	4	

There are four main areas in Melanesia known to produce glassy rocks: three with obsidians are located in Papua New Guinea (Figure 1a) and the other with tachylite (basaltic glass) is in the New Hebrides. All have been used prehistorically. Their locations are:

(a) Lou and Pam Lin Islands to the southeast of Manus Island in the Admiralty Group (Figure 2);

(b) the isthmus area of the Willaumez Peninsula at Talasea on New Britain in the Bismarck Archipelago (Figure 3);

(c) Fergusson, Sanaroa and Dobu Islands in the D'Entrecasteaux Group (Figure 1b); and

(d) Gaua and Vanua Lava Islands in the Banks Group of the New Hebrides Archipelago (Figure 4).

Each contains more than one chemically distinguishable source and, together, they comprise about 16 localised deposits which could produce artefact quality glasses. Of these, the deposits that regularly contributed waste flakes or artefacts in archaeological collections are probably less than ten. A description of the sources and deposits sampled is given in Appendix A.

The discovery of deposits likely to have been used prehistorically is complicated by the fact that there are active volcanoes in all the source regions. Eruptions have occurred in the three Papua New Guinea source areas over the last few thousand years and up to recent times. The source area of the Banks Islands comprises youthful deposits and some activity persists in geologically related volcanoes [Mallick 1973]. The extreme difficulty of field sampling can be appreciated by considering the case of the three Papua New Guinea sources.

3.1 Admiralty Islands

Lou Island (Figure 2) has 12 principal volcanic centres which have produced pumice, ash and some flow deposits [Johnson and Smith 1974]. There are at present thermal areas with warm springs and mud pools. A soil horizon, buried beneath 3 m of pumice and ash, near the village of Rei, contains pottery and obsidian flakes and has been carbon-14 dated to 1710 ± 70 before present (BP) (ANU2018). The event that sealed this dated horizon must have had a major impact on the surrounding landscape and possibly obscured the obsidian quarry at that time. A series of obsidian mine shafts was sunk through up to 18 m of pumice and ash near the abandoned village of Umrei. The age and history of this mining operation is probably within the last 200 years, based on traditional accounts and archaeological excavations. The presence of Lou obsidian flakes on sites distant from the source and dated to 3000 BP indicates a long history of obsidian exploitation, accompanied by volcanic events which could have interrupted the supply of raw material, introduced new material, or changed the availability of a former supply.

The detailed geological history of Lou is not known but the occurrence of active vulcanism over thousands of years suggests the need to introduce different source sampling procedures in this case. It may be more appropriate to use artefacts from dated horizons, such as that described above, to provide data on the source or sources operational at the time. Whether or not the individual flows are capable of being chemically differentiated remains to be tested by detailed analysis but there is the possibility that the sequence of obsidian exploitation on Lou Island will find its reflection in the chronology of sites far from the source. The fact that volcanic eruptions and an obsidian flow occurred as recently as 1953 [Reynolds and Best 1976], resulting in the emergence of the small Tuluman Island from the sea one kilometre south of Lou Island, indicates a long history of volcanic events spanning the prehistoric to present. The consequent ashes and flows could be very useful in unravelling the prehistory of the recipients of the obsidian trade. Sampling of these sources is, however, not a simple matter for there is also evidence for subsidence of north and south coastal areas on Lou Island.

3.2 New Britain

The isthmus area of the Willaumez peninsula is a region of fairly intense volcanic activity. The peninsula is formed of a chain of eleven Quaternary volcanoes [Lowder and Carmichael 1970], and hot springs and related thermal areas are spread throughout the region [Johnson and Blake 1972]. Mount Makalia and Mount Pago, both located at the northern end of the peninsula, erupted in the late 19th century. Fifty kilometres to the east, volcanoes at Cape Hoskins have produced massive deposits over the past two and a half thousands years; at least one buried soil horizon [Blake and McDougall 1973] contained obsidian that was different from the Talasea deposits. Johnson and Blake [1972] believe that some of the Cape Hoskins tephra (fragmented volcanic products) has been contributed by eruptions in the Willaumez peninsula. A 50 km distribution of tephra from the peninsular volcanoes suggests that the closer Talasea obsidian source could have been inundated during the last few thousand years. In the Talasea area there are archaeological deposits which have been sealed in by tephra and there is evidence of two to three thousand year old coastal occupation around Talasea in an area which has subsequently subsided below sea level. The evidence, in the form of scattered pottery and obsidian flakes, is now only visible on mud flats at low tide [Specht 1974]. On the other hand, Lowder and Carmichael [1970] reported raised coral reefs near Talasea. It is clear that tectonic land movements and volcanic eruptions have done much to alter the face of the landscape in an area now seen as the source of high flake quality obsidian. The archaeological evidence from sites outside Talasea indicates that these sources have been exploited for at least the last 6000 years [Ambrose 1976b ; White et al. 1978], a period which spans that of active vulcanism in the region. Therefore, sampling at the Talasea deposits is not likely to locate all the quarries used over the 6000 years.

3.3 D'Entrecasteaux Islands

On Fergusson and the adjacent islands the age of the obsidian sources ranges from Pleistocene to Recent. The most important prehistoric source area is the Kukuia peninsula at the southwest corner of Fergusson Island. The area appears to be fairly stable volcanically, with potassium-argon dates between about 0.41 and 1.3 million years for the parent rock [Smith 1973]. On the other hand, the other western Fergusson source at Fagululu lies in the most active thermal area of eastern Papua New Guinea and is considered to be geologically recent.

The Kukuia source is very accessible being present as cobble size deposits carried down by streams to form beach boulder banks at the south of the peninsula.

The three eastern Fergusson sources, which have been sampled for glassy artefact quality obsidian, are in an active volcanic zone. The deposit at Aiasuna village on the south side of Numanuma Bay is on the east flank of Mount Oiau. This volcano was producing lava within the last 100-200 years; however, its predominant long-term activity has been from explosive eruptions, producing a high proportion of pumice.

Dobu Island is also an active volcano, composed mainly of pumiceous ash with small flows of rhyolite and obsidian. One of these flows is recent, the volcano having erupted within the last two centuries. An older flow on the eastern tip of Dobu has glassy artefact quality obsidian but appears to be in a zone of active beach erosion.

The third collection area was at Sanaroa Island. Sanaroa is mainly of volcanic origin having both basalt and rhyolite and some associated obsidian. The landforms are rounded and not as youthful as those of Dobu and east Fergusson. Smith [1973] noted the lack of volcanic landforms. The more ancient appearance of Sanaroa may indicate that its obsidian sources have been permanently accessible for at least the last 2000 years. High quality glassy obsidian is deposited as small irregular bomb scatters containing individual pieces up to 15 cm long. The surface of the obsidian is highly eroded with deep etch pits, a factor which suggests that it has been exposed to weathering for a considerable period. None of the Sanaroa obsidian has so far been identified in archaeological deposits.

The three obsidian source regions in Papua New Guinea (Lou, Talasea and the D'Entrecasteaux group) vary in volcanic activity, the West Fergusson source at Kukuia probably being the most consistently accessible to exploitation. The Lou source seems to have been severely affected by local volcanic eruptions, but it is not known whether the small deposit on nearby Pam Lin was available over the last 3000-4000 years. The Talasea source area is in a zone of cataclysmic caldera formation with the carbon-14 dates of nearby volcanic events [Blake 1976] corresponding with the known human occupation of the district.

It follows, from the above considerations, that the chance of field sampling being able to duplicate the prehistoric utilisation of a quarry deposit is at present fairly remote, especially for time spans greater than 6000 years, as is the case with the Talasea sources. The possibility that a prehistorically utilised source has been overlain by later deposits, has sunk beneath the sea, or has been superseded by a newer deposit makes it necessary to attribute an analysed artefact to a precise source location with caution. A thorough sampling may not necessarily encompass the geochemical range of the obsidian obtainable during prehistoric times.

This raises the question of the most appropriate chemical analysis to use when dealing with a geological problem of this type. Ideally the analysis should provide data which would allow an artefact to be located, in the first approximation, to a geochemically defined province; such an analysis was used by Smith et al. [1977] to differentiate the volcanic glasses of Oceania. The discussion by Ward [1978] on the alleged ease of 'sourcing' and the difficulty of 'knowing' prehistory is pertinent to this question.

The Ward hypothesis is that chemical or petrographic similarity between an artefact material and a source is not sufficient argument for the derivation of the artefact from the source; conversely, dissimilarity is a good argument for a difference in geographical source. This view may or may not be correct, depending on the quality and completeness of the characterisation data. 'Similarity' and 'dissimilarity' are both relative terms of equal strength in a situation where the data are treated simply as numerical quantities. However, in dealing with geochemical data of the type that geologists normally generate, there are strict hierarchies of discrimination which allow the data to be systematically 'read'. Therefore the analyses relevant to identifying the source of obsidian can be used in terms of their likely chemical associations. This treatment can give a more positive picture of the likely sources in a geochemical province than an analysis which simply uses the source data as the limits of the universe of data within which the artefacts are to be precisely located. Where there is possible impermanence in the availability of any source, as is the general case in Melanesia, it may be necessary to persist with working in degrees of similarity between an artefact and a general source zone, utilising broader geochemically distinguishing criteria rather than the more statistically oriented 'exclusion' principle of Ward.

In the Melanesian situation, the ideal analytical technique to apply to characterisation and source studies of obsidian will be that which first has some geochemical validity on a broad regional basis, and second, includes chemical elements which allow finer discriminations to be made at a more localised level. The three element measurements described in this report cannot completely fulfil these requirements, but they have proved to be a fast, useful, first step in sorting hundreds of obsidian artefacts and attributing them to one of the main sources.

4. EXPERIMENTAL TECHNIQUES

4.1 Method

Samples ranging from 2 mm to 4 cm in diameter are mounted on a metal holder within a vacuum chamber (Figure 5) connected to a beam line from the 3 MV Van de Graaff accelerator at Lucas Heights. When irradiated with 2.5 MeV protons, gamma-rays are produced by nuclear reactions which take place within the first 50 μm below the sample surface. The gamma-rays are detected by a lithium-drifted germanium detector which is placed outside the target chamber. Precision measurements of the gamma-ray energies are used to attribute each gamma-ray to a nuclear reaction in a specific isotope in the sample. Gamma-ray intensities are then derived from the areas of the peaks observed in the pulse-height spectrum from the detector.

When the aim is solely to characterise each piece of obsidian according to its place of origin, the ratios of the areas of particular peaks in the gamma-ray spectrum can be used without further calibration [Bird and Russell 1976]. If element concentrations are required, corrections must be made for detector efficiency, gamma-ray attenuation before reaching the detector, and production cross sections. This is achieved by calibrating the experimental system using appropriate standard samples.

4.2 Incident Beam

A proton beam from the Lucas Heights accelerator is collimated to 2, 3 or 5 mm diameter (depending on the size and shape of the sample) and used to irradiate a selected portion of the surface of the sample. The sample chamber is insulated so that the total proton current incident on the sample can be measured with a current integrator. A secondary electron suppression electrode is used at the entrance to the chamber.

A proton energy of 2.5 MeV is selected for convenience, even though the gamma-ray yield curves show a rapid increase in this energy region for all the reactions used. However, the energy stability during a series of measurements is ± 1 keV which is sufficient to maintain constant cross sections. Beam currents of 200 nA give high count rates so that useful results can be obtained with measuring times of three to five minutes per sample.

Irradiation by a 600 nA proton beam with a diameter of 2 mm has produced some evidence for a drop in count rate with time of irradiation, presumably arising from the effect of beam heating of the sample, possibly combined with ion migration under the influence of charge build-up from the proton beam. This is illustrated in Figure 6 in which a drop in yield from fluorine and sodium but not from aluminium is observed. Not all samples have shown this effect and no changes in yield have been observed with beam currents of 400 nA or less. However, when loose material is attached to the surface of a sample, this is heated very quickly by the proton beam, even with very low beam currents.

The effects of charge build-up in insulating samples during irradiation have been observed with silica samples coated with thin layers of aluminium oxide. These have shown that effective voltages up to 10 kV are present unless electron flood or other neutralising methods are used. The presence of such voltages is also revealed by occasional sparks from the sample to the metal sample holder. No sparking was observed when using obsidian samples and no special techniques were used to dissipate surface charge. Should any charging occur it is unlikely to be more than a few kV and the effect of this on gamma-ray yield will be quite small.

During irradiation, beam-induced fluorescence provides a convenient visual method for locating the irradiated part of the sample and checking it for flaws or inhomogeneities. Although an abnormal appearance of the fluorescence does not necessarily imply that anomalous results would be observed, it makes it possible to avoid irradiating flawed positions.

4.3 Sample Positioning

The obsidian samples are mounted on a carrier which is positioned at 45° to the direction of the proton beam (see Figure 5). One end of the carrier is attached to a trolley which moves inside a 5 cm diameter side arm of the vacuum chamber, while the other end is attached to a steel rod passing through a sliding seal in a side arm on the opposite side of the chamber. The steel rod is moved in and out by a lathe screw driven by a stepping motor. A particular location on a selected sample is moved to the beam position, either by manually controlling the pulses to the stepping motor or by a sequence of pulses from an on-line computer. Silica or glass discs are mounted at each end of the sample carrier to allow visual checks of the alignment of the carrier relative to the proton beam position.

Samples are attached to the interchangeable carriers by a variety of techniques devised to accommodate different sizes and shapes. The largest samples that have been used to date are obsidian daggers approximately 25 cm long and 4 cm wide. The majority of samples are 2 cm or less in length and 30 or 40 such samples can be mounted on one carrier. Installation of a loaded carrier into the vacuum system and evacuation requires 15 to 20 minutes compared with a total measuring time of 200 to 300 minutes for this number of samples.

After mounting, the samples and the carrier are washed in nanograde benzene using ultrasonic agitation. Otherwise, no special precautions are taken in surface preparation or in obtaining a high vacuum in the target chamber - the pressure being typically 0.1 to 1 mPa during irradiation.

The flattest face of each sample is usually placed against the carrier to minimise differences in position and angle of the irradiated portion. Mechanical errors in positioning are less than 1 mm, but the different shapes of the samples can result in individual pieces being offset from the carrier by several millimetres at the beam position. The distance from the surface of the carrier to the gamma-ray detector is 155 mm so the offset of individual pieces will result in changes of a few per cent in the number of gamma-rays recorded by the detector.

The angle of orientation of the irradiated surface to the proton beam can also vary from sample to sample because of differences in shape; this was found to have some effect on the observed gamma-ray count rates. Tests of a piece of obsidian mounted on a rotating holder which enabled the angle of the surface to the proton beam to be changed gave the results shown in Figure 7. Estimates of the variation in angle arising from changes in shape indicate that changes in count rate of 1 to 2 per cent can be attributed to this cause.

4.4 Gamma-ray Detection

A lithium-drifted germanium detector (ORTEC Model 8101-2023) is placed adjacent to a port in the sample chamber at 90° to the incident proton beam. A 1 mm thick aluminium window in the vacuum system minimises the attenuation of gamma-rays but additional attenuators can be inserted outside the window to reduce the proportion of low energy gamma-rays reaching the detector. The detector is surrounded by a 5 cm thick lead shield with additional shielding placed between the detector and the portion of the beam line containing the beam collimator to absorb gamma-rays from contaminants which could build up on the collimator during long periods of irradiation.

The electronics for processing pulses from the detector are shown in Figure 8. Pulse height spectra with 2048 or 4096 channels are accumulated in a DEC PDP15 on-line computer. Gain stabilisation is used to maintain standard conditions for determining peak areas of selected gamma-rays. The spectrum peak at 122 keV from a ^{57}Co source, placed close to the detector, is used for zero stabilisation, and the 1634 keV gamma-ray from the ^{23}Na (p,$\alpha\gamma$) reaction is used for gain stabilisation.

4.5 Data Collection and Analysis

Sample positioning, beam current monitoring and data collection, storage and analysis are all controlled by the on-line computer system. A predetermined sequence of these steps is carried out: for example, irradiation of a particular sample for a fixed dose of protons (corrected for dead-time of the pulse height analysis system), transfer of the accumulated spectrum to a buffer store, and movement of the sample carrier to the next position. During irradiation of the next sample, the integrated counts in specified gamma-ray peaks and related background regions are determined for the spectrum in the buffer store and the results printed out together with run details and sample identification. The complete spectrum can, if necessary, be filed for future reference or for more detailed analysis.

Several methods for the determination of peak areas were compared, including the use of an automated peak search routine which had been tested internationally. All the peaks of interest are well separated and have adjacent flat background regions, so the simplest procedures give reliable results when compared with more advanced peak fitting methods. In most obsidian work, the counts in channels spanning each peak are integrated; the background is determined by summing the number of counts just above the peak in an equal number of channels and this is then substracted. Print out of peak areas during a sequence of measurements allows immediate inspection of the results and identification of anomalous data arising from surface faults or other factors. It is also possible to include a search for peaks that are characteristic of the brass sample carrier to indicate misalignment with the proton beam. The information can also be filed for use in such statistical analysis as the calculation of correlation coefficients between specified data sets or discriminant function analysis to test for groups of similar results.

5. PROMPT GAMMA-RAYS FROM OBSIDIAN

5.1 Observed Reactions

A typical pulse height spectrum is shown in Figure 9. A list of peak energies and intensities is given in Table 2 together with the total number of counts occurring between 5 and 7.2 MeV which can be used as a measure of the number of high energy gamma-rays produced by the $^{19}F(p,\alpha\gamma)$ reaction. The low count rate above 7.2 MeV verifies that few high energy gamma-rays are produced by other reactions. In addition to the peaks listed in Table 2, weaker peaks can be observed in longer runs but these are of limited usefulness for element characterisation.

Two strong gamma-rays are observed from different reactions in sodium and a comparison of results for the set of obsidian source samples shows a good correlation between their peak areas (Figure 10). Since the intensity of the 0.440 MeV gamma-ray is approximately six times that at 1.634 MeV, only the former has been used for characterisation. Although sodium is a major constituent of obsidian and only varies by a factor of 2.5 in the sources studied, the precision of the measurements is sufficiently high and the intra-source variation sufficiently low for it to be very useful for characterisation.

Three strong peaks observed from reactions in aluminium are compared in Figures 11 and 12. A satisfactory correlation is observed between the 0.843 and 1.013 MeV gamma-rays but not between those at 0.170 and 1.013 MeV. The peak at 0.170 MeV is broader than other peaks and includes events due to detection of photons after large angle Compton scattering in surrounding materials; it is thus not suitable for characterisation studies. The 1.013 MeV gamma-ray has been used in most of these studies since, although the summed intensity of the 0.843 and 1.013 MeV peaks can be used to obtain higher count rates, this does not significantly improve the results.

Gamma-rays from reactions in fluorine are observed at 0.110, 0.198 and 6.129 MeV. An additional gamma-ray at 7.119 MeV can be observed as a very broad peak in Figure 9 since this gamma-ray is emitted by excited ^{16}O nuclei before they come to rest after recoil from the (p,α) reaction. Both the 6.129 and 7.119 MeV gamma-rays are included in the sum of counts between 5 and 7.2 MeV (FSUM). A comparison of FSUM with the count rate from the 0.198 MeV gamma-ray (Figure 13) shows a good correlation. However, for the gamma-ray

TABLE 2

GAMMA RAY ENERGIES AND PEAK INTENSITIES FOR KUKUIA OBSIDIAN

(40 μC of 2.5 MeV protons; 21% Ge(Li) detector at 15 cm 90°)

Energy (keV)	Reaction	Peak Area (counts)
76	Pb X-ray	3270
110	$^{19}F(p,p')$	2528
170	$^{27}Al(p,p')$	5162
198	$^{19}F(p,p')$	4793
426	$^{10}B(p,\alpha)$	329
440	$^{23}Na(p,p')$	68651
479	$^{7}Li(p,p')$	385
511	annihilation	2833
606	double escape	841
843	$^{27}Al(p,p')$	3149
1013	$^{27}Al(p,p')$	5468
1119	single escape	1110
1368	$^{27}Al(p,\alpha)$	905
1632	$^{23}Na(p,\alpha)$	11448
5-7.2 MeV	$^{19}F(p,\alpha)$	7111

detector used in the present work, FSUM provides a higher count rate and lower background than the 0.198 or 0.110 MeV gamma-rays and has therefore been preferred for characterisation studies.

Coote, et al. [1972] showed that, using a smaller Ge(Li) detector, successful measurements of fluorine could be made using the 0.110 MeV gamma-ray and, if necessary, information from the three different energies could be combined for fluorine determination.

Gamma-rays from other nuclides such as lithium, boron, etc. are too weak to provide sufficient accuracy in the short runs used for the present work. Extended measurements or irradiations with other ion beams could be used to increase the number of elements determined, but in this report only three elements are considered.

5.2 Element Determination

The number of gamma-rays produced by a thick sample of a pure element is given by:

$$Y = PN \int_{E_p}^{0} \frac{\sigma(E,\theta)}{(dE/dx)} \, dE \ , \tag{1}$$

where P is the number of incident protons, N is the atom density (atom g^{-1}), $\sigma(E,\theta)$ is the cross section for production of the particular gamma-ray as a function of the incident proton energy(E) and angle of detection (θ), (dE/dx) is the stopping power of the sample (keV g^{-1} cm^2) which is also a function of proton energy. In the case of a mixture of elements such as obsidian, the yield of gamma-rays from element i is:

$$Y_i = f_i PN \int_{E_p}^{0} \frac{\sigma t(E,\theta)}{(dE/dx)_m} \, dE \ , \tag{2}$$

where f_i is the weight fraction of element i in the mixture m and the stopping power of the mixture is given by:

$$\left(\frac{dE}{dx}\right)_m = \sum_i f_i \left(\frac{dE}{dx}\right)_i \ . \tag{3}$$

The cross sections, as a function of proton energy, for gamma-ray production have been reported for pure sodium [Bodart et al. 1977], aluminium

[Deconninck and Demortier 1972] and fluorine [Stroobants et al. 1976]. The energy dependence of proton stopping power is also readily available [Anderson and Ziegler 1977].

The evaluation of the integrals in Equations (1) and (2) is unnecessary if a comparison is made between the gamma-ray yields from known and unknown samples with similar stopping powers. A satisfactory approximation to Equation (2) is:

$$\frac{Y_1}{Y_2} = \frac{f_1}{f_2} \frac{P_1}{P_2} \frac{S_2}{S_1} , \tag{4}$$

where S is the stopping power evaluated at a proton energy for which the gamma-ray yield from element i is one-half of the value at the proton energy used in the measurements. Deconninck and Demortier [1972] describe tests of this approximation which indicate less than 1 per cent error for 2 per cent of Al in Ni.

For these obsidian studies, a standard glass from the National Bureau of Standards (USA) was used to calibrate the Na and Al yields. The difference in stopping power of this glass and obsidian of various compositions is less than 1 per cent and thus can be ignored. The weight per cent of Na and Al in obsidian was obtained directly from the ratio of gamma-ray yields for equal proton charge incident on the samples (after correction for instrumental dead-times).

The fluorine content of the standard glass was not known, so special comparison samples were made from mixtures of powdered calcium fluoride in alumina or magnesia. These samples also had stopping powers close to those for obsidian. In some cases, a small amount of powdered silver was included in the mixture to obtain a match in the stopping power and also to provide sufficient electrical conductivity to prevent charge build-up at the end of the proton range during irradiation.

The mean values of sodium, aluminium and fluorine concentrations found by these methods are listed in Table 3. The standard deviations are those observed among the repeated measurements on each source. Repeated measurements on one sample, such as a standard glass, gave standard deviations of less than 1 per cent during one set of runs, and between 1 and 2 per cent for independent measurements made at different times [Owen et al. 1976]. In most cases, therefore, the standard deviations observed for obsidian can be attributed chiefly to the intrinsic variability of the surface spots although in some cases too few measurements have been made to be able to derive the intrinsic variability. Likewise, the number of samples tested may not be representative of the total obsidian flow. Only a very extensive sampling program could hope to reveal the full extent of the variability of one source and the difficulty, or impossibility, of such a program has been discussed in Section 2. The results given in Table 3 can only be regarded as setting the lower limits to the variability for each source.

Measurements using X-ray fluorescence techniques have been reported for some of these sources by Smith et al. [1977]. Their results have been included in Table 3 for comparison. A mean ratio of 0.95 is observed for sodium concentrations and 0.97 for aluminium concentrations. No previous measurements have been reported for the fluorine content of these obsidians.

6. SOURCE OBSIDIAN RESULTS

6.1 Measurements

Several series of measurements were made over several years and the gamma-ray count rate ratios were used for initial comparisons of sources and artefacts [Bird and Russell 1976]. In any particular series, the count rates were determined by choices of accelerator energy, detector distance and such factors as the occasional use of a gamma-ray filter to reduce the high sodium count rate relative to aluminium and fluorine. Each of these series of results has been appropriately normalised to obtain element concentrations and these are listed in Appendix B. The two most useful element ratios are also included in the Appendix together with the mean, minimum and maximum values for each source. These results are used in the following discussion, but some improvement in precision can be achieved by selecting results measured in one series of runs.

Occasional measurements gave much lower count rates than were observed at other times for the same samples. Such results mostly arise from the presence of inclusions or other surface anomalies which can reduce the fraction of the incident beam which impinges on good quality obsidian. In such cases, the element ratios can still be compared satisfactorily with other data. However, such runs have been omitted from the data in Appendix B.

TABLE 3

THREE ELEMENT CONCENTRATIONS FOR OBSIDIAN SOURCES

		N_m^*	Na %		SW&A	Al %		SW&A	F µg g^{-1}	
			Mean SD	Range		Mean SD	Range		Mean SD	Range
Indonesia										
IN1	Leles	5	2.44±0.04	2.38-2.51		6.36±0.16	6.20-6.65	6.5	697± 9	685- 707
IN2	Talaud	2		3.64-3.67			7.97-8.03			1196-1198
IN3	Minahasa	7	3.30±0.04	3.27-3.37		6.82±0.11	6.64-7.01		648±24	624- 689
Admiralty										
AD1	Pam Lin	8	3.37±0.06	3.26-3.46	3.7	6.97±0.13	6.96-7.15	7.0	1294±20	1266-1308
AD2	Lou (Solang)	8	3.67±0.06	3.55-3.73		7.54±0.14	7.29-7.75		1129±54	1071-1206
AD3	Lou (Umrei)	8	3.60±0.07	3.48-3.68	4.0	6.37±0.19	6.96-7.53	7.4	1249±41	1206-1321
AD4	Lou (Lakou)	4	3.51±0.18	3.30-3.12		6.99±0.43	6.47-7.48		1340±40	1293-1397
AD5	Tuluman	5	3.78±0.17	3.55-4.00		7.36±0.34	6.87-7.77		1432±70	1314-1498
New Britain										
NB10	Pilu	3	2.48	2.44-2.53		6.14	6.08-6.25		447	423- 460
NB11	Voganakai	8	2.44±0.10	2.33-2.67		6.21±0.31	5.75-6.53		544±24	513- 595
NB2	Talasea	31	2.71±0.11	2.58-2.96	3.0	6.47±0.30	5.99-7.11	6.7	529±17	493- 571
NB3	Garua	8		2.14-2.64			5.10-6.97			444- 500
NB4	Waisisi	14	3.17±0.08	3.04-3.38		6.49±0.21	6.17-6.92		473±12	462- 505
NB5	Schaumann	4		1.68-2.52			3.85-6.27			272- 566

(Continued)

		N_m*	Na %		SW&A#	Al %		SW&A#	F μg g^{-1}	
			Mean SD	Range		Mean SD	Range		Mean SD	Range
d'Entrecasteaux										
WF1	Kukuia	31	3.50±0.11	3.33-3.73	3.0	7.25±0.29	6.79-7.73	6.9	569±26	519- 628
WF2	Fagalulu	13	3.24±0.12	3.00-3.45	3.7	6.85±0.24	6.33-7.17	7.5	311±17	297- 361
WF3	S182 (Kukuia)	5	3.57	3.45-3.70		7.56	7.36-7.75		636	618- 657
XX		57	2.86±0.17	2.30-3.38		6.66±0.38	5.23-7.22		232±14	203- 280
EF1	Sanaroa	19	4.03±0.19	3.67-4.38	4.3	6.40±0.47	5.62-7.12	6.6	855±45	788- 992
EF2	Aiasuna	16	4.27±0.21	3.93-4.63	4.7	6.97±0.45	6.00-7.61	7.5	1033±43	841-1121
EF3	S245 (Sanaroa)	1		4.15			6.23			992
EF4	Old	8	4.34±0.19	3.97-4.55	4.5	5.74±0.21	5.43-5.99	5.9	1979±89	1836-2092
EF5	Numa Nth	5	4.10	3.87-4.47		6.00	5.56-6.73		1589	1540-1713
New Hebrides										
NH1	Vanua Lava	23	3.12±0.14	2.88-3.37		7.24±0.42	6.39-7.99	7.4	663±37	603- 736
NH2	Gaua	14	3.81±0.16	3.49-4.17		8.33±0.51	7.33-9.31	8.9	805±27	766- 847
NH3	Vanua Lava (318)	2		3.51-3.79			7.63-8.47			798- 814
New Zealand										
ZD23	Taupo	4	2.95	2.74-3.09		6.64	6.25-6.91		376	345- 399

*N_m is the number of measurements

#SW&A = Smith (1977)

The frequency distributions of each parameter, measured with samples from a particular obsidian source, are usually asymmetric. This can be attributed to a number of factors:

- surface anomalies cause low count rates and hence tailing on the low side of a distribution;
- inaccuracies in sample positioning, including variations in the angle of the sample surface relative to the direction of the incoming beam (caused by irregular shapes) will also give more low values than high values; and
- intrinsic variability in the source material and the effects of limited sampling may lead to a variety of distribution shapes.

The first two factors may be reduced or even eliminated by the use of element ratios and these are indeed found to have narrower and more symmetrical distributions.

The three-parameter data can be presented in a variety of ways but the most useful plot has been found to be that of Al/Na v. F/Na (Figure 14). Further useful distinctions between sources can be displayed by plotting Na v. F (Figure 15) and Al v. F (Figure 16). A comparison of Na and Al is not of great value since it shows, chiefly, that these two elements are well correlated within most of the source groups and for more than half of the groups studied. This is also evident in Figure 14 and, as has already been discussed, is to be expected on the basis of the chemistry of the acid volcanic glasses.

Figures 14 to 16 include only those results obtained with samples whose origin from one of the four Melanesian areas is well established and which, for reasons of quality and age, are likely to have been useful for artefact production. The solid lines in the figures are drawn to enclose 95 per cent or more of all the results from each source. The orientation of the resulting polygons in Figures 15 and 16 show that correlations are present. However, it should be noted that this effect is graphically enlarged by the suppressed zero used in the scales for the figures.

6.2 Characterisation

Seventy-seven specimens from the Melanesian area were submitted for analysis and 29 source groups were identified in the field, 22 of which are of potential archaeological interest. However, some of these groups give results that are so similar that it is impractical to try to show them separately in Figures 14 to 16, hence only 15 separate clusters are shown by the solid line boundaries. A number of additional isolated samples, for which results are given in Appendix B, are also omitted from these figures. The figures thus represent only well-attested Melanesian sources and in no way define the complete range of material available either now or at various periods of archaeological interest. The study of these samples can, however, provide a very useful basis for initial comparison with artefact collections.

An inspection of element ratios (Figure 14) shows differences between results for obsidian from the four main geographical regions - although there is some overlap in the case of New Britain and New Hebrides samples. This overlap can be resolved by reference to Figure 15. Within each region, some of the individual sources can be distinguished satisfactorily while others give overlapping results. The main features of the results are discussed below.

Admiralty Islands

Obsidian from the Admiralty Islands is clearly different to the other material studied but between the individual sources there are only marginal differences. The most recent obsidian from the Tuluman eruption in the 1950s is quite similar to older material, which suggests that only minor changes of Na, Al and F have occurred in the geochemistry of successive lava flows in the St. Andrew Strait.

New Britain

There are lower concentrations of Al, F and Na in New Britain obsidian than in that from the New Hebrides but the element ratios overlap to some extent. Most of the samples from the Willaumez Peninsula give similar results and those from Pilu and Voganakai are not sufficiently different to permit a reliable distinction. However, the samples from Garua and Schauman Islands vary considerably and further work is needed to establish their properties. They have not been included in Figures 14 to 16.

The Waisisi artefacts from Cape Hoskins are quite different from other known New Britain sources and can be distinguished from Kukuia obsidian by having lower concentrations of the three elements.

West Fergusson

Samples from three locations around the Kukuia Peninsula give a very compact group of results which are readily separable from those of the nearby Fagalulu flow. Sample S182 differs slightly from the Kukuia results, but being a partly devitrified specimen it is unlikely to have been used prehistorically as a raw material.

East Fergusson

Many different compositions are observed in the East Fergusson, Dobu and Sanaroa Island material. This includes obsidian from geologically older and younger flows in the same neighbourhood which are very different in composition. The results are very different from those for the other areas. Seemingly, significant changes have occurred in the geochemistry of successive volcanic events in this area.

New Hebrides

The difference between these samples and those from New Britain has already been mentioned. The highest aluminium values were observed in Gaua obsidian; one of the Vanua Lava sources (318) yielded results that were quite similar to this rather than to the other Vanua Lava samples.

6.3 Statistical Analysis

Some consideration was given to using multivariate statistical techniques first, for defining the known source groups and second, for allocating unknown artefacts to one or other of the defined groups. Previous work by Ward [1974] on New Zealand obsidians suggested a useful technique would be the use of the Mahalanobis D2 statistic, which is a generalised distance measure for estimating resemblance between three or more groups. Ward applied the method using five elements [op cit:47] with a population of 18 obsidian groups. A test of the validity of the groups was made by considering each specimen as an 'unknown' which was then allocated to its nearest group. In this procedure 98 per cent of specimens were correctly reallocated to their original groups.

Although the number of groups in the present study is comparable to that in Ward's study the lesser number of variables, namely three, is probably too few for achieving the fullest advantage of the D2 statistic. Nevertheless several runs were made using the Mahalanobis discriminant function analysis according to the system described by Klecka [1975]. The raw corrected counts of the PIGME analysis for Na, Si and F were used for this procedure.

The data from 27 field collections, including Waisisi flakes and the anomalous artefact group XX which had been identified in the plots of ratios described previously, were processed using the Mahalanobis statistic, with the result that only 77 per cent of the cases were reallocated to their defined groups. This indicated the chemical affinity of some groups and demonstrated that the separation of several was invalid on the basis of the data from the three elements used in the analysis. Although these results indicate the impracticality of differentiating between all obsidians from flows within a regional source, they do not detract from the utility of the project in differentiating between regional sources, as well as a limited number of subregional obsidian varieties.

When the original 29 collections were selectively combined, so that geographically contiguous groups that were not chemically distinguishable were placed together, there was an increase in the number of correct allocations of the source specimens. Reducing the number of groups to 15 resulted in the correct reallocation of 92 per cent of cases in the source collections. The 15 collections comprised three from the Admiralty Islands, three from New Britain, six from the D'Entrecasteaux Islands, and three from the Banks Islands. Further reduction to eleven groups resulted in an improvement of reallocations to 97 per cent. This may appear to be satisfactory but, given the narrower variance in the source groups, compared with the greater total variance expected from the artefact collections, a perfect 100 per cent of reallocated source specimens would be preferable. In the present study it is important that the obsidians from New Britain and the Banks Islands be unequivocally distinguished. A perfect separation of these two widely separated sources is not possible using the elements Na, Si and F. However, it is possible to uniquely separate these two source regions by using density as a fourth measure, but a preferable system would be one which differentiated all the sources or flows according to their chemical composition. This has been achieved by using the extended element determinations made possible by using simultaneous gamma-ray and X-ray measurements [Duerden et al. 1979].

7. OBSIDIAN ARTEFACT RESULTS

7.1 Measurements

The results of measurements on more than 700 artefacts are listed in Appendix C together with information on the possible origin of each sample. A plot of the two most useful ratios is given in Figure 17, including the polygons transferred from Figure 14 to show the location of source results. In Figure 17, circles represent artefact results for which only one measurement has been made and crosses signify the mean of a number of measurements. Observed element concentrations are plotted in Figures 18 (Na v. F) and 19 (Al v. F).

In the first measurement, approximately 5 to 10 per cent of artefact results were found to differ widely from those expected; this can largely be attributed to the presence of extraneous surface material or surface deterioration. It should be noted that the artefacts were washed in nanograde benzene and received no other preparatory treatment but, although the best face of each was presented to the incoming proton beam, they were not always devoid of defects. Those samples giving divergent results were remounted with extra care to locate a suitable spot for measurements; most of these then gave results that were compatible with other associated samples. However, some artefacts gave such anomalous or variable results on repeated measurements that no relation could be established between their composition and that of the known sources, or of other groups of artefacts not represented by known sources.

Two groups of artefact results suggest the presence of additional unlocated obsidian sources. The flakes from the Waisisi site at Cape Hoskins, New Britain are quite different from those from the known New Britain sources and can be distinguished from the Kukuia obsidians (which have similar element ratios) by the lower concentrations of all three elements. Additional artefacts have a very similar composition to those from Waisisi and may be attributed to a new source that is not yet located geographically, although it may tentatively be attributed to New Britain, and possibly to the Cape Hoskins volcanic events.

A number of artefacts give results which are indicated in Figures 17 to 19 as group XX. This group is nearest in composition to Fagalulu obsidian and includes samples which were found with others that are likely to be from West

Fergusson Island. It is thus tempting to assume that there is another source, as yet unlocated, in the West Fergusson area.

When these two unlocated sources are included, practically all of the artefacts having compositions falling within the range of Figures 17 to 19 can be allocated to one of the studied groups. However, it is evident that the artefacts show a greater variation in composition than does the source material described in Section 5. The main effect appears to be a trend towards low sodium; this can be attributed to the effect of the leaching of sodium from the surface of the artefacts, some of which had been buried for up to 6000 years.

Measurements were made on a number of samples which had been fractured to permit a direct comparison of weathered and fresh surfaces. The changes were comparable to those found among source samples; extensive measurements of this kind would be needed to determine the relative importance of weathering and intrinsic source variability.

7.2 Artefact Groups

The results of discriminant function analysis have been used, together with a visual comparison of artefact and source results (Figures 17 to 19), to suggest a geographical origin for most of the artefacts; this information is also included in Appendix C. Group numbers are given in the case of unambiguous assignments whereas numbers in parentheses indicate plausible assignments. It is important to emphasise again that these assignments, made on the basis of chemical similarity, must be used with caution.

Admiralty Islands

A considerable number of the artefacts studied give ratios within the range of those for the Umrei (Lou Island) source, but there is a considerable scatter of results. Some of the results just above the Umrei polygon in Figure 17 can be reasonably explained as being due to low sodium - giving rise to high points in this figure and low points in Figure 18. However, it is possible that the points outside the main cluster may belong to different groups. A greater range of Na and Al values is observed than for the known sources. Figures 17 and 18 provide further evidence that other obsidian deposits in the Admiralty region were used.

New Britain

Most of the artefacts attributed to New Britain sources agree well in composition with obsidian from the Willaumez Peninsula with little evidence of low Na. However, some of the results lie outside the range observed for this source and may be attributed to other New Britain sources. Eleven samples have element ratios in the range of those observed for Talasea or Waisisi obsidian but their high Na concentration is characteristic of the Waisisi material. The range of concentrations is greater than that observed for Waisisi artefacts and further measurements are needed to verify the assignment.

West Fergusson

A compact group of results agree well with those for West Fergusson obsidian; this tends to confirm the quality of Kukuia material. A quite narrow range of F/Na values is observed but the Al/Na values extend a little beyond that for source material. An additional group of artefacts can be assigned as Fagalulu obsidian, although this is not of high quality and hence less suitable for artefact production. The new source (XX) is quite distinct from Fagalulu obsidian and is especially low in fluorine.

East Fergusson

Only five of the artefacts resemble East Fergusson obsidian and two of these have slightly higher Al than was observed for the source material.

New Hebrides

Two groups of artefacts show the higher Na and, to some extent, F which distinguishes New Hebrides from Talasea obsidian (see Figure 18). However, the boundaries of the Vanua Lava and Talasea groups are so close that assignment probabilities fall to 50 per cent for samples giving results near the boundaries. Some samples give values outside the source results and cannot be given plausible assignments without further study.

8. CONCLUSIONS

A field survey of the Papua New Guinea region has provided a collection of obsidian samples which can be used with other specimens from Melanesia in the study of the relation between artefact composition and that of known sources. Such a comparison is of considerable interest for the study of trade and usage patterns in prehistoric times. However, the physical difficulties in sampling present-day exposures of obsidian are compounded by the fact that major geological and geomorphological changes have occurred at source locations, even within the last thousand years. It is also true that although chemical composition can prove the dissimilarity of two specimens, it can only suggest possible links between artefacts and sources with similar composition. Provided that these limitations are kept in mind, compositional analysis has a role to play in archaeological studies.

The PIGME technique has been shown to be suitable for rapid non-destructive determination of Na, Al and F in obsidian. A precision of two to five per cent can be achieved for relative measurements, requiring three to five minutes per sample. This performance is adequate for studying the intrinsic variability of obsidian from one volcanic flow; this was in the range 5 to 25 per cent for the three elements measured. A significant degree of correlation is observed between Na and Al concentrations. Source variability is less than the changes in composition among the major Melanesian source areas.

Measurements on obsidian artefacts from a number of Melanesian localities and having ages ranging up to 6000 BP, give very similar results to those for the known sources except for the appearance of two additional groups and the possible presence of a number of additional sub-groups. However, a greater range of variability occurs among the artefact groups and approximately five per cent of the samples give such anomalous results that no characterisation is possible. There is some evidence for occasional low Na values which can be attributed to leaching of the artefact surface.

9. ACKNOWLEDGEMENTS

We wish to acknowledge the support of the operators of the 3 MeV accelerator at Lucas Heights and the staff of the Australian Institute of Nuclear Science and Engineering.

10. REFERENCES

Ambrose, W. [1976a] - In 'Advances in Obsidian Glass Studies' (ed. Taylor, R.E.), Noyes Press, New Jersey, p.81.

Ambrose, W. [1976b] - In 'Ancient Chinese Bronzes and Southeast Asian Metal and Other Archaeological Artifacts' (ed. Barnard, N.), National Gallery of Victoria, p.351.

Andersen, H.H. and Ziegler, J.F. [1977] - Hydrogen, Stopping Powers and Ranges in all Elements, Pergamon, New York.

Bird, J.R. and Russell, L.H. [1976] - In 'Ancient Chinese Bronzes and Southeast Asian Metal and Other Archaeological Artifacts' (ed. Barnard, N.), National Gallery of Victoria, p.317.

Bird, J.R., Campbell, B.L. and Price, P.B. [1974] - At. Energy Rev., 12:275.

Bird, J.R., Campbell, B.L. and Cawley, R.J. [1978a] - AAEC/E449.

Bird, J.R., Russell, L.H., Scott, M.D. and Ambrose, W.R. [1978b] - Anal. Chem., 50:2082.

Blake, D.H. [1976] - In 'Volcanism in Australasia' (ed. Johnson, R.W.), Elsevier, Amsterdam, p.191.

Blake, D.H. and Ewart, A. [1974] - J. Geol. Soc. Aust., 21:319.

Blake, D.H. and McDougall, I. [1973] - J. Geol. Soc. Aust., 20:199.

Bodart, F., Deconninck, G. and Demortier, G. [1977] - J. Radioanal. Chem., 35:95.

Coote, G.E., Whitehead, N.E. and McCallum, G.J. [1972] - J. Radioanal. Chem., 12:491.

Deconninck, G. and Demortier, G. [1972] - J. Radioanal. Chem., 12:189.

Dixon, J.E. [1976] - In 'Advances in Obsidian Glass Studies' (ed. Taylor, R.E.), Noyes Press, New Jersey, p.15.

Duerden, P., Bird, J.R., Scott, M.D., Clayton, E., Russell, L.H. and Cohen, D.D. [1980] - Nucl. Instrum. Methods, 168:447.

Duerden, P., Cohen, D.D., Clayton, E., Bird, J.R., Ambrose, W.R. and Leach, B.F. [1979] - Anal. Chem., 51:2351.

Johnson, R.W. and Blake, D.H. [1972] - Bur. Min. Res. (Aust.), Geol. Geophys. Rec., 1972/133.

Johnson, R.W., Mackenzie, D.E., Smith, I.E. and Taylor, G.A.M. [1973] - In 'The Western Pacific: Island Arcs, Marginal Seas, Geochemistry' (ed. Coleman, P.J.), Univ. Western Australia Press, p.523.

Johnson, R.W. and Smith, I.E.M. [1974] - J. Geol. Soc. Aust., 21:333.

Key, C.A. [1968] - Nature, 219:360.

Key, C.A. [1969] - Arch. Phys. Anthrop. Oceania, IV:45.

Klecka, W.R. [1975] - In 'SPSS, Statistical Package for the Social Sciences' (ed. N.H. Nie et al.), McGraw Hill, USA, p.434.

Lowder, G.G. and Carmichael, I.S.E. [1970] - Geol. Soc. Am. Bull., 81:17.

Mallick, D.I.J. [1973] - In 'The Western Pacific: Island Arcs, Marginal Seas, Geochemistry' (ed. Coleman, P.J.), Univ. Western Australia Press, p.193.

Owen, D.G., Bird, J.R., Russell, L.H. and Scott, M.D. [1976] - Proc. Aust. Conf. Nuclear Techniques of Analysis, 3-6 May, p.89.

Reeves, R.D. and Ward, G.K. [1976] - In 'Advances in Obsidian Glass Studies' (ed. Taylor, R.E.), Noyes Press, New Jersey, p.259.

Reynolds, M.A. and Best, J.G. [1976] - In 'Volcanism in Australasia' (ed. Johnson, R.W.), Elsevier, Amsterdam, p.287.

Smith, I.E.M. [1974] - Arch. Phys. Anthrop. Oceania, XI:18.

Smith, I.E.M., Ward, G.K. and Ambrose, W.R. [1977] - Arch. Phys. Anthrop. Oceania, XII:173.

Specht, J. [1974] - Antiquity, 48:302

Stroobants, J., Bodart, F., Deconninck, G., Demortier, G. and Nicholas, G. [1976] - Proc. Int. Conf. on Ion Beam Surface Layer Analysis, Plenum, New York, p.433.

Stross, F.H., Hester, T.R., Heizer, R.F. and Jack, R.N. [1976] - In 'Advances in Obsidian Glass Studies' (ed. Taylor, R.E.), Noyes Press, New Jersey, p.240.

Wall, T. [1976] - In 'Ancient Chinese Bronzes and Southeast Asian Metal and Other Archaeological Artifacts' (ed. Barnard, N.), Nat. Gallery of Victoria, p.337.

Ward, G.K. [1974] - Archaeometry, 16:41.

Ward, G.K. [1978] - N.Z. Arch. Assoc. Newsletter, 20:188.

White, J.P., Downie, J.E. and Ambrose, W.R. [1978] - Science, 199:877.

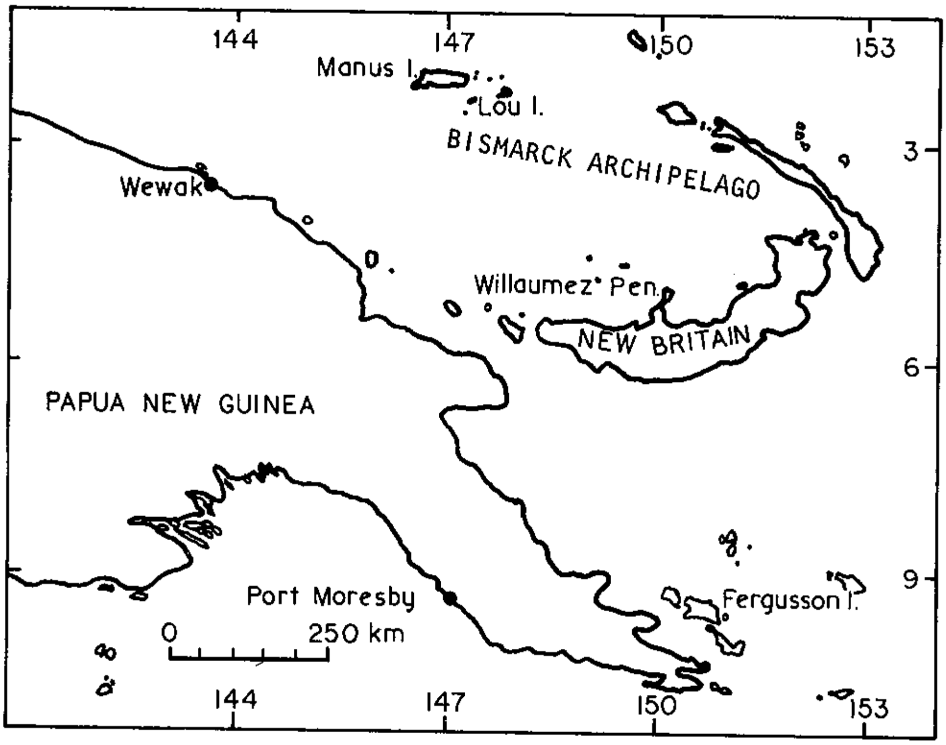

FIGURE 1a. THE PAPUA-NEW GUINEA REGION

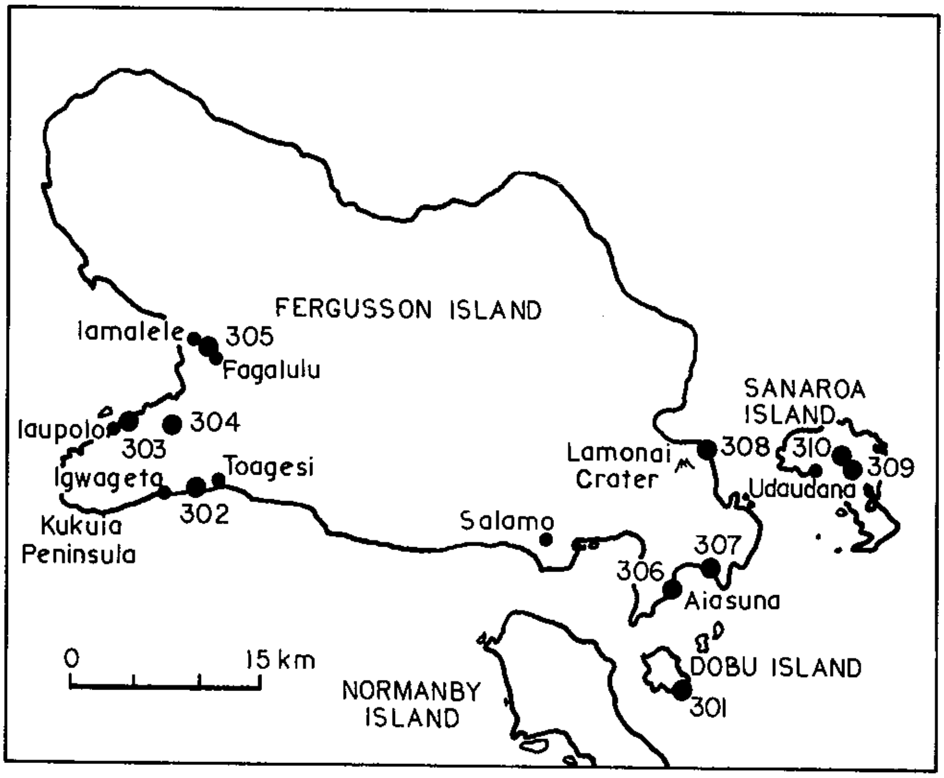

FIGURE 1b. FERGUSSON AND NEIGHBOURING ISLANDS (D' ENTRECASTEAUX GROUP)

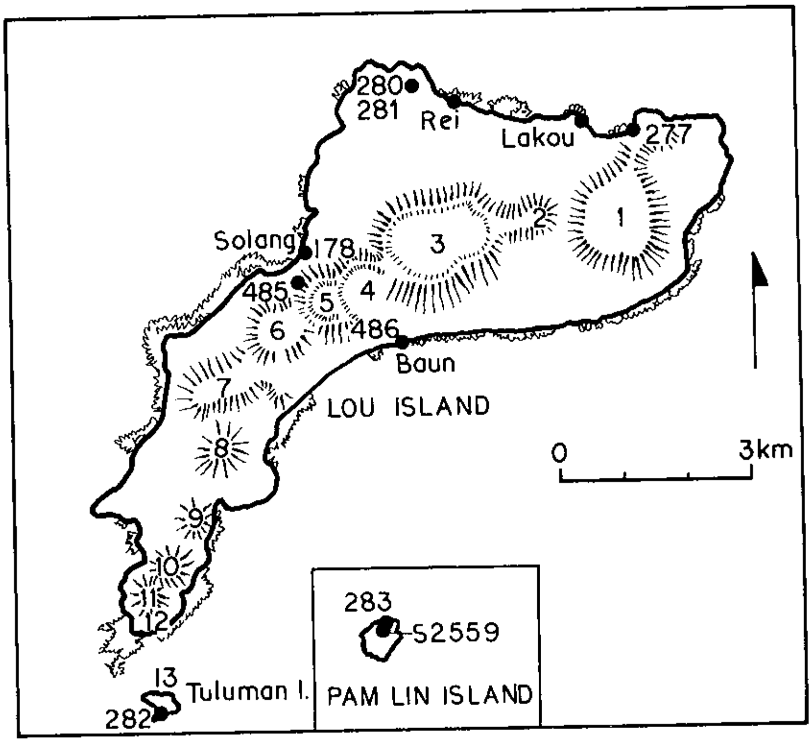

FIGURE 2. LOU ISLAND (ADMIRALTY GROUP)

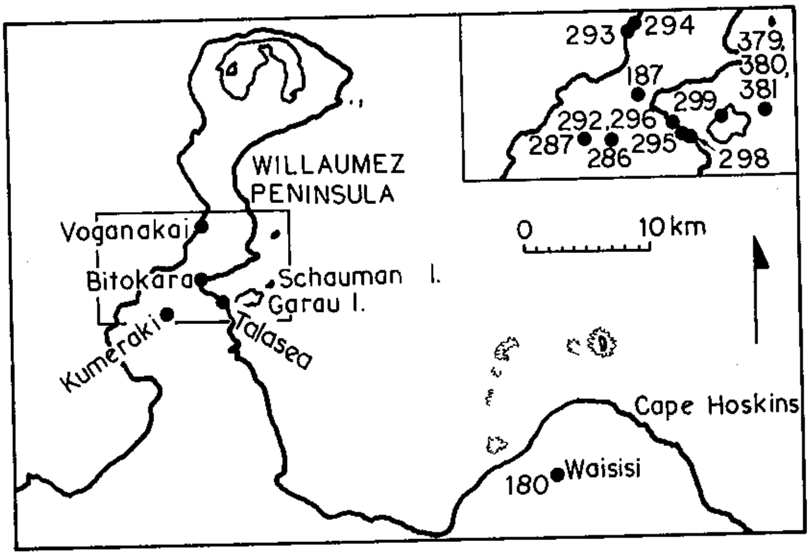

FIGURE 3. WILLAUMEZ PENINSULA (NEW BRITAIN)

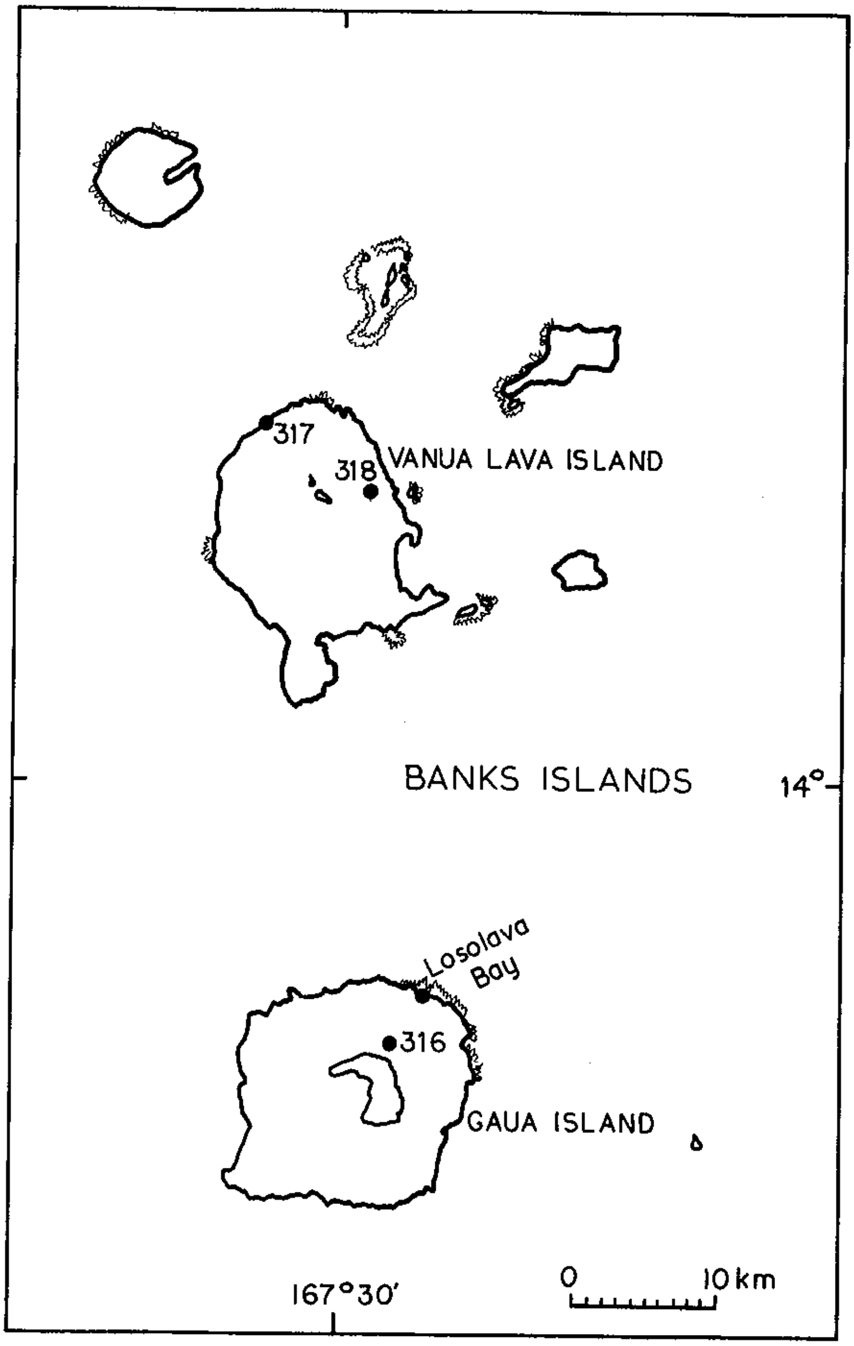

FIGURE 4. BANKS ISLANDS (NEW HEBRIDES)

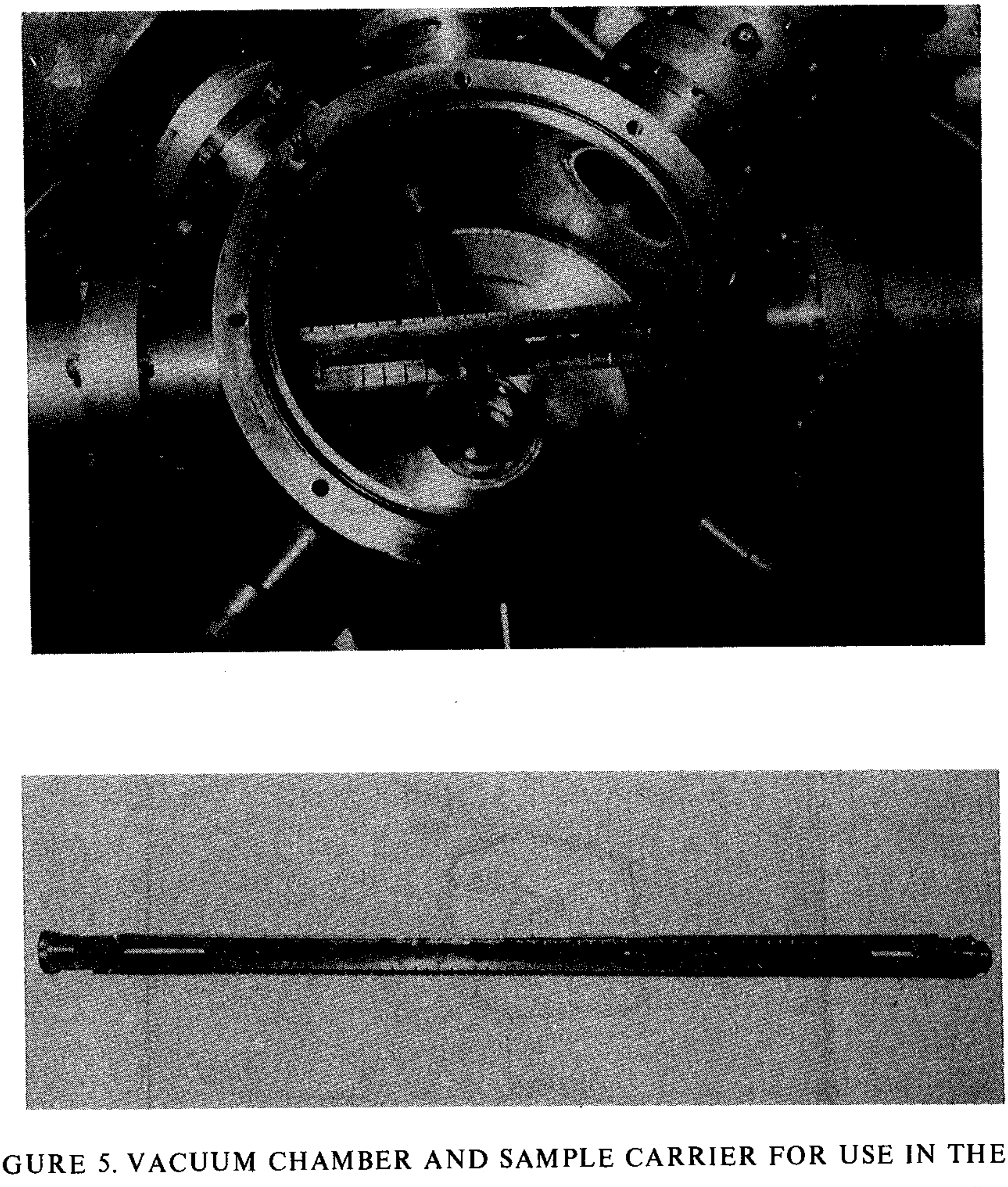

FIGURE 5. VACUUM CHAMBER AND SAMPLE CARRIER FOR USE IN THE AUTOMATED ANALYSIS OF OBSIDIAN BY (p,p') REACTIONS

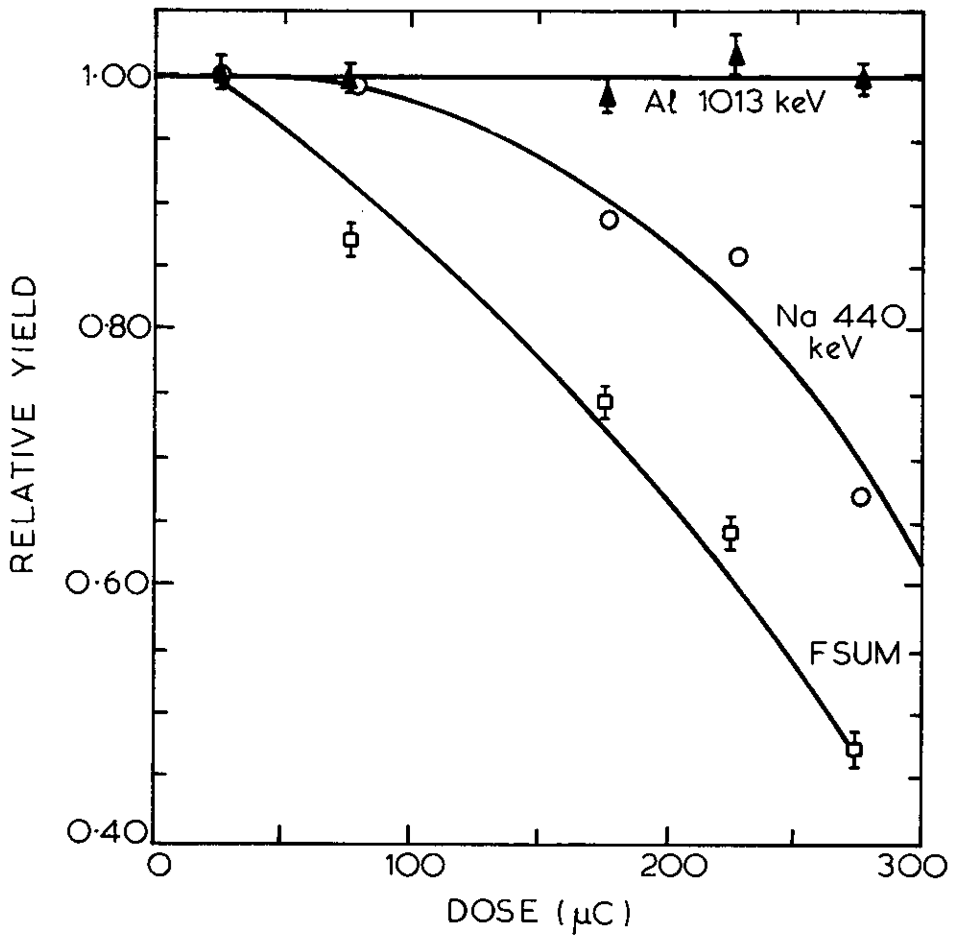

FIGURE 6. CHANGE IN GAMMA-RAY YIELDS DURING IRRADIATION WITH 0.6 μA OF 2.5 MeV PROTONS

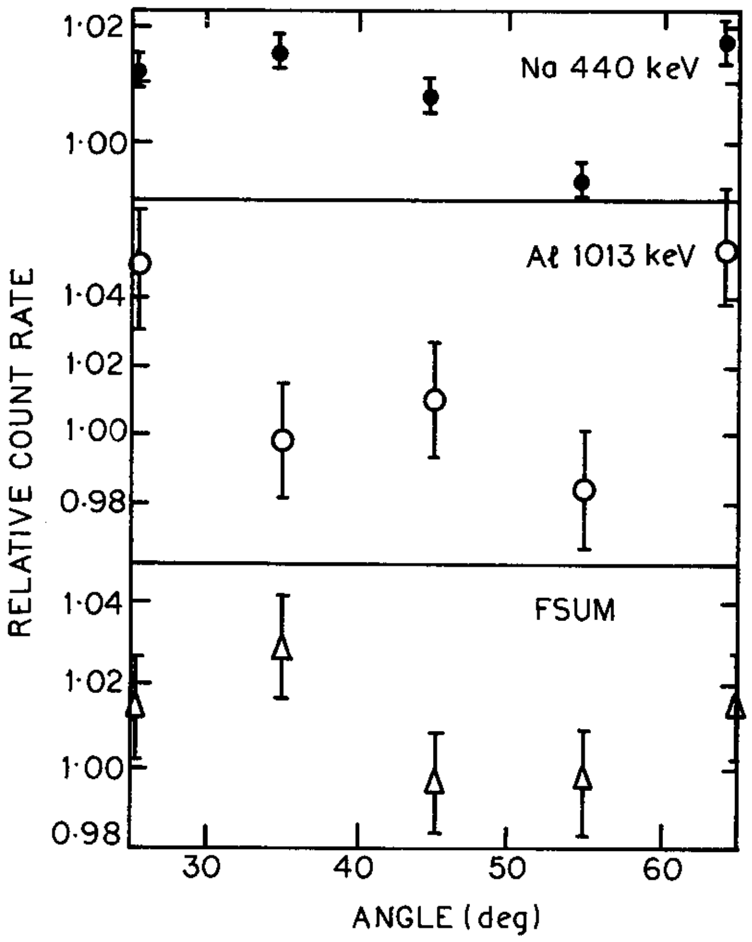

FIGURE 7. VARIATION OF GAMMA-RAY YIELDS WITH ANGLE OF SAMPLE WITH RESPECT TO THE INCIDENT BEAM

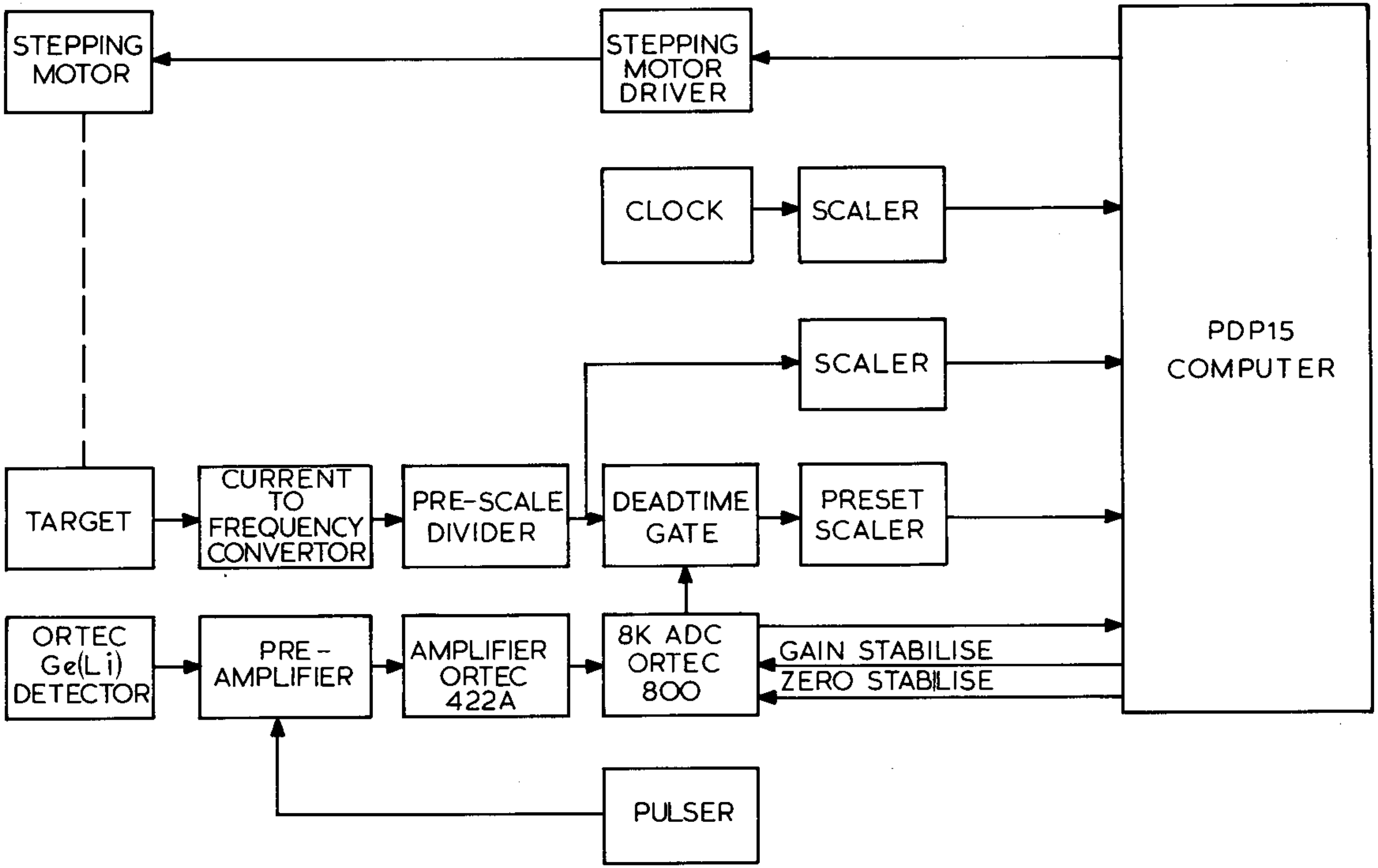

FIGURE 8. BLOCK DIAGRAM OF MEASURING EQUIPMENT

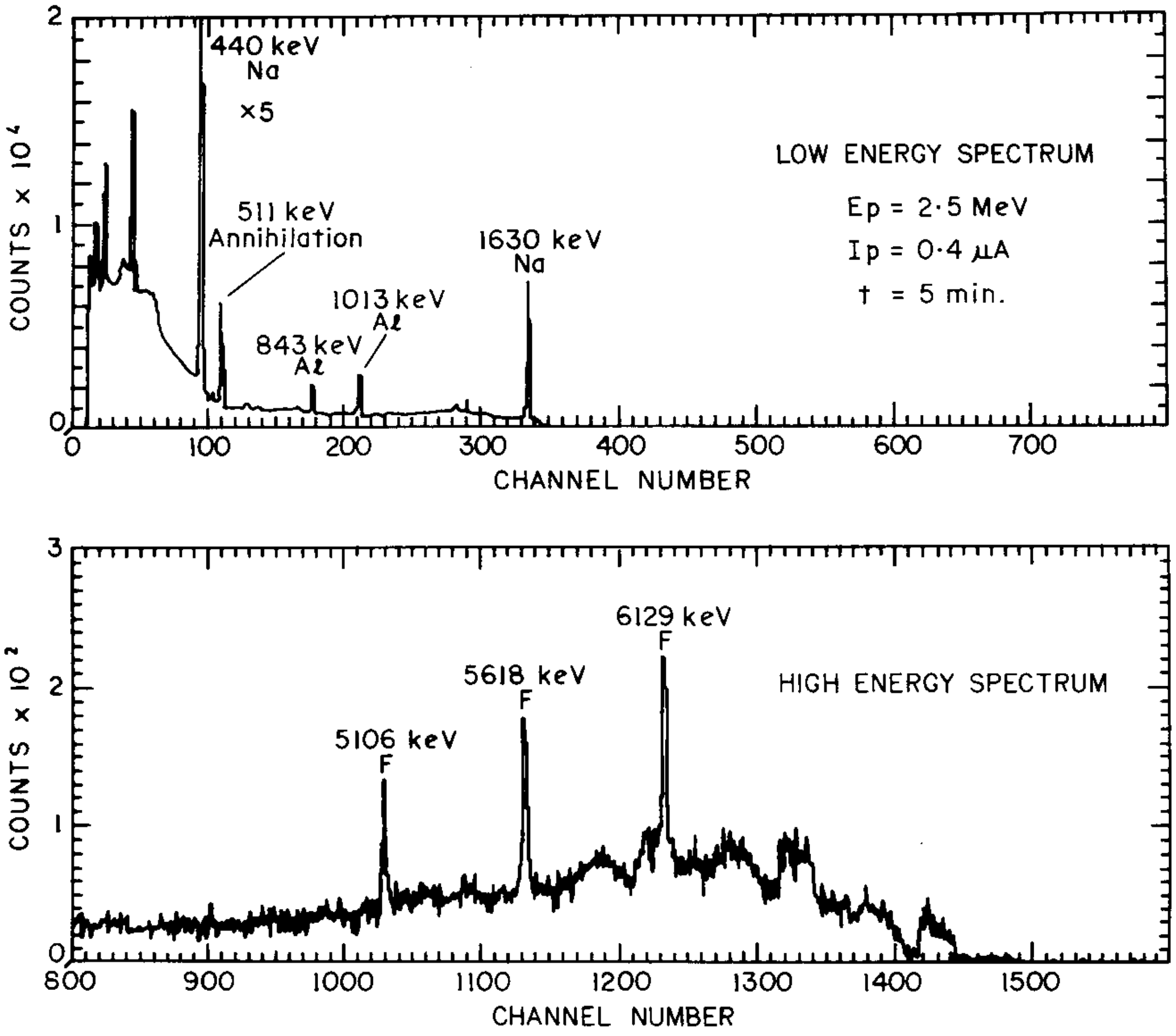

FIGURE 9. TYPICAL PULSE HEIGHT SPECTRUM FROM PROTON IRRADIATION OF OBSIDIAN

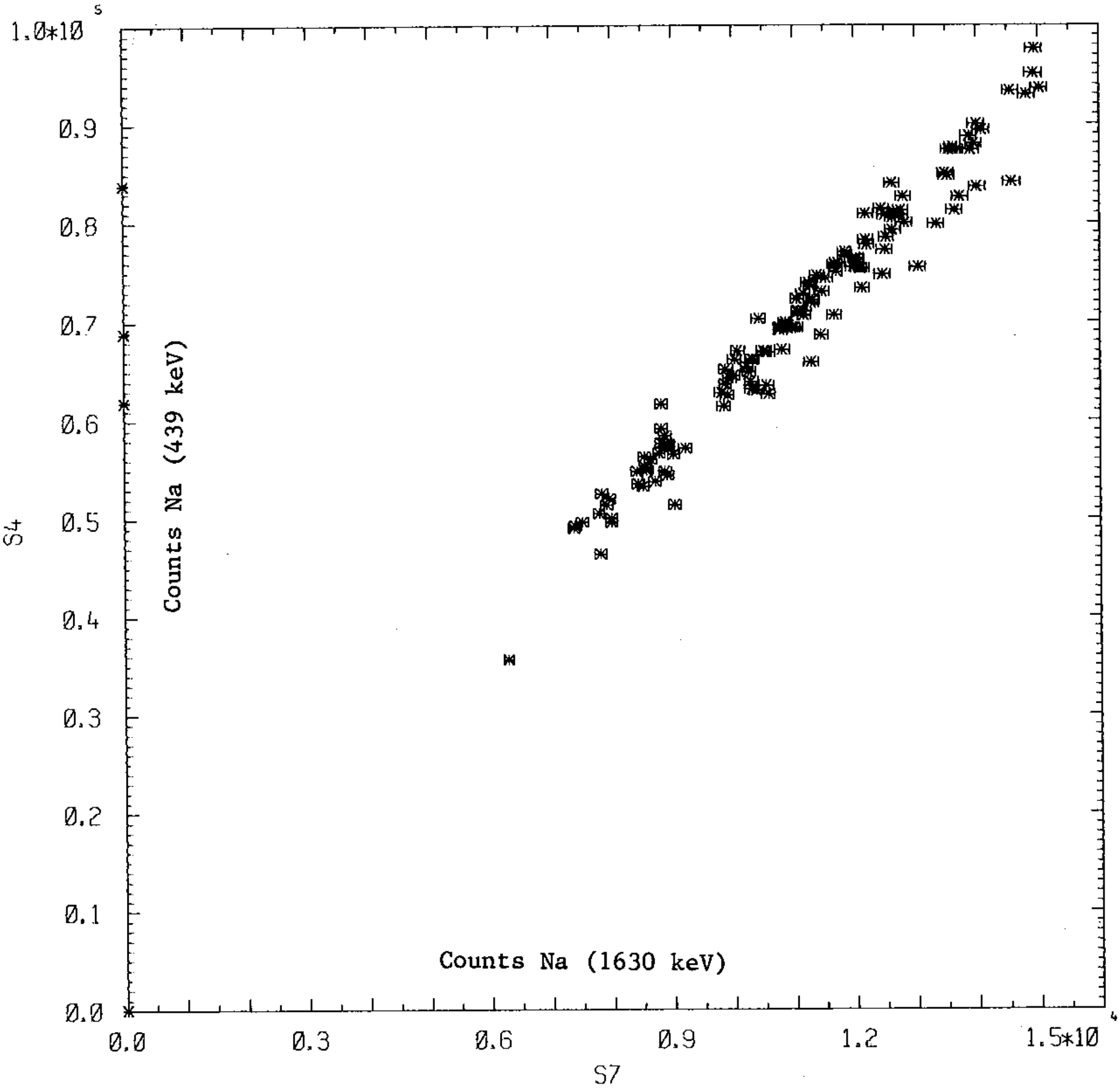

FIGURE 10. COMPARISON OF THE YIELDS OF 439 AND 1630 keV GAMMA-RAYS FROM NUCLEAR REACTIONS IN Na

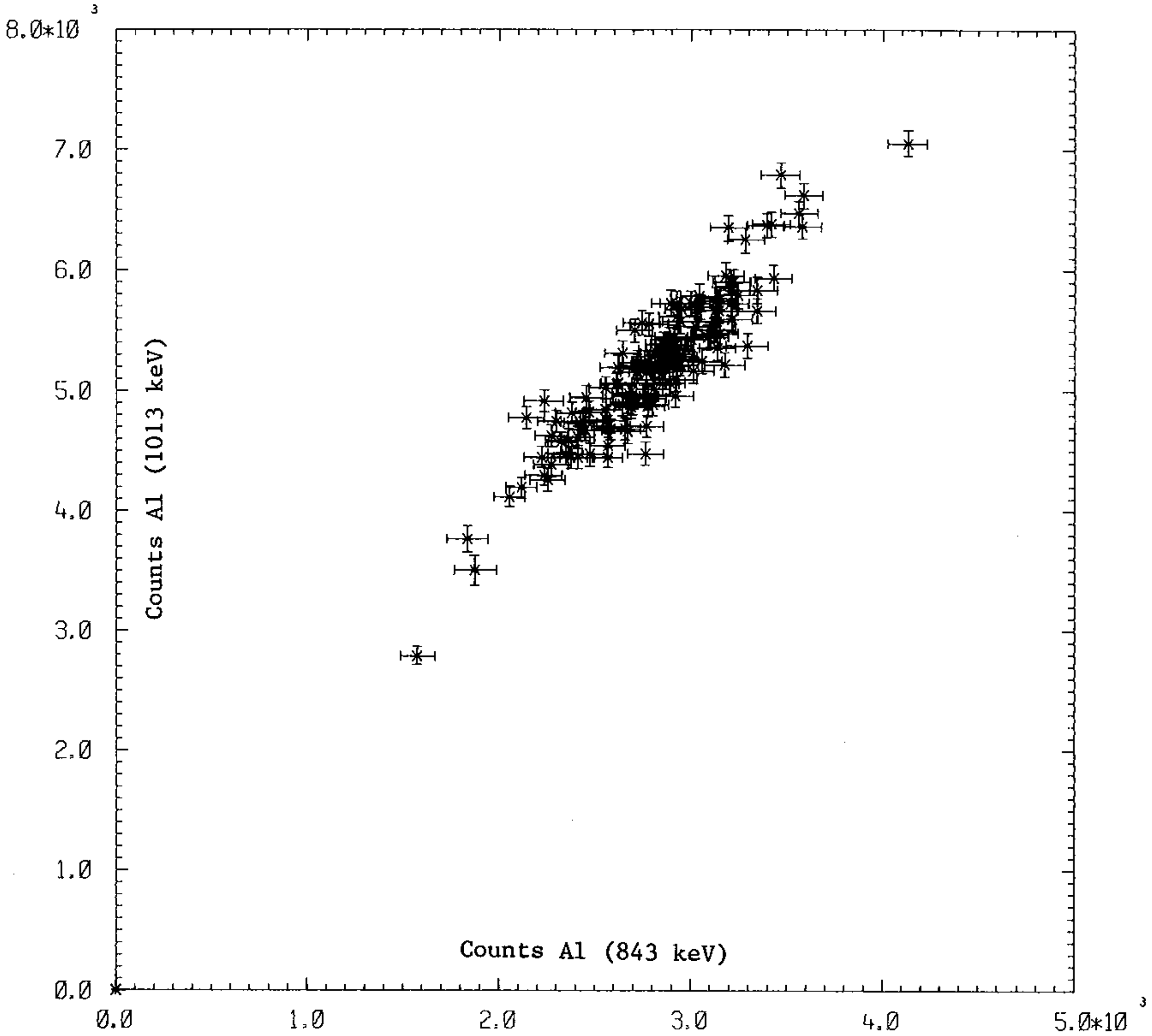

FIGURE 11. COMPARISON OF THE YIELDS OF 843 AND 1013 keV GAMMA-RAYS FROM NUCLEAR REACTIONS IN Al

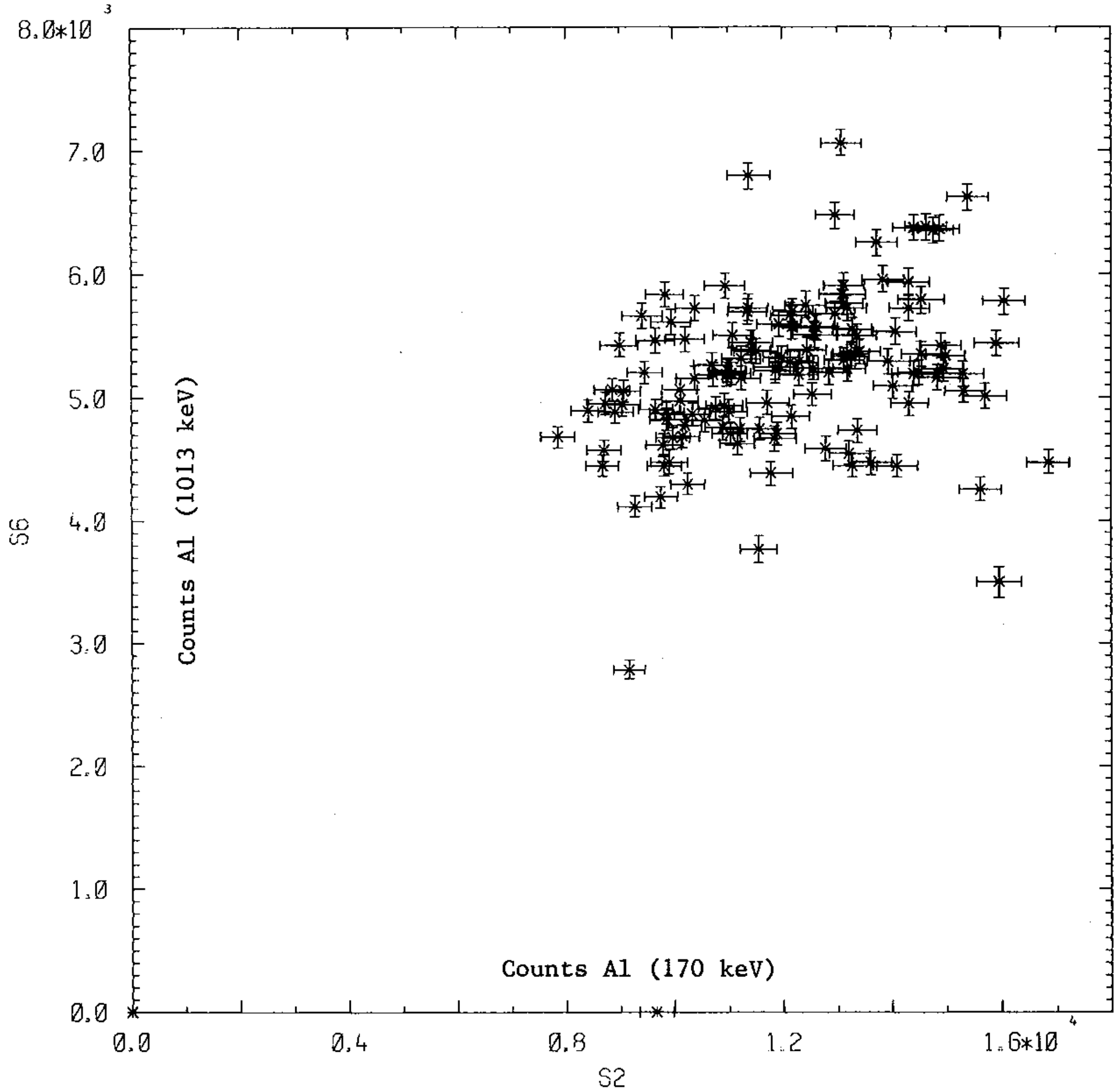

FIGURE 12. COMPARISON OF THE YIELDS OF 170 AND 1013 keV GAMMA-RAYS FROM NUCLEAR REACTIONS IN Al

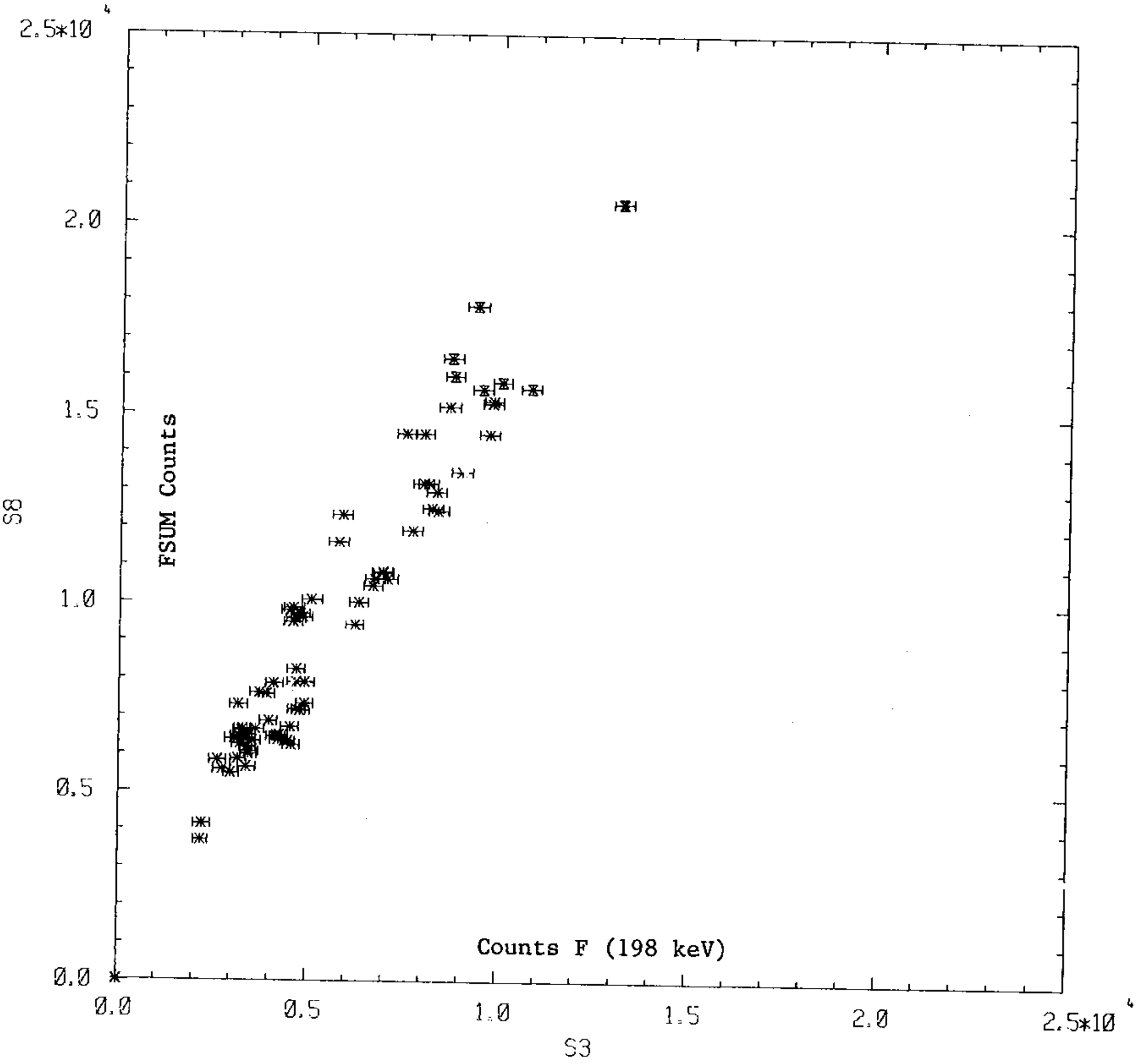

FIGURE 13. COMPARISON OF THE YIELDS OF 198 keV AND HIGH ENERGY GAMMA-RAYS (FSUM) FROM NUCLEAR REACTIONS IN F

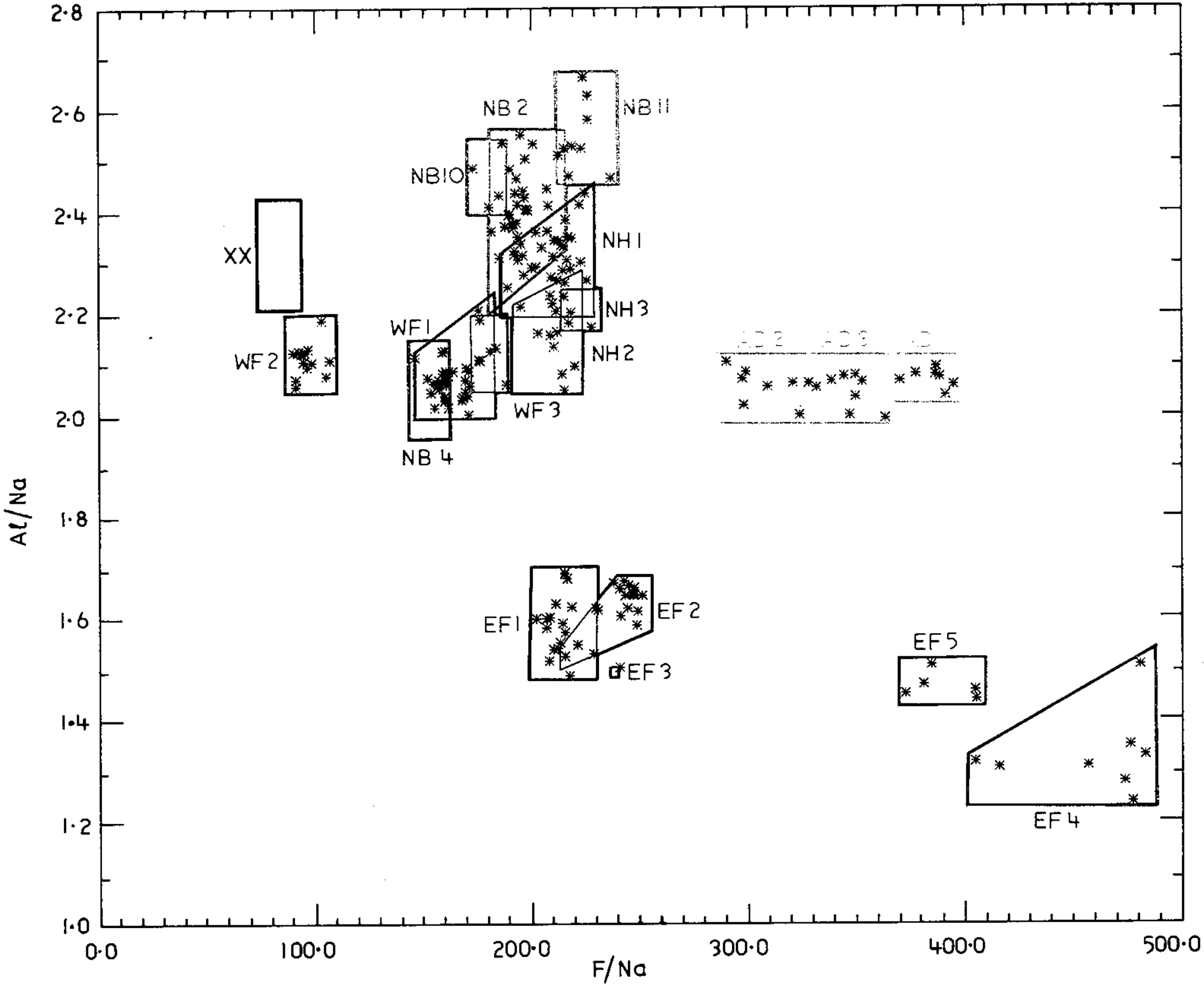

FIGURE 14. COMPARISON OF THE RATIOS Al/Na AND F/Na FOR MELANESIAN OBSIDIAN SOURCES

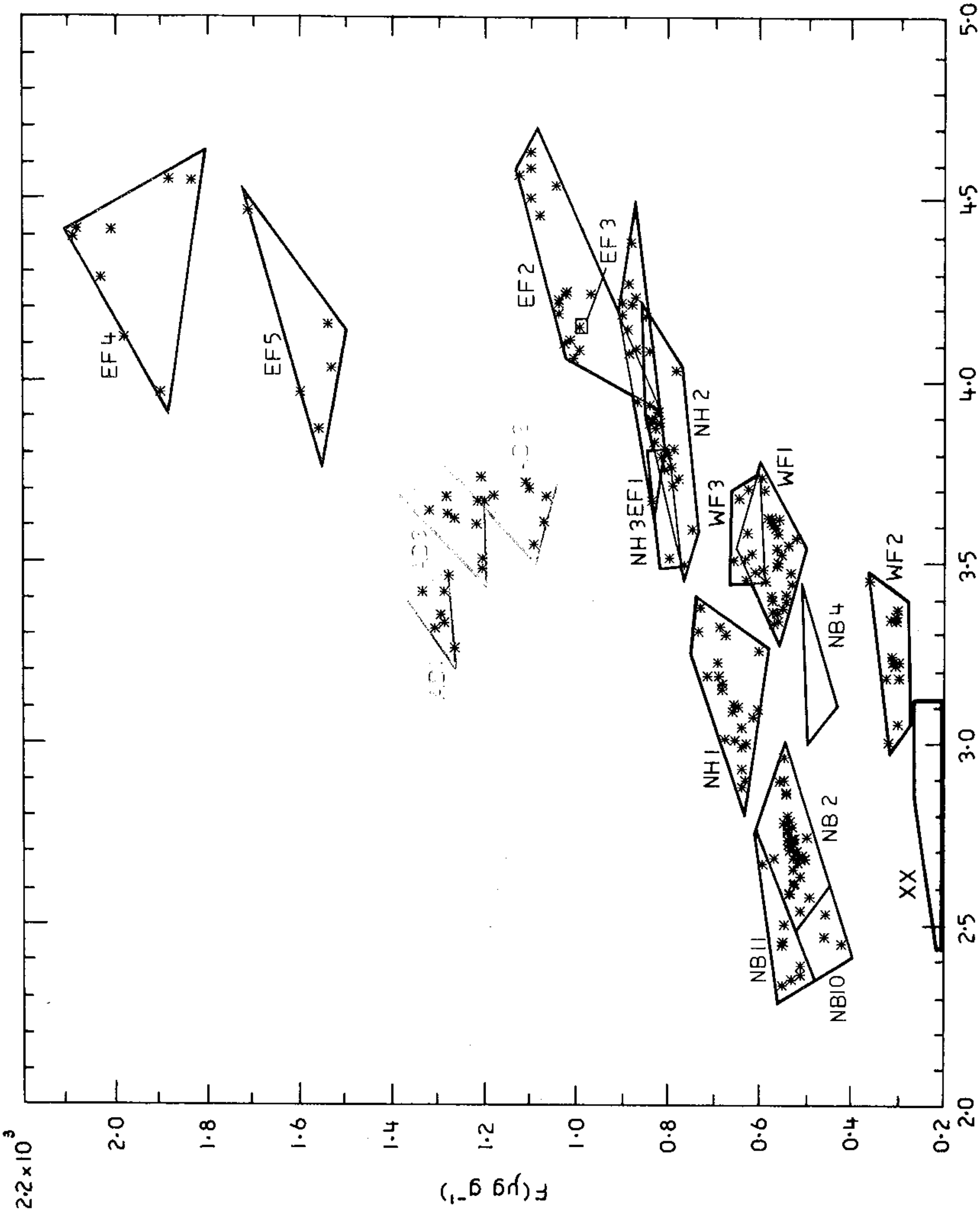

FIGURE 15. COMPARISON OF Na AND F CONCENTRATIONS FOR MELANESIAN OBSIDIAN SOURCES

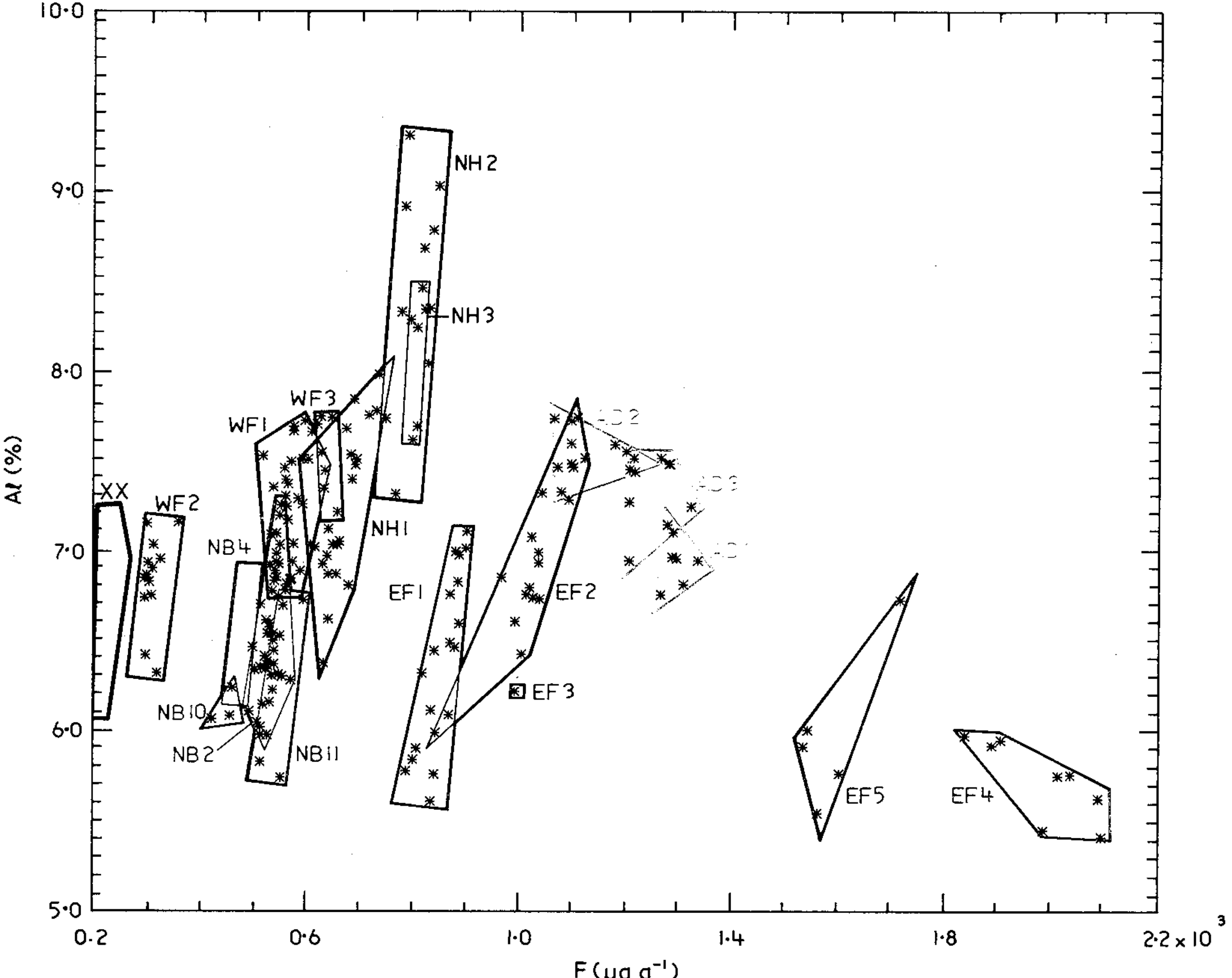

FIGURE 16. COMPARISON OF Al AND F CONCENTRATIONS FOR MELANESIAN OBSIDIAN SOURCES

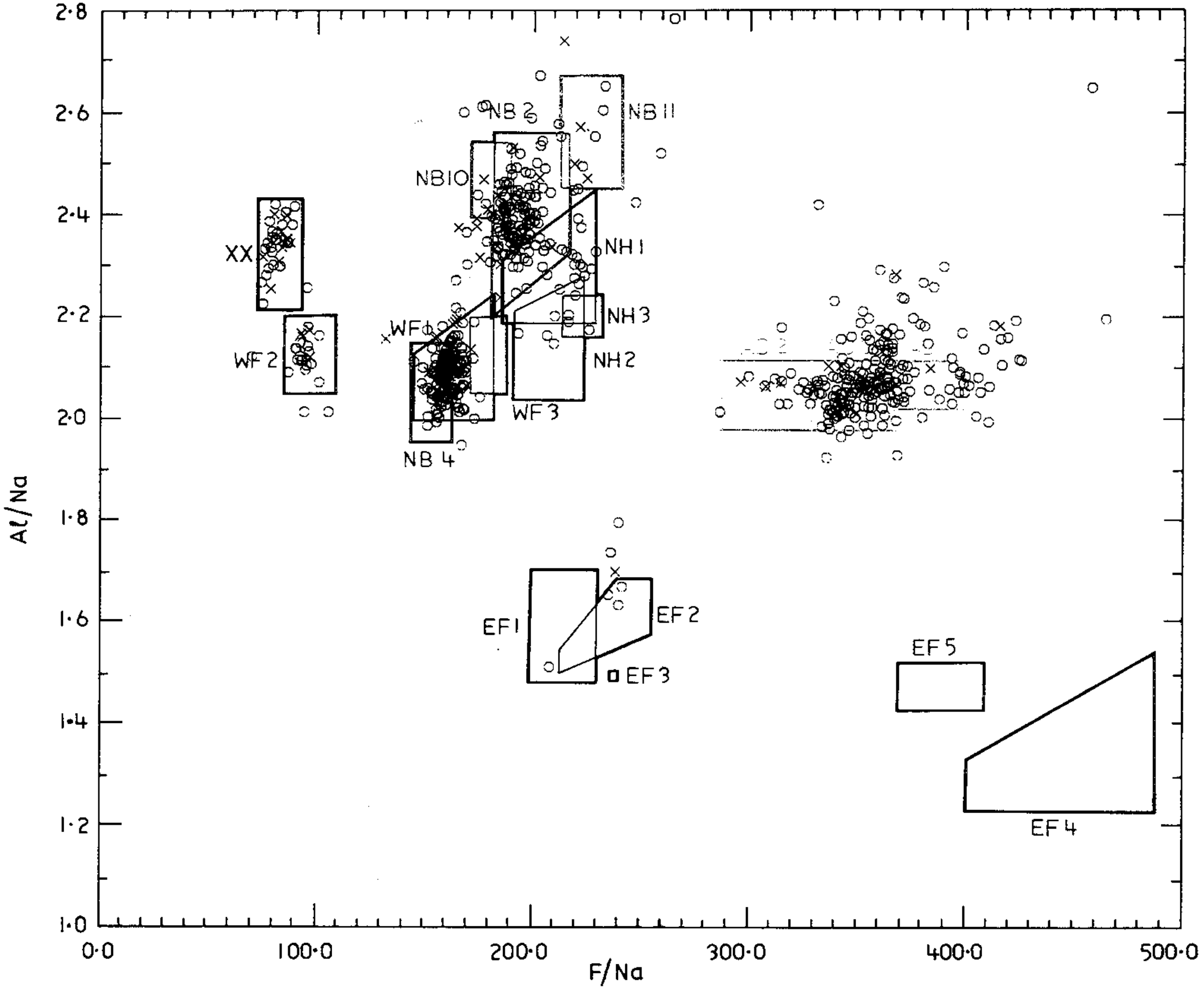

FIGURE 17. COMPARISON OF THE RATIOS Al/Na AND F/Na FOR OBSIDIAN ARTEFACTS

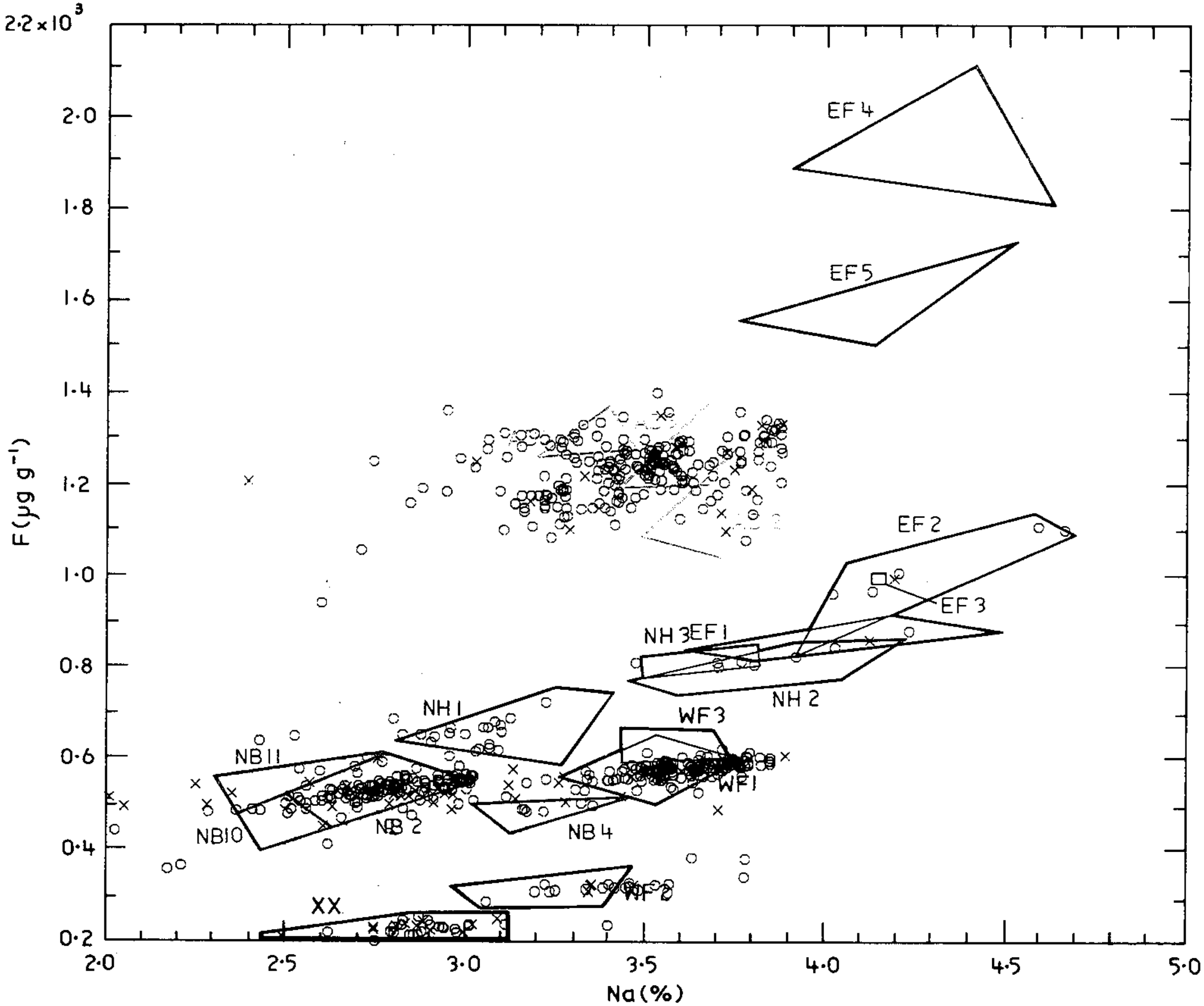

FIGURE 18. COMPARISON OF Na AND F CONCENTRATIONS FOR OBSIDIAN ARTEFACTS

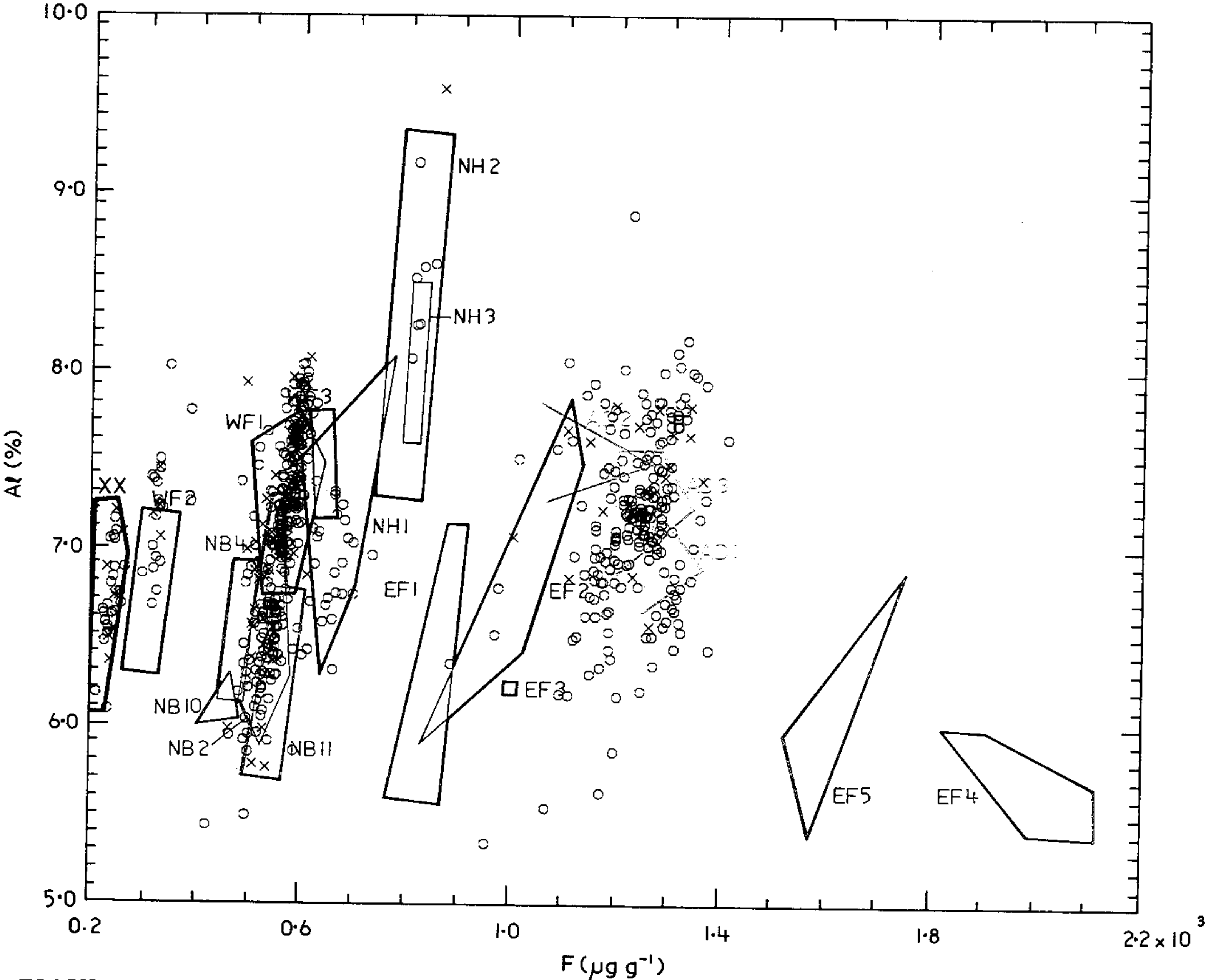

FIGURE 19. COMPARISON OF Al AND F CONCENTRATIONS FOR OBSIDIAN ARTEFACTS

APPENDIX A
SOURCE LOCATIONS

A brief description is given of sample locations. The numbers refer to the index of obsidian specimens at the Prehistory Department, Research School of Pacific Studies, Australian National University.

ADMIRALTY ISLANDS
(Figure 2)

Lou Island

Umrei 280, 281 - Specimen collected from area of mine shafts as discarded blocks from flaking operations. Good quality material.

178 - Specimen reported to be from Lou Island and collected near Solang village.

Lakou 277 - Specimen from beach cliff exposures at the east end of Lakou Bay. Poor quality, partly perlitised material; unsuitable for artefacts but collected to test chemical range of Lou Island source.

Tuluman Island

282 - Specimen from the exposed beach cliff of the island about 1 km south of Lou and formed in 1953. Collected in order to test the chemical range of the Lou source.

Pam Lin Island

283, S2559 - Specimens from the centre of Pam Lin. The source has been quarried and discarded blocks and flakes are present. Good quality flake material was used in the analysis.

NEW BRITAIN

(Figure 3)

Willaumez Peninsula (Talasea)

Kumeraki 286 - Collected from the convergence of two small dry gullies about 300 m east of Kumeraki village. High quality flake obsidian related to the Mount Bao 287 source and present as boulder-size lumps in an ash matrix.

Mount Bao 287 - Specimens collected from road cuttings about 1 km northwest from Kumeraki. Very high quality, flawless, glassy obsidian present as cobble- and boulder-size lumps imbedded in ash beds.

Bitokara 292, 296 - Deposits of good quality, but microscopically vesicular material from the seashore road cutting, below the Bitokara mission. Present as large boulders.

Hospital 295 - Collected from a low level flow which was exposed by road-making operations in front of the Talasea hospital.

Admin. 298 - Specimens of brown coloured obsidian from ash beds near the road to Talasea district office. Occurs as cobble-size lumps.

Garua 299 - Partly devitrified flow beds exposed on the beach on the western shore of Garua Island. Poor quality material collected to provide information on the chemical variability of the Talasea sources. It is unsuitable for artefact production.

Voganakai 293 - From massive flow beds extending to the beach south of Voganakai village. Good quality flaking obsidian is present.

Pilu 294 - Beach front exposure to the north of 293 but south of Voganakai village. Good quality flaking obsidian is present and appears to have been quarried from a small excavation near the high water mark.

Schauman Island 379, 380, 381 - Obsidian from an islet about 500 m northeast of Garua Island.

Cape Hoskins

Waisisi 180 - Flakes supplied by D. Blake, Bureau of Mineral Resources, from a buried soil site to the south of Mount Oto and ^{14}C dated to 2590 ± 250 (GaK-3076) [Blake and McDougall 1973: 202]. The specimens include flakes which have been used as artefacts. The Waisisi material raises the problem of a source which has not been re-located but whose presence is known because of the artefacts made from it. Blake and Ewart [1974:320] refer to rhyolite composition in fragments of welded tuff from Witori volcano; at this stage it is reasonable to infer that the Waisisi obsidian flakes are derived from the Cape Hoskins area.

FERGUSSON ISLAND, WEST

(Figure 1b)

Kukuia Peninsula

Igwageta 302 - Beach boulders carried down by streams. Specimens collected between 2 and 3 km east of Igwageta village and providing good flake quality materials.

Iaupolo 303 - Collected from exposures about 1.5 km west of Iaupolo village. Contains many crystallites and, therefore, would be an inferior source for artefact material.

Iaupolo East 304 - Stream boulders from inland of Iaupolo village. Specimens contain good flake quality material including mottled brown examples.

Fagalulu

305 - Specimens collected from around an area of boiling mud pools in the Fagalulu thermal area. The obsidian occurs in very weathered cobble-size blocks, some of which are coated with sulphur. The glass at this source is not highly suitable for flaking since it contains small crystallites and tends to have an uneven flake surface.

FERGUSSON ISLAND, EAST

(Figure 1b)

Aiasuna

306 - Obsidian flows from Mount Oiau are exposed at the beach at Aiasuna village. The material is of poor flake quality and contains bands of vesicular glass and crystallites.

Numanuma Bay, North

307 - Poor flake quality material is exposed as cliff-face deposits on the north side of Numanuma Bay. It flakes with an irregular surface and contains crystallites.

Lamonai

308 - Extensive flows of obsidian are exposed at the shore line on the northeast flank of Mount Lamonai. The specimens are of poor quality obsidian which tends to fracture into very small blocks, is partly devitrified and contains crystallites.

SANAROA ISLAND

(Figure 1b)

Boulder obsidian (309) - Up to 40 cm in diameter and of poor quality material. Contains crystallites and flakes with an irregular fracture. Specimens are from about 1 km inland from Udaudana village.

Small ejecta obsidian (310) - Very high quality specimens scattered over elevated areas about 1 km inland from Udaudana village. The obsidian is present as small (up to 15 cm) irregular pieces which are heavily weathered but is practically a flawless glass. It occurs in a range of colours from green to grey-blue and black.

DOBU ISLAND

(Figure 1b)

301 - Small masssive flow deposit exposed at the eastern end of Dobu at beach level. The obsidian is not of high quality and flakes with a finely

textured surface.

BANKS ISLAND*

(Figure 4)

Gaua Islands

316 - Specimens from upper and mid slopes on the northeast of Gaua Island. Some specimens are from detrital deposits brought down by streams to Losalava Bay. Although the Gaua material is vitreous and can be flaked into useful implements, it lacks clean flake scars (G.K. Ward site BN-GA-6).

Vanua Lava

317, 318 - Specimens from the northwest of Losa Bay as an exposed flow at beach level, and in nearby stream. The material has a flake quality like that of Gaua Island (G.K. Ward site BN-VL-80).

---

* Banks Island specimens were provided by G.K. Ward, Prehistory Department, Australian National University.

APPENDIX B
OBSIDIAN SOURCE RESULTS

	ANU No.	Na %	Al %	F (μg g^{-1})	Al/Na	F/Na x10^4
INDONESIA						
IN1 Leles	254	2.38	6.20	685	2.60	288
		2.47	6.42	707	2.60	287
		2.42	6.31	687	2.61	284
		2.44	6.22	696	2.56	286
		2.51	6.65	706	2.65	281
IN2 Talaud	332/1	3.67	7.97	1196	2.17	326
		3.64	8.03	1198	2.21	329
IN3 Minaha	333	3.27	6.82	689	2.09	211
		3.27	6.64	661	2.03	202
	332/2	3.26	6.78	624	2.08	191
		3.28	6.80	626	2.07	191
		3.29	6.83	626	2.07	190
	332/3	3.35	7.01	648	2.09	193
		3.37	6.89	661	2.04	196
ADMIRALTY ISLANDS						
AD1 Pam Lin	283	3.42	6.96	1334	2.04	390
		3.33	6.98	1287	2.09	386
		3.42	7.11	1288	2.08	377
		3.46	7.15	1279	2.07	369
	283/1	3.32	6.83	1308	2.06	394
	2559	3.26	6.77	1266	2.07	388
		3.35	6.97	1295	2.08	386
AD2 Lou (Solang)	178	3.55	7.29	1094	2.06	308
		3.61	7.47	1071	2.07	297
		3.67	7.56	1200	2.06	327
		3.68	7.60	1179	2.06	320
		3.70	7.48	1102	2.02	298
		3.73	7.46	1206	2.00	323
		3.72	7.75	1110	2.08	299
		3.68	7.74	1065	2.10	289

	ANU No.	Na %	Al %	F (μg g^{-1})	Al/Na	F/Na x10^4
AD3 Lou (Umrei)	280	3.51	7.28	1206	2.07	344
		3.64	7.25	1321	1.99	363
		3.68	7.49	1283	2.04	349
	281	3.48	6.96	1206	2.00	346
		3.63	7.50	1279	2.06	352
		3.62	7.52	1264	2.08	349
		3.60	7.45	1217	2.07	338
		3.67	7.53	1215	2.05	331
AD4 Lou (Lakou)	277	3.72	7.34	1397	1.97	375
		3.65	7.48	1354	2.05	371
		3.30	6.47	1317	1.96	399
		3.38	6.66	1293	1.97	382
AD5 Tuluman	282	3.66	7.05	1372	1.92	375
		3.77	7.77	1498	2.06	397
		3.94	7.66	1487	1.94	377
		3.55	6.87	1314	1.94	370
		4.00	7.43	1447	1.86	362
NEW BRITAIN						
NB10 Garpil (Pilu)	294	2.53	6.10	457	2.41	181
		2.44	6.08	423	2.49	173
		2.46	6.25	460	2.54	187
NB11 Voganakai	293/1	2.50	6.32	548	2.53	219
		2.45	6.53	550	2.66	224
		2.36	5.83	513	2.47	218
		2.39	6.03	514	2.53	215
		2.67	6.74	595	2.53	223
		2.35	6.17	531	2.63	226
	293/2	2.33	5.75	552	2.47	237
		2.44	6.31	553	2.58	226

	ANU No.	Na %	Al %	F ($\mu g\ g^{-1}$)	Al/Na	F/Na x10^4
NB2 Talasea (Dire)	175	2.65	6.37	526	2.40	199
	187	2.80	6.90	541	2.47	193
		2.86	7.11	544	2.49	190
Talasea (Kumeraki)	286	2.73	6.60	530	2.41	194
		2.59	6.24	537	2.41	208
		2.58	6.32	535	2.45	207
		2.71	6.51	536	2.41	198
		2.96	7.21	549	2.43	185
Talasea (Mt Bao)	287	2.76	6.38	539	2.32	196
		2.67	6.16	517	2.31	194
		2.90	6.93	548	2.39	189
		2.86	6.86	543	2.40	190
		2.72	6.55	537	2.41	197
		2.73	6.85	539	2.50	197
Talasea (Bitokara)	292/1	2.70	6.43	521	2.38	193
		2.73	6.36	525	2.33	192
		2.68	6.55	526	2.44	196
		2.61	5.99	527	2.29	202
	292/2	2.78	6.76	547	2.43	197
		2.69	6.06	508	2.25	189
		2.68	6.35	504	2.37	188
		2.68	6.35	504	2.37	188
	296/1	2.63	6.71	514	2.55	195
		2.76	6.45	539	2.34	195
		2.54	5.99	513	2.36	202
		2.57	6.12	493	2.38	192
	296/2	2.72	6.40	527	2.35	194
		2.77	6.59	531	2.38	192
		2.74	6.48	498	2.36	182
Talasea (Hospital)	295	2.61	6.63	525	2.54	201
		2.68	6.30	571	2.35	213

	ANU No.	Na %	Al %	F ($\mu g\ g^{-1}$)	Al/Na	F/Na $x10^4$
Talasea (Admin)	298	2.89	6.71	556	2.32	192
		2.78	6.79	536	2.44	192
		2.68	6.36	514	2.37	192
NB3 Garua Is.	299	2.33	5.91	500	2.54	215
		2.33	5.93	497	2.55	213
		2.64	6.79	488	2.57	185
		2.59	6.97	470	2.69	181
		2.55	6.38	444	2.50	174
		2.29	5.76	482	2.52	211
		2.14	5.10	471	2.39	220
		2.14	5.22	476	2.44	222
NB4 Waisisi	180	3.04	6.35	485	2.09	160
		3.08	6.44	464	2.09	151
		3.20	6.69	470	2.09	147
		3.15	6.30	464	2.00	147
		3.15	6.34	466	2.01	148
		3.11	6.45	462	2.07	148
		3.13	6.34	463	2.03	148
		3.14	6.40	466	2.04	148
		3.19	6.54	471	2.05	148
		3.38	6.92	505	2.05	150
		3.25	6.56	482	2.02	148
		3.21	6.50	467	2.03	145
		3.14	6.17	480	1.97	153
		3.22	6.88	481	2.14	149
NB5 Schaumann Is.	379	2.52	5.79	566	2.30	224
	380	1.68	3.85	272	2.29	162
		2.29	5.24	308	2.29	134
	381	2.40	6.27	471	2.61	196
D'ENTRECASTEAUX ISLANDS						
WF1 Kukuia	302/1	3.48	7.27	593	2.09	170
		3.39	6.99	543	2.06	160
		3.45	6.90	588	2.00	171
	302/2	3.49	7.26	562	2.08	161

	ANU No.	Na %	Al %	F ($\mu g\ g^{-1}$)	Al/Na	F/Na x10^4
WF1 Kukuia						
		3.50	7.31	559	2.09	160
	302/3	3.44	6.93	531	2.02	155
	302/4	3.41	6.95	543	2.04	159
	303	3.51	7.45	633	2.13	181
		3.47	7.67	609	2.21	175
		3.33	6.79	561	2.04	168
		3.39	6.95	573	2.05	169
	304/1	3.41	7.05	575	2.07	169
		3.58	7.56	628	2.11	175
		3.56	7.54	519	2.12	146
		3.37	7.04	550	2.09	163
	304/2	3.73	7.73	595	2.07	160
	304/3	3.70	7.52	591	2.03	160
		3.60	7.50	570	2.08	158
	304/4	3.62	7.47	558	2.06	154
		3.54	7.18	564	2.03	159
		3.62	7.70	575	2.13	159
		3.59	7.38	564	2.06	157
		3.62	7.30	583	2.02	161
		3.61	7.68	575	2.13	159
		3.36	6.85	571	2.04	170
		3.36	6.83	562	2.03	167
		3.33	6.85	569	2.06	171
	304/6	3.52	7.26	551	2.06	157
		3.58	7.41	560	2.07	157
	304/7	3.54	7.36	537	2.08	152
	304/8	3.47	7.10	532	2.05	153
WF2 Fagalulu	305	3.45	7.17	361	2.08	105
		3.00	6.33	319	2.11	106
		3.22	6.86	297	2.13	92
		3.18	6.96	326	2.19	102

	ANU No.	Na %	Al %	F ($\mu g\ g^{-1}$)	Al/Na	F/Na $x10^4$
		3.34	6.87	302	2.06	90
		3.22	6.76	309	2.10	96
		3.18	6.75	297	2.12	93
		3.05	6.43	300	2.11	98
		3.24	6.91	312	2.13	96
		3.37	7.16	301	2.13	89
		3.35	6.95	304	2.07	91
		3.21	6.84	305	2.13	95
		3.34	7.04	314	2.11	94
WF3	S182	3.50	7.22	657	2.06	188
		3.70	7.75	626	2.10	169
		3.67	7.75	646	2.11	176
		3.52	7.71	618	2.19	176
		3.45	7.36	631	2.13	183
EF1 Sanaroa Is.	309	4.18	7.02	899	1.68	215
		4.14	6.99	887	1.69	214
	309/1	3.81	5.79	788	1.52	207
	310	3.67	5.62	834	1.53	227
		4.08	6.46	840	1.58	206
		3.89	6.12	834	1.57	214
		3.94	6.10	866	1.55	220
		4.23	6.77	870	1.60	206
		4.26	6.84	884	1.60	207
	310/1	4.08	6.50	870	1.59	213
		4.21	7.12	901	1.69	214
		3.88	6.33	817	1.63	210
		4.07	6.61	886	1.62	217
	310/2	3.79	5.85	800	1.54	211
	310/3	3.81	5.92	807	1.55	212
	310/4	3.88	5.77	840	1.49	217
	310/5	4.38	7.01	880	1.60	201
		4.21	6.48	878	1.54	209

	ANU No.	Na %	Al %	F (μg g^{-1})	Al/Na	F/Na x10^4
EF2 Aiasuna	308	4.45	7.34	1079	1.65	242
		4.56	7.53	1121	1.65	246
		4.54	7.33	1042	1.62	230
		4.18	6.75	1038	1.61	248
	308/1	4.06	6.44	1004	1.59	247
	306	4.21	7.00	1036	1.66	246
		4.63	7.73	1097	1.67	237
	306/1	4.11	6.77	1013	1.65	246
	301	4.58	7.61	1097	1.66	239
		4.23	7.09	1023	1.67	242
		4.10	6.75	1026	1.65	250
		4.22	6.95	1037	1.65	246
		4.23	6.86	967	1.62	228
		4.24	6.81	1019	1.61	240
		3.93	6.00	841	1.53	214
		4.08	6.62	992	1.62	243
	S210	4.50	7.50	1097	1.67	244
EF3	S245	4.15	6.23	992	1.50	239
EF4 Old	S258	3.97	5.96	1904	1.50	480
		4.55	5.93	1885	1.30	414
		4.55	5.99	1836	1.32	403
		4.12	5.46	1982	1.33	481
		4.28	5.77	2033	1.35	475
		4.41	5.76	2010	1.31	455
		4.42	5.64	2086	1.28	472
		4.40	5.43	2092	1.23	476
EF5 Numanuma Nth	307	3.97	5.78	1599	1.46	403
		4.47	6.73	1713	1.51	383
		4.03	5.92	1532	1.47	380
		4.15	6.02	1540	1.45	371
	307/1	3.87	5.56	1560	1.44	403

	ANU No.	Na %	Al %	F ($\mu g\ g^{-1}$)	Al/Na	F/Na $x10^4$
NEW HEBRIDES (Banks Is.)						
NH1 Vanua Lava	182	3.37	2.79	730	2.31	216
		3.01	6.88	654	2.29	218
		2.99	6.98	639	2.34	214
		3.04	7.13	640	2.35	210
		3.16	7.54	683	2.39	216
	249	3.30	7.69	674	2.33	205
		3.32	7.85	688	2.36	207
		3.00	6.94	630	2.31	210
		3.10	7.04	648	2.27	209
		3.09	7.04	606	2.28	196
		3.07	7.03	614	2.29	200
	317/1	3.09	7.06	661	2.29	214
		3.18	7.49	691	2.35	217
		3.01	6.82	678	2.27	225
		3.18	7.76	715	2.44	224
		3.31	7.99	736	2.41	222
		3.22	7.52	692	2.33	215
	317/2	3.25	7.52	603	2.31	185
	317/3	2.93	6.88	640	2.35	218
		3.15	7.41	683	2.35	217
	317/4	2.90	6.39	632	2.20	218
	317/5	2.88	6.63	641	2.30	222
		3.11	7.04	657	2.27	211
NH2 Gaua	250	4.03	8.92	783	2.22	195
	316/2	3.81	8.25	807	2.17	212
	316/3	3.71	9.31	789	2.51	213
		4.17	9.03	847	2.16	203
		2.87	8.05	827	2.08	214

	ANU No.	Na %	Al %	F ($\mu g\ g^{-1}$)	Al/Na	F/Na $x10^4$
	316/4	3.91	8.35	822	2.14	210
		3.83	8.36	829	2.18	217
		3.88	8.79	836	2.26	215
	316/5	3.75	7.70	807	2.05	215
	316/6	3.76	8.29	794	2.21	211
	316/7	3.59	7.75	747	2.16	208
	316/8	3.91	8.69	819	2.22	210
	316/10	3.73	8.34	777	2.24	209
	316/11	3.49	7.33	766	2.10	219
NH3 Vanua Lava	318/1	3.51	7.63	798	2.17	227
	318/2	3.79	8.47	814	2.24	215
NEW ZEALAND						
ZD23 Taupo	177	2.74	6.25	345	2.28	126
		2.91	6.53	384	2.25	132
		3.05	6.91	399	2.26	131
		3.09	6.89	377	2.23	122

APPENDIX C
ARTEFACT RESULTS

PAPUA NEW GUINEA

			(a)	Na	Al	F	Al/Na	F/Na	Group
HIGHLANDS				%	%	µg g^{-1}		x 10^4	
Manim (O. Christensen)									
223			4	3.12	6.98	575	2.24	184	-
Mendi (B.J. Egloff)									
276			3	2.66	6.57	537	2.47	202	NB2
EASTERN HIGHLANDS									
Kainantu area (V. Watson)									
324/1	"	NFB/TAI 1A/1018	3	2.96	7.04	554	2.38	187	NB2
324/2	"	" 1A/1120	3	2.91	7.10	532	2.44	183	NB2
324/3	"	" 1A/1134	2	2.95	7.01	487	2.37	165	(NB2)
324/4	"	" 1A/1178		2.88	7.09	535	2.46	186	NB2
324/5	"	" 1A/1211	3	0.37	6.53	493	17.80	1345	-
324/6	"	" 1A/1226	2	2.78	6.67	501	2.40	180	NB2
324/7	"	" 1A/1231		2.99	7.05	564	2.35	189	NB2
324/8	"	" 1A/1280		2.97	7.02	501	2.36	169	(NB2)
324/9	"	" 1A/1290		2.92	7.18	548	2.46	188	NB2
324/10	"	" 1A/1370		2.97	7.12	552	2.40	186	NB2
324/11	"	" 1A/1443	2	2.83	6.61	517	2.34	183	NB2
324/12	"	" 1A/1452	3	2.96	7.00	557	2.37	188	NB2
324/13	"	" 1A/1633	2	3.88	8.09	604	2.09	156	WF1
324/14	"	" 1A/1667		2.73	6.90	515	2.53	189	NB2
324/15	"	" 1A/1779		2.99	7.06	554	2.36	185	NB2
324/16	"	" 1A/1844		2.94	7.03	534	2.39	182	NB2
324/17	"	" 1A/1852	2	2.95	7.29	521	2.47	176	(NB2)
325/1	"	NFE,Tae/200		2.91	6.96	553	2.39	190	NB2
325/2	"	NGL,TAI,27/3		2.93	7.03	538	2.40	184	NB2
325/3	"	NGT,TAI,38/10	2	2.90	6.89	502	2.37	173	NB2
325/4	"	NHC,AUY,5/1	4	0.55	6.38	537	11.59	976	-
325/5	"	Tt		2.91	7.17	548	2.46	188	NB2
325/6	"	Tu		2.94	7.15	563	2.43	191	NB2

(Continued)

		(a)	Na %	Al %	F µg g^{-1}	Al/Na	F/Na x 10^4	Group
MILNE BAY								
Collingwood Bay (B.J. Egloff)								
1	Mound B	4	2.89	6.51	225	2.25	78	XX
3	"		3.49	7.13	611	2.04	175	WF1
5	"	4	2.85	6.74	236	2.36	83	XX
6	"	3	3.70	7.93	599	2.14	162	WF1
8	"	2	2.48	5.80	214	2.34	87	XX
9	"		2.96	6.59	220	2.22	74	XX
10	"	2	3.42	7.14	516	2.09	151	WF1
11	"	2	2.73	6.55	234	2.40	85	XX
12	"	2	3.25	6.70	546	2.06	168	-
13	"	3	3.65	7.60	589	2.08	161	WF1
14	"	3	3.53	7.36	574	2.08	163	WF1
15	"	3	2.80	6.55	235	2.34	84	XX
16	"		3.81	8.00	599	2.10	157	WF1
17	"		2.86	6.90	254	2.41	89	XX
18	"	3	3.27	7.04	503	2.16	154	-
19	"	3	2.82	6.64	241	2.35	85	XX
20	"	2	2.87	6.75	244	2.35	85	XX
21	"	3	3.62	7.62	571	2.10	158	WF1
22	"		3.70	7.70	584	2.08	158	-
23	"	5	3.34	7.08	323	2.12	97	WF2
24	"		3.49	7.55	571	2.16	163	WF1
25	"		3.42	7.32	569	2.14	166	WF1
26	"		2.20	4.43	368	2.01	167	-
27	"		2.87	6.69	224	2.34	78	XX
28	"		3.18	6.69	308	2.10	97	WF2
29	"		2.61	5.46	413	2.09	159	-
30	"		3.39	7.25	323	2.14	95	WF2
32	"		3.55	7.41	306	2.09	86	WF2
33	"		3.54	7.47	560	2.11	158	WF1
34	"		2.78	6.53	224	2.35	80	XX
35	"		3.67	7.40	308	2.14	89	WF2
46	"		3.44	7.28	318	2.11	92	WF2
47	"		2.79	6.60	219	2.36	79	XX
48	"		3.43	7.37	315	2.15	92	WF2
49	"		2.78	6.57	223	2.36	80	XX
50	"	5	2.98	6.91	221	2.32	74	XX
51	"	2	3.33	7.21	307	2.17	92	WF2
52	"	2	3.49	7.12	563	2.04	161	WF1
53	"		3.53	7.26	550	2.06	156	WF1
54	"		3.22	7.02	307	2.18	95	WF2
55	"		3.51	7.10	551	2.02	157	WF1
56	"		3.53	7.27	559	2.06	158	WF1
57	"		3.57	7.33	531	2.06	149	WF1
58	"		3.55	7.51	323	2.11	91	WF2
59	"		4.22	6.37	874.	1.51	207	EF1
60	"		3.34	7.03	547	2.10	164	WF2
61	"	2	3.59	7.39	570	2.06	159	WF1
62	"		3.24	6.89	309	2.13	96	WF2
63	"		3.37	6.77	316	2.01	94	WF2
64	"		2.81	6.76	239	2.40	85	XX
65	"		3.05	6.87	289	2.25	95	-
66	"	2	3.61	7.48	571	2.07	158	WF2

(Continued)

			(a)	Na %	Al %	F µg g^{-1}	Al/Na	F/Na x 10^4	Group
67	"		2	3.46	7.46	321	2.16	93	WF2
68	"			3.71	7.53	578	2.03	156	WF1
69	"			3.21	6.93	322	2.16	100	WF2
70	"			4.12	6.79	964.	1.65	234	EF2
71	"			2.61	6.11	223	2.34	86	XX
72	"			2.83	6.64	216	2.34	76	XX
73	"		2	3.45	7.23	558	2.10	162	WF1
74	"			3.40	7.19	314	2.11	92	WF2
75	"			3.47	7.33	561	2.11	162	WF1
76	"			3.51	7.45	321	2.12	91	WF2
77	"			3.44	7.24	326	2.10	95	WF2
78	"			3.64	7.52	576	2.07	158	WF1
79	"			3.38	7.20	551	2.13	163	WF1
80	"			3.76	8.04	338	2.14	90	WF2
Collingwood Bay (B.J. Egloff) Mound D									
82	"			3.33	7.34	552	2.21	166	(WF1)
84	"			3.32	6.96	314	2.09	94	WF2
87	"			3.32	6.82	527	2.05	159	WF1
90	"			2.92	7.08	234	2.42	80	XX
91	"			2.84	6.49	216	2.28	78	XX
92	"			2.92	6.85	233	2.35	80	XX
93	"			2.82	6.70	248	2.38	88	XX
95	"		2	3.34	7.25	319	2.17	96	WF2
96	"			3.38	7.17	236	2.12	70	-
99	"			3.56	7.31	562	2.05	158	WF1
100	"			2.79	6.64	232	2.38	83	XX
101	"			3.53	7.06	551	2.00	156	WF1
102	"		3	2.73	6.38	227	2.33	83	XX
103	"			3.30	6.94	531	2.11	161	WF1
104	"			3.62	7.64	575	2.11	159	WF1
105	"			3.61	7.68	579	2.13	160	WF1
107	"			3.53	7.36	572	2.09	162	WF1
108	"			3.63	7.41	571	2.04	157	WF1
109	"		2	3.68	7.65	582	2.08	158	WF1
D'ENTRECASTEAUX ISLANDS									
Woodlark Island, (B.J. Egloff)									
319/1	"	BKE	4	3.49	7.65	574	2.19	164	WF1
319/2	"	BKF	3	4.18	7.08	991.	1.69	237	EF2
319/3	"	BKO	11	3.11	7.42	539	2.39	173	-
319/4	"	BKP	3	3.13	6.84	519	2.19	163	-
319/5	"	BKQ		2.78	6.96	455	2.15	164	-
319/6	"	BKS		4.01	6.53	958.	1.63	239	EF2
PAPUAN GULF									
Mailu (G. Irwin)									
320/1	"	01 A1		3.83	7.91	593	2.07	155	WF1
320/2	"	01 A2		2.86	6.66	215	2.33	75	XX
320/3	"	01 A3		3.48	7.58	547	2.18	157	WF1
320/4	"	01 B2		3.74	7.60	588	2.03	157	WF1
320/5	"	01 B3		3.62	7.52	572	2.08	158	WF1
320/6	"	01 B4		3.55	7.49	572	2.11	161	WF1
320/7	"	01 B5		3.44	7.40	554	2.15	161	WF1

(Continued)

			(a)	Na %	Al %	F µg g^{-1}	Al/Na	F/Na x 10^4	Group
320/9	"	01 A1		4.65	8.07	1095.	1.73	235	(EF2)
320/10	"	01 A2		3.00	7.06	236	2.35	79	XX
320/11	"	01 A3		3.70	7.80	589	2.11	159	WF1
320/12	"	01 B2		3.76	7.94	592	2.11	157	WF1
320/13	"	01 B3		3.64	8.05	594	2.22	163	WF1
320/14	"	01 B4		3.75	7.83	578	2.09	154	WF1
320/15	"	01 D3		3.75	7.86	586	2.10	156	WF1
320/16	"	01 D3		3.77	7.71	587	2.04	156	WF1
321/1	"	01 E1		3.72	7.81	591	2.10	159	WF1
321/2	"	01 E1	2	3.70	7.97	573	2.16	155	WF1
321/3	"	01 E2		3.74	7.68	591	2.06	158	WF1
321/4	"	01 E2		3.72	7.96	583	2.14	157	WF1
321/5	"	01 E3		3.65	7.62	576	2.09	158	WF1
321/6	"	01 E3		3.64	7.66	604	2.10	166	WF1
321/7	"	01 E5		4.58	7.63	1103.	1.67	241	EF2
321/8	"	01 E5		3.75	7.64	581	2.04	155	WF1
321/9	"	01 F		3.50	7.93	573	2.27	164	WF1
321/10	"	01 F		3.62	7.27	379	2.01	105	WF2
321/11	"	01 G1		3.77	7.86	602	2.09	160	WF1
321/12	"	01 G1		3.73	7.82	597	2.10	160	WF1
321/13	"	01 G2		3.68	7.59	588	2.06	160	WF1
321/14	"	01 G2	2	3.26	6.97	557	2.13	171	WF1
321/15	"	01 G3		3.76	7.59	581	2.02	154	WF1
321/16	"	01 G3		3.66	7.70	587	2.11	161	WF1
321/17	"	01 G4		3.41	6.98	553	2.05	162	WF1
321/18	"	01 G4		3.39	7.16	571	2.11	168	WF1
321/19	"	01 G5		3.78	7.86	583	2.08	155	WF1
321/20	"	01 G5		3.39	7.18	551	2.12	163	WF1
321/21	"	01 G6		3.70	7.82	617	2.11	167	WF1
321/22	"	01 G6		3.62	7.25	545	2.00	150	(WF1)
321/23	"	01 G7		3.59	7.54	555	2.10	155	WF1
322/1	"	3 A2		3.69	7.78	588	2.11	160	WF1
322/2	"	3 A2		3.71	7.93	586	2.14	158	WF1
322/3	"	3 F/A		3.48	7.60	580	2.19	167	WF1
322/4	"	3 F/B		3.84	7.84	585	2.05	153	WF1
322/5	"	3 F/B		3.67	7.53	559	2.05	152	WF1
322/6	"	3 B1		3.66	7.65	604	2.09	165	WF1
322/7	"	3 B1		3.70	7.73	590	2.09	159	WF1
322/8	"	3 B2	2	3.52	7.33	558	2.08	159	WF1
322/9	"	3 B2	2	3.01	7.22	239	2.40	79	XX
322/10	"	3 B3	2	3.70	7.57	577	2.04	156	WF1
322/11	"	3 B3		3.83	7.97	598	2.08	156	WF1
322/12	"	3 B4		3.16	6.31	544	2.00	172	WF1
322/13	"	3 B5		3.68	7.79	586	2.12	159	WF1
322/14	"	3 B5		3.64	7.67	524	2.11	144	WF1
322/15	"	3 B6		2.89	6.76	247	2.34	86	XX
322/16	"	3 B6		3.48	7.39	569	2.12	163	WF1
322/17	"	3 B7		3.53	7.39	584	2.09	165	WF1
322/18	"	3 B7		3.66	7.61	578	2.08	158	WF1
322/19	"	3 B8		2.89	6.65	237	2.30	82	XX
322/20	"	3 B8		3.52	7.37	575	2.09	163	WF1
322/21	"	3 B9		2.93	6.81	229	2.33	78	XX
322/22	"	3 B9		3.76	7.79	378	2.07	101	(WF2)
322/23	"	3 B10		3.64	7.42	581	2.04	160	WF1

(Continued)

			(a)	Na %	Al %	F µg g^{-1}	Al/Na	F/Na x 10^4	Group
322/24	"	3 B10		3.54	7.62	572	2.16	162	WF1
322/25	"	3 B11		3.54	7.31	593	2.06	167	WF1
322/26	"	3 B11		3.77	7.67	601	2.03	159	WF1
322/27	"	3 B12	3	3.69	7.95	484	2.15	131	XX
322/28	"	3 B12		2.96	7.06	228	2.39	77	XX
322/29	"	3 C1		4.19	7.52	1002.	1.79	239	(EF2)
322/30	"	3 C1		3.00	6.90	237	2.30	79	XX
322/31	"	3 C2		3.78	7.77	609	2.05	161	WF1
322/32	"	3 C3	2	3.08	7.10	250	2.31	81	XX
322/33	"	3 C3		3.10	7.10	238	2.29	77	XX
322/34	"	3 D1	2	3.65	7.60	571	2.08	156	WF1
322/35	"	3 D1		3.81	7.96	583	2.09	153	WF1
322/36	"	3 D2		3.74	7.62	584	2.03	156	WF1
323/2	"	S C1		3.69	7.70	563	2.09	153	WF1
323/3	"	S C2		3.65	7.79	557	2.14	153	WF1
323/4	"	S C2	3	3.53	7.70	571	2.18	162	WF1
323/5	"	S C3		3.73	7.93	591	2.12	158	WF1
323/6	"	S C3		3.62	7.52	566	2.08	156	WF1
323/7	"	S C4	2	3.45	7.30	558	2.12	162	WF1
323/8	"	S C4		3.43	7.26	556	2.12	162	WF1
323/9	"	S C5		3.63	7.67	571	2.11	157	WF1
323/11	"	S C6		3.76	7.88	557	2.10	148	(WF1)
323/12	"	S C6		3.70	7.83	570	2.11	154	WF1
323/13	"	S D1	3	3.69	7.71	574	2.09	155	WF1
323/14	"	S D1		3.73	7.76	596	2.08	159	WF1
323/15	"	S D2		3.83	8.04	589	2.10	154	WF1
PAPUAN GULF									
Air (J. Allen)									
369/1	(MA-7) Maopa Village			3.33	6.96	562	2.09	169	WF1
369/2	"			3.47	7.25	578	2.09	166	WF1
369/2	"			3.47	7.26	578	2.09	166	WF1
369/3	"			3.40	6.99	550	2.05	162	WF1
369/4	"			3.46	7.36	575	2.12	166	WF1
369/5	"			2.73	6.20	201	2.27	74	XX
369/6	"			3.54	7.40	579	2.09	164	WF1
369/7	"			3.54	7.24	583	2.05	165	WF1
Nebira 4 (J. Allen)									
370/1	Pom 23/G20/11			3.55	7.26	583	2.04	164	WF1
370/2	"			3.62	7.25	561	2.01	155	WF1
370/3	Pom 23/G20/5B, G22			3.56	7.46	576	2.10	162	WF1
370/4	" /11B			3.56	7.26	577	2.04	162	WF1
370/5	" /9			3.55	7.32	576	2.06	162	WF1
370/6	" /5C			3.52	7.27	588	2.06	167	WF1
370/7	" /7A			3.62	7.77	581	2.15	160	WF1
370/8	" /11C			3.32	7.03	570	2.12	171	WF1
370/9	"			3.31	7.19	499	2.17	151	WF1
370/10	"			3.57	7.71	588	2.16	165	WF1
370/11	" /13,	Retouched		2.16	4.20	359.	1.94	166	WF1
370/12	" /6C			3.55	7.29	577	2.06	163	WF1
370/13	" /14A	"		3.54	7.46	587	2.11	166	WF1
370/14	" /11	"		3.54	7.16	563	2.02	159	WF1
370/15	" /13B	"		3.43	7.24	574	2.11	167	WF1

(Continued)

		(a)	Na %	Al %	F µg g^{-1}	Al/Na	F/Na x 10^4	Group
370/16	" /14		3.57	7.28	561	2.04	157	WF1
370/17	"		3.53	7.17	578	2.03	164	WF1
370/18	" /13		3.56	7.32	536	2.06	151	WF1
370/19	"		3.61	7.61	569	2.11	158	WF1
370/20	" /12		3.54	7.15	583	2.02	165	WF1
370/21	"		3.56	7.16	588	2.01	165	WF1
370/22	" /7A, Retouched		3.52	7.42	553	2.11	157	WF1
370/23	" /3B, Waste flakes		3.61	7.41	588	2.05	163	WF1
370/24	" "		3.59	7.51	601	2.09	167	WF1
370/25	" "		3.55	7.31	591	2.06	166	WF1
370/26	" "		3.54	7.34	554	2.07	156	WF1
370/27	" "		3.46	7.05	529	2.04	153	WF1
370/28	" "		3.49	7.04	583	2.02	167	WF1
370/29	" "		3.45	7.25	582	2.10	169	WF1
370/30	" /5A No 568		3.53	7.24	574	2.05	163	WF1
370/31	" "		3.56	7.57	569	2.13	160	WF1
370/32	Nebira 4		3.64	7.59	583	2.08	160	WF1
Motupore (J. Allen)								
224		2	3.50	7.37	576	2.11	164	WF1
PAPUAN GULF								
Ape (R. Vanderwal)								
162	"		3.10	6.63	516	2.14	166	-
163	"	2	3.65	7.70	579	2.11	159	WF1
164/3	"		3.56	7.65	576	2.15	162	WF1
164/4	"		3.72	7.93	591	2.93	159	WF1
AITAPE								
Leask Coll. (S.A. Museum)								
371/2	"		3.41	6.83	1160	2.00	340	AD
371/3	"		3.39	6.75	1139.	1.99	336	AD
371/4	"		2.94	5.88	1186	2.00	404	AD
371/5	"		3.27	6.64	1131	2.03	345	AD
371/6	"		3.27	6.74	1147	2.06	351	AD
WEWAK								
Moem Peninsular (W. Ambrose)								
315/1	"		3.61	7.46	1274	2.07	353	(AD)
315/2	"		2.59	5.36	942	2.07	364	(AD)
315/3	"		3.27	7.48	1173	2.29	359	(AD)
315/4	"		3.21	6.84	1148	2.13	358	(AD)
315/5	"		3.15	6.31	1140	2.00	362	(AD)
MADANG								
Yabob (B.J. Egloff)								
346/5	JB2-1E 24/5/43 70-90cm		2.72	6.45	602	2.37	222	-
346/6	"		2.55	6.12	503	2.40	198	NB2
MOROBE								
Sio (J. Specht)								
373/1	KBQ/762		2.69	6.33	506	2.35	188	NB2
373/2	KBQ/765	2	2.64	6.20	471	2.35	178	NB2
374	KBP/1 1697		2.79	6.49	531	2.33	191	NB2

(Continued)

		(a)	Na %	Al %	F $\mu g\ g^{-1}$	Al/Na	F/Na x 10^4	Group
VITIAZ STRAIT								
Long Island, Biliau (I. Hughes)								
206			2.35	5.51	487	2.34	207	(NB2)
ADMIRALTY ISLANDS								
Lou Island, Umrei, (W. Ambrose)								
300/3		2	3.59	7.48	1289	2.09	359	AD
300/5	"	2	3.50	7.23	1230	2.07	351	AD
ST. MATTHIAS ISLANDS								
Eloaue Island (B.J. Egloff)								
330/1	E14472 FCA, unit A, L3,20-78cm		3.36	7.03	1334	2.09	397	AD
330/2	" "		2.77	6.73	531	2.43	192	NB2
330/3	" "		3.59	7.79	1289	2.17	360	(AD)
331/1	E14484 ECA, UNIT B, L2, 8-16cm		3.58	7.37	1292	2.06	361	AD
331/2	"		2.82	7.03	533	2.49	189	NB2
331/3		2	3.71	7.80	1268	2.10	341	AD
331/4	"	2	3.74	7.71	1229	2.06	329	AD
331/5	"		3.80	7.85	1271	2.06	334	AD
331/6	"		3.37	7.53	1245	2.23	370	(AD)
331/7	"		3.57	7.13	1241	2.00	348	AD
331/8	"		2.77	6.68	540	2.41	195	NB2
331/9	"		2.75	6.69	549	2.43	200	NB2
331/10	"		3.01	6.93	508	2.30	169	(NB2)
331/11	"		3.52	7.63	1400	2.17	397	AD
331/12	"		3.05	6.58	1278	2.16	419	AD
331/13	"		2.98	7.22	550	2.42	184	NB2
331/14	"		2.99	7.24	531	2.42	178	(NB)
331/15	"		3.68	7.55	1248	2.05	339	AD
331/16	"		3.76	7.70	1304	2.05	347	AD
331/17	"		2.96	7.23	560	2.45	190	NB2
331/18	"		3.00	7.05	544	2.35	181	(NB)
331/19	"		3.01	7.11	562	2.36	187	NB2
331/20	"		2.85	7.23	579	2.53	203	NB2
331/21	"		3.82	7.98	1340	2.09	350	AD
331/22	"		3.21	7.03	552	2.19	172	-
331/23	"		2.97	6.98	564	2.35	190	NB2
331/24	"		3.87	8.04	1307	2.08	338	AD
347/11	ECA, AA, Level 1 0-10cm		3.38	7.36	1284	2.18	380	(AD)
347/12	"		3.32	6.84	1330	2.06	401	AD
347/13	"		3.47	7.11	1240	2.05	358	AD
347/14	"		2.79	6.27	535	2.24	191	NB2
347/15	"		3.41	6.94	1213	2.04	356	AD
347/16	"		3.49	7.20	1221	2.06	350	AD
347/17	"		3.21	7.26	1217	2.26	379	(AD)
347/18	"		2.82	6.78	559	2.40	198	NB2
347/19	"		3.53	7.13	1227	2.02	348	AD
347/20	"		3.50	7.20	1219	2.06	348	AD
347/21	"		3.41	7.52	1197	2.21	352	(AD)
347/22	"		3.54	7.32	1261	2.07	357	AD
347/23	"		2.81	6.69	525	2.38	187	NB2
347/24	"		3.36	7.37	1259	2.19	375	(AD)
347/25	"		2.70	5.55	1057	2.06	391	AD

(Continued)

		(a)	Na %	Al %	F µg g^{-1}	Al/Na	F/Na x 10^4	Group
348/1	ECA, AA, Level 2 10-20cm		3.50	7.16	1275	2.04	364	AD
348/2	"		3.45	7.15	1149	2.07	333	AD
348/3	"		2.84	6.58	555	2.31	195	NB2
348/4	"		3.49	7.20	1232	2.06	353	AD
348/5	"		3.43	7.12	1269	2.08	370	AD
348/6	"		3.51	7.46	1273	2.13	363	(AD)
348/7	"		3.54	7.33	1242	2.07	351	AD
348/8	"		2.80	6.64	544	2.37	194	NB2
348/9	"		3.49	7.47	1268	2.14	363	(AD)
348/10	"		3.41	6.91	1178	2.02	345	AD
349/1	ECA, AA, Level 3 20-28cm		3.27	6.65	1265	2.03	387	AD
349/2	"		3.26	6.89	1280	2.12	393	AD
349/3	"		3.41	6.83	1163	2.00	341	AD
349/4	"		3.43	7.06	1232	2.06	359	AD
349/5	"		2.76	6.47	526	2.35	191	NB2
349/6	"		3.51	7.08	1266	2.02	360	AD
350	ECA (E14478) AA Level 4 20-35cm		2.50	6.10	518	2.44	207	NB2
351/1	ECA, A, Level 1 0-10cm		2.98	6.52	1256	2.19	422	(AD)
351/2	"		3.60	7.22	1207	2.01	336	AD
351/3	"		3.27	7.30	1211	2.23	371	(AD)
351/4	"		3.47	7.21	1234	2.08	355	AD
351/5	"		2.69	6.39	527	2.38	196	NB2
351/6	"		2.69	6.57	533	2.44	198	NB2
351/7	"		3.42	7.37	1183	2.16	346	(AD)
351/8	"		3.21	7.31	1176	2.27	366	(AD)
351/9	"		3.42	7.29	1218	2.13	356	(AD)
351/10	"		3.50	7.31	1257	2.09	359	AD
351/11	"		3.52	7.43	1256	2.11	357	AD
351/12	"		3.18	6.94	1310	2.18	412	(AD)
351/13	"	2	3.02	6.58	1251	2.18	415	AD
351/14	"		3.59	7.27	1202	2.02	335	AD
351/15	"		2.51	5.87	491	2.34	196	NB2
352/1	ECA, A, Level 2 10-20cm		3.37	7.05	1186	2.09	351	AD
352/2	"		2.72	6.40	517	2.36	190	NB2
352/4	"		3.39	6.53	1246.	1.93	368	AD
352/5	"		2.42	6.06	487	2.50	201	NB2
352/6	"		3.39	7.33	1249	2.16	368	(AD)
352/7	"		3.50	7.19	1243	2.06	355	AD
352/8	"		2.71	6.30	513	2.32	189	NB2
352/9	"		2.84	5.64	1161.	1.99	409	(AD)
352/10	"		2.79	6.75	688	2.42	247	(NH1)
352/11	"		3.26	6.94	1191	2.13	365	(AD)
352/12	"		2.61	6.24	516	2.39	198	NB2
353/1	ECA (14483) B, Level 1 0-8cm		3.23	6.65	1170	2.06	362	AD
353/2	"		3.51	7.29	1273	2.08	363	AD
353/3	"		3.36	6.98	1158	2.08	344	AD
353/4	"		3.36	6.81	1230	2.03	366	AD
353/5	"		2.74	6.51	517	2.38	189	NB2
353/6	"		3.33	6.96	1251	2.09	375	AD
353/7	"		3.26	6.88	1127	2.11	345	AD
353/8	"		3.46	7.03	1265	2.03	365	AD
353/9	"		3.36	7.22	1212	2.15	361	(AD)
353/11	"		3.49	7.32	1297	2.10	372	AD
353/12	"		3.38	7.02	1149	2.08	340	AD

(Continued)

		(a)	Na %	Al %	F μg g^{-1}	Al/Na	F/Na x 10^4	Group
353/13	"		3.30	7.21	1247	2.18	378	(AD)
353/14	"		2.42	6.73	640	2.78	265	-
353/15	"		2.76	6.57	545	2.38	198	(AD)
354/2	ECA, (E14487) C Level 1 0-15cm		3.14	6.61	1307	2.10	416	AD
354/3	"		3.26	6.80	1293	2.09	396	AD
354/4	"		3.44	7.00	1264	2.04	368	AD
354/5	"		3.06	6.45	1299	2.11	425	AD
354/6	"		3.10	6.55	1312	2.11	424	AD
354/7	"		3.43	6.85	1298	2.00	379	AD
354/8	"		3.02	6.22	1237	2.06	410	(AD)
354/9	"		2.94	6.45	1364	2.19	463	(AD)
354/10	"		3.10	6.19	1099	2.00	355	AD
360/1	ECA, (E14491) D Level 2 10-22cm		3.25	6.80	1198	2.09	369	AD
360/2	"		3.19	6.55	1174	2.05	368	AD
360/3	"		2.51	6.33	650	2.52	259	-
360/4	"		3.17	6.67	1174	2.10	370	AD
361/1	ECA,(E14481) AB Level 3 20-28cm		2.59	6.23	517	2.40	199	NB2
361/2	"		2.62	6.37	512	2.43	195	NB2
361/3	"		3.31	6.89	1146	2.08	346	AD
361/4	"		2.50	5.93	481	2.38	193	NB2
361/5	"		2.67	6.32	518	2.36	194	NB2
361/6	"		3.34	6.97	1147	2.08	343	AD
361/7	"		3.38	7.25	1233	2.15	365	(AD)
361/8	"		3.15	6.45	1174	2.05	373	AD
361/9	"		3.25	7.08	1188	2.18	365	(AD)
361/10	"		3.13	6.35	1159	2.03	371	AD
362/1	ECA,(E14479) AB Level 1 0-10cm		3.15	6.71	1282	2.13	408	(AD)
362/2	"		3.39	7.29	1202	2.15	355	AD
362/3	"	2	3.32	6.86	1218	2.07	367	AD
362/4	"		3.40	7.36	1231	2.16	362	(AD)
362/5	"		3.44	7.01	1273	2.04	370	AD
362/6	"		3.39	7.23	1238	2.14	365	AD
362/7	"		2.69	6.38	492	2.37	183	NB2
362/8	"		3.27	7.08	1187	2.17	363	(AD)
362/9	"		3.53	7.20	1245	2.04	352	AD
362/10	"		3.15	6.64	1149	2.10	364	AD
362/11	"		3.21	6.76	1166	2.11	363	AD
362/12	"		3.29	7.06	1257	2.15	382	AD
363/1	ECA,(14480) AB Level 2 10-20cm		3.53	7.24	1249	2.05	354	AD
363/2	"		2.57	5.98	508	2.32	198	NB2
363/3	"		3.47	7.10	1238	2.05	357	AD
363/4	"		3.11	6.37	1260	2.05	406	AD
363/5	"		3.17	6.50	1107	2.05	349	AD
363/6	"		3.42	7.10	1243	2.08	363	AD
363/7	"		2.79	6.41	538	2.30	192	NB2
363/8	"		3.21	6.67	1299	2.08	405	AD
363/9	"		2.74	7.24	1252	2.65	458	-
363/10	"		2.54	6.49	540	2.55	212	NB2
364/1	ECA,(E14482) AB Level 4,28-35cm		3.25	6.53	1114	2.01	343	AD
364/2	"		3.52	7.26	1280	2.06	363	AD
364/3	"		3.23	6.61	1285	2.05	398	AD
365/1	ECA,(E14490) D Level 1, 0-10cm		3.54	7.30	1282	2.06	362	AD
365/2	"		3.36	7.70	1305	2.30	389	(AD)
366/1	ECB,(E14493) A Level 1, 0-15cm		3.57	7.03	1264.	1.97	354	AD

(Continued)

		(a)	Na %	Al %	F μg g^{-1}	Al/Na	F/Na x 10^4	Group
366/2	"		3.25	6.77	1298	2.08	399	AD
366/3	"		2.80	6.58	544	2.35	194	NB2
366/4	"		2.73	6.69	539	2.45	197	NB2
366/5	"		2.27	6.82	485.	3.00	213	-
366/6	"		3.26	6.83	1186	2.09	364	AD
366/7	"		2.71	6.53	521	2.41	193	NB2
366/8	"		2.65	6.51	540	2.45	204	NB2
366/9	"		3.40	7.25	1234	2.13	363	AD
366/10	"		3.09	6.96	1186	2.26	384	(AD)
367/1	ECB,(E14494) A Level 2, 15-25cm		3.42	7.07	1254	2.07	367	AD
367/2	"	2	3.28	6.85	1099	2.10	336	AD
367/3	"		3.30	6.69	1295	2.03	392	AD
368/1	ECA,(E14486) B Level 4, 20-30cm		3.51	7.35	1252	2.10	357	AD
368/2	"		3.49	7.34	1231	2.10	353	AD
368/3	"		2.49	6.65	504	2.67	202	(NB)
368/4	"		3.29	6.80	1309	2.07	398	AD
368/5	"		2.77	6.50	541	2.35	196	NB2
NEW IRELAND								
Lesu (J.P. White)								
328/1	L69 V/K5/10		3.75	7.94	1357	2.11	362	AD
328/2	"		3.79	7.88	1132	2.08	299	AD
328/3	"		3.87	7.84	1267	2.03	327	AD
328/4	"		3.87	8.18	1322	2.12	342	AD
328/5	"		3.87	8.01	1277	2.07	330	AD
328/6	"		3.76	7.68	1250	2.05	333	AD
328/7	"		3.85	7.87	1315	2.05	342	AD
328/8	"	2	3.81	7.65	1327	2.01	348	AD
328/9	"		3.58	7.73	1264	2.16	353	(AD)
328/10	"		3.77	7.80	1184	2.07	314	AD
329/1	"		3.87	8.02	1203	2.08	311	AD
329/2	"		3.82	7.75	1304	2.03	341	AD
329/3	"		3.80	7.77	1252	2.04	329	AD
329/4	"	2	2.93	7.06	523	2.41	179	NB2
329/5	"		3.71	7.67	1202	2.07	324	AD
329/6	"		3.81	7.76	1291	2.04	339	AD
329/7	"		3.68	8.89	1217	2.42	331	(AD)
329/8	"		3.67	7.44	1164	2.03	317	AD
329/9	"		2.88	6.65	550	2.31	191	NB2
329/10	"		2.93	6.79	533	2.32	182	NB2
211	L69/V/K5/10A		2.90	6.98	541	2.41	186	NB2
Balof (J.P. White)								
342/1	C3 '69 (1 + 11)		3.52	7.23	1266	2.06	360	AD
342/2	"		3.60	7.26	1274	2.02	354	AD
342/3	D3 2.5 A.E. (1 + 11		3.54	6.93	1208.	1.96	342	(AD3)
342/4	E3(1 + 11)		3.62	7.23	1225	2.00	338	AD
342/5	E3/2 PNU.3 (1 + 11)		3.63	7.46	1186	2.06	327	AD
342/6	E4/1 .2g (1 + 11)		2.81	6.86	489	2.44	174	(NB2)
342/7	E5/2 .6 (1 + 11)		3.54	7.03	1248.	1.98	352	AD
342/8	E6 .5 (1 + 11)		3.62	7.42	1202	2.05	332	AD
343/2	C3/3		3.59	7.10	1208.	1.98	336	AD
343/3	"		2.78	6.41	547	2.31	197	NB2
343/4	"		3.42	7.07	1211	2.07	355	AD

(Continued)

		(a)	Na %	Al %	F μg g^{-1}	Al/Na	F/Na x 10^4	Group
343/5	"		3.29	6.75	1303	2.05	396	AD
343/6	D3/3		3.59	7.19	1218	2.00	339	AD
343/7	E3/3 .4, .3, .3	2	3.17	7.23	1163	2.28	367	(AD)
343/8	"		3.59	7.12	1295.	1.98	360	AD
343/9	"	2	2.39	7.27	1210.	3.04	506	-
343/10	E4/3 5 bits		3.61	7.48	1293	2.07	358	AD
343/11	"		3.41	6.98	1110	2.05	326	AD
343/12	"		3.21	6.36	482.	1.98	150	(NB4)
343/13	"		3.53	7.12	1188	2.02	336	AD
343/14	"		2.87	6.19	1193	2.15	415	(AD)
343/15	E5/3 .6		2.74	5.93	528	2.16	193	NB2
343/16	E6/3 .1		2.82	6.63	554	2.35	197	NB2
344/1	(1V) C3/4 .3		3.57	7.16	1234	2.01	346	AD
344/2	(1V) D3/4 .5		3.57	7.04	1232.	1.97	345	AD
344/3	"		2.88	6.71	526	2.33	183	NB2
344/4	"		3.52	7.21	1209	2.05	344	AD
344/5	(1V) E6/4 .3 flaked		2.82	6.73	564	2.38	200	NB2
345/1	(V) D3/5		2.73	6.46	539	2.36	197	NB2
345/2	"		3.25	7.12	1149	2.19	354	AD
345/3	(V) E6/5 1.0g		2.69	6.30	540	2.34	201	NB2
345/4	" .1, .2		2.83	6.37	555	2.25	196	NB2
345/5	" .1, .2		2.80	6.52	534	2.33	191	NB2
346/1	(V1) D3/6	2	2.81	6.53	539	2.33	192	NB2
346/2	(V1) B3/6 .5		2.74	6.69	531	2.44	194	NB2
346/3	(V1) E3/6		2.59	6.45	574	2.49	222	NB
346/4	(V1) E4/6		3.16	6.48	482	2.05	152	(NB4)
347/1	(V11) C3/7 3.7g	2	2.26	5.80	500	2.57	221	NB
347/2	"		2.53	6.07	515	2.40	204	NB2
347/3	"	2	2.62	6.59	496	2.53	190	NB2
347/4	"	2	2.04	6.40	497.	3.13	242	-
347/5	"	2	2.82	6.47	517	2.30	184	NB2
347/6	(V11) D3/7	2	2.00	6.00	518.	3.00	258	-
347/7	(V11) E3/7	2	2.34	5.78	524	2.47	224	(NB1)
347/8	(V11) E4/7		2.02	4.94	444	2.45	220	(NB)
Muliama (W.Ambrose)								
334/1	Surface site		3.76	7.75	1244	2.06	331	AD
334/2	"		2.61	6.65	532	2.54	204	NB2
334/3	"		2.73	6.40	516	2.34	189	NB2
334/4	"		2.70	6.69	534	2.48	198	NB2
334/5	"		3.50	7.14	1212	2.04	346	AD
Tatau Island (W. Ambrose)								
335/1	Surface site at Mabua		3.82	7.77	1303	2.03	341	AD
335/2	" Maragot	2	3.35	6.84	481	2.04	144	(NB4)
335/3	" Toigitoig		3.72	8.12	1303	2.18	351	(AD)
335/4	" Mapua,Tokara		3.84	7.89	1237	2.06	322	AD
Lihir Island (W. Ambrose)								
339/1	Surface site at Putput		3.52	7.19	1273	2.04	362	AD
339/2	"		2.97	7.38	582	2.48	196	NB2

(Continued)

		(a)	Na %	Al %	F µg g^{-1}	Al/Na	F/Na x 10^4	Group
Masahet Island (W. Ambrose)								
336/1	Surface site at Musoi		2.90	7.58	510	2.61	176	(NB2)
336/2	"		2.85	7.11	546	2.49	191	NB2
336/3	"		2.84	7.38	476	2.60	167	(NB2)
336/4	"		2.88	7.14	545	2.48	189	NB2
336/5	"		2.69	6.93	568	2.58	211	NB2
337/1	Surface site at Ton		3.69	7.69	1174	2.09	318	AD
337/2	"	5	2.24	6.39	546	2.85	205	-
337/3	"		3.57	7.07	1187.	1.98	333	AD
337/4	"		3.64	7.83	1242	2.16	342	(AD)
337/5	"		3.59	7.26	1122	2.03	313	AD
337/6	"		3.77	7.58	1076	2.01	286	AD
337/7	"		3.72	7.52	1264	2.02	340	AD
337/8	"		3.84	7.79	1319	2.03	343	AD
337/9	"		3.46	6.95	1169	2.01	338	AD
337/10	"		3.23	6.20	1082.	1.92	335	AD
337/11	"		3.51	7.09	1250	2.02	356	AD
338	Surface site at Malal Bilbil		3.75	7.61	1270	2.03	338	AD
Tanga Island (W. Ambrose)								
340/1	Surface site		3.67	7.49	1241	2.04	338	AD
340/2	"		3.84	7.64	1290.	1.99	336	AD
Ambitle Island (W. Ambrose)								
188	West Extn. 53 70-80cm		3.43	7.19	1348	2.10	393	AD
190	"		3.00	7.13	562	2.37	187	NB2
192	"	2	3.66	7.58	1299	2.07	355	AD
194	West Extn. 53 80-90cm		3.55	7.29	1358	2.05	382	AD
195	"		2.66	6.69	513	2.52	193	NB2
197	"		3.01	7.27	559	2.41	186	NB2
198	"		3.76	7.84	1307	2.08	347	AD
199	"		3.80	7.83	1165	2.06	307	AD
200	"		2.94	7.10	552	2.41	188	NB2
228	West Extn. North 90-100cm		3.51	7.16	1242	2.04	354	AD
229	"		3.42	7.00	1171	2.05	342	AD
230	West Extn. 53 60-70cm	2	3.87	7.81	1329	2.02	343	AD
231	"		3.83	7.70	1290	2.01	337	AD
232	"		3.86	8.01	1333	2.07	345	AD
234	"		3.03	7.08	620	2.34	205	NB2
235	"	2	2.56	7.00	547	2.74	214	(NB2)
236	"		3.34	6.91	494	2.07	148	-
237	"		3.85	7.75	1319	2.01	342	AD
238	"	2	3.81	7.66	1296	2.01	340	AD
239	"		3.00	7.34	554	2.45	185	NB2
284	"	2	3.54	7.34	1246	2.08	352	AD
285	"	2	3.57	7.42	1280	2.08	358	AD

(Continued)

		(a)	Na %	Al %	F $\mu g\ g^{-1}$	Al/Na	F/Na $\times 10^4$	Group
NEW BRITAIN								
Watom (J. Specht)								
372/1	Top of crater wall,(Coll.1967)		2.80	6.87	559	2.46	200	NB2
372/2	"		2.72	6.43	539	2.36	198	NB2
372/3	"		2.75	6.61	518	2.41	189	NB2
372/4	"		3.15	6.31	487	2.01	155	WF1
372/5	"		3.15	6.27	487.	1.99	155	WF1
173	W16, 816, Site 6, VFSpit 9		2.97	7.07	554	2.38	186	NB2
BOUGAINVILLE								
Buka (J. Specht)								
326/1	(11676) BP1/I L.XIII		3.70	7.63	1274	2.06	344	AD
326/2	(11558) BP1/II L.3 mid	2	3.70	7.62	1136	2.06	307	AD
326/3	(11555) BP1/II L.3 upp		3.65	7.94	1146	2.18	314	(AD)
326/4	(11668) BP1/I L.IV upp	2	3.78	7.82	1187	2.07	314	AD
326/5	(13298) BP4 Buka airfield	2	3.71	7.68	1095	2.07	295	AD
326/6	(6291) BP9A Surface		3.48	7.76	1179	2.23	338	(AD)
326/7	(15524) BP33 Surface		3.58	7.50	1227	2.10	343	AD
265	(11554) BP1/11 L.3 upp		3.21	6.40	1178.	1.99	367	AD
SOLOMON ISLANDS								
Reef/Santa Cruz Islands (R.C. Green)								
165	BS-RL-2 W-21-0-1		3.34	6.79	556	2.03	166	WF1
166	"		2.74	6.67	523	2.43	191	NB2
167	BS-RL-2 W-27-0-1		2.90	6.73	541	2.32	186	NB2
168	BS-RL-2 T-38-0-1		2.97	6.89	551	2.32	185	NB2
169	BS-RL-2 S-38-0-1							-
170	BS-RL-2 P-39-0-1		2.97	7.21	552	2.43	186	NB2
171	BS-RL-2 T-39-0-1		2.88	6.65	518	2.31	180	NB2
172	BS-RL-2 M-51-0-1		2.98	7.05	547	2.37	184	NB2
213	BS-RL-6 Grey sand		2.96	7.13	551	2.41	186	NB2
214	BS-RL-6 M23		2.87	7.05	527	2.46	184	NB2
215	"		3.00	7.00	550	2.34	183	NB2
217	BS-SZ-8 JJ52,2nd Level		2.95	7.07	531	2.40	180	NB2
218	"		2.86	7.48	508	2.61	178	(NB)
219	BS-SZ-8 JJ52, 3rd Level	2	2.79	6.85	521	2.45	186	NB2
220	"		2.62	6.16	530	2.35	202	NB2
221	BS-SZ-8 JJ52,4th Level		2.66	6.89	527	2.59	198	NB2
222	"		2.61	6.19	513	2.38	197	NB2
375/1	BS-RL-6 C20, Brown, 1st Level		2.78	6.66	543	2.40	195	NB2
375/2	" "		3.05	6.93	667	2.27	219	NH1
375/3	" "		2.40	5.97	490	2.49	205	NB2
375/4	BS-RL-6 E25, Brown, 2nd Level		2.67	6.43	519	2.41	195	NB2
375/5	" "		2.81	6.45	534	2.30	190	NB2
375/6	BS-RL-6 P24, Brown and grey		2.79	6.61	544	2.37	195	NB2
376	BS-RL-6 V26, Black, 1st Level		3.07	7.07	679	2.30	221	NH1
377/1	BS-SZ-8 CC-59,2nd Level/15-30cm		3.05	6.60	629	2.16	206	NH1
377/2	" "		2.64	6.30	522	2.39	198	NB2
377/3	"	2	2.59	6.00	453	2.31	175	(NB2)
377/4	BS-SZ-8 VV-50,1st Level,0-15cm		2.75	6.45	529	2.35	192	NB2
377/5	" "							-
377/6	" "		2.95	6.75	667	2.29	226	NH1
377/7	BS-SZ-8 U57, 1st Level,0-15cm		3.21	6.88	1154	2.14	360	AD
377/8	" "		2.90	6.61	648	2.28	223	NH1

(Continued)

		(a)	Na %	Al %	F µg g^{-1}	Al/Na	F/Na x 10^4	Group
377/9	" "		2.76	6.41	592	2.33	215	-
377/10	BS-SZ-8 EE58,Back dirt fill		3.05	7.11	623	2.33	204	NH1
377/11	BS-SZ-8 U54, 1st Level,0-15cm		2.94	6.71	606	2.28	206	NH1
377/12	" "		3.09	7.17	672	2.32	218	NH1
377/13	" "		2.53	6.15	507	2.43	200	NB2
377/14	" "							-
377/15	" "		2.65	6.31	533	2.38	201	NB2
377/16	BS-SZ-8 VV54, 1st Level,0-15cm		3.56	7.20	1252	2.02	352	AD
377/17	" "							-
377/18	BS-SZ-8 R55, 1st Level,0-15cm		3.07	7.04	642	2.29	209	NH1
377/19	" "		3.09	7.20	657	2.33	213	NH1
377/20	" "		2.59	6.26	508	2.41	196	NB2
377/21	" "		2.68	6.59	502	2.46	187	NB2
377/22	" "		2.55	6.23	490	2.45	192	NB2
377/23	" "							-
378	BS-SZ-10,Surface E.of Mbumbir		3.43	7.11	1275	2.08	372	AD
VANUATU								
Malo (J.Hedricks)								
327/1	NH Ma-8 Naone Tavera		2.91	7.04	562	2.42	193	NB2
327/2	NH Ma-8 Naone Tavera	2	4.11	9.60	856	2.33	208	NH2
203	NH Ma-8 Naone Tavera	2	2.85	6.89	528	2.42	185	NB2
205	NH Ma-8 Naone Tavera	2	3.53	7.40	1351	2.10	383	AD
VANUATU								
Banks Islands (G.K. Ward)								
382			3.91	8.59	819	2.20	210	NH2
383			3.69	8.08	797	2.19	216	NH2
384			3.76	8.27	811	2.20	216	NH2
385			3.69	8.27	807	2.24	219	NH2
386			3.11	7.05	688	2.26	221	NH1
387			3.46	9.18	806	2.65	233	NH2
389			3.04	7.26	668	2.39	220	NH1
390			2.68	6.56	584	2.45	218	-
391			2.86	7.31	652	2.55	228	-
392			3.02	6.93	615	2.30	204	(NH)
393			3.21	6.97	724	2.17	225	NH
394			2.53	5.88	578	2.32	229	-
395			3.08	7.38	618	2.40	201	NH1
396			4.01	8.61	839	2.14	209	NH2
397			2.99	6.88	653	2.30	218	NH1
398			2.82	7.33	652	2.60	231	-
399			2.95	6.76	655	2.29	222	NH1
400			3.79	8.53	802	2.25	218	NH2
401			2.89	6.70	636	2.31	220	NH1
INDONESIA								
Leles III, PS L10 (N. Angraeni)								
291/9		6	2.75	6.86	600	2.50	218	-