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CHARACTERIZATION STUDIES OF NEW ZEALAND OBSIDIANS: TOWARD A REGIONAL PREHISTORY [1976]

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(Published in 1976 as Chapter 14 of *Advances in Obsidian Glass Studies: Archaeological and geochemical perspectives*, edited by E. R. Taylor. Noyes Press, Park Ridge, NJ)

Introduction

Igneous activity has been an important feature of the geological history of the northern half of the North Island of New Zealand since the later part of the Tertiary Period. During the early Miocene andesitic volcanoes erupted on both sides of a trough now occupied by the North Auckland Peninsula (Figure 1) and andesitic flows occurred on the Coromandel Peninsula. Andesitic activity continued through the late Miocene in these areas and in Auckland. In the Pliocene dacitic volcanism occurred in the eastern part of North Auckland, followed by rhyolite eruptions along the line of the Coromandel Peninsula, Great Barrier Island and other offshore islands further north.

In the Quaternary, the centres of activity moved further south. The rhyolites of Mayor Island are probably of Middle Pleistocene age or younger. Andesitic and basaltic volcanism has occurred in the Auckland area, the most recent events having been dated over a period of 42 000 years terminating with the eruption of Rangitoto Island about 1200 A.D. In the western part of the North Island andesitic and dacitic activity has taken place since the Miocene, culminating with Mount Egmont, an andesitic volcano the last eruption of which has been dated to about 1600 A.D.

Much of the Quaternary activity, however, has been concentrated in the Taupo Volcanic Zone, which runs 250 km northeast from Lake Taupo. Early eruptions of andesite were followed by immense ignimbrite eruptions which resulted in vitric tuffs being spread widely over the central part of the North Island. In all, more than 12 000 cubic kilo-

[pp.259-260]

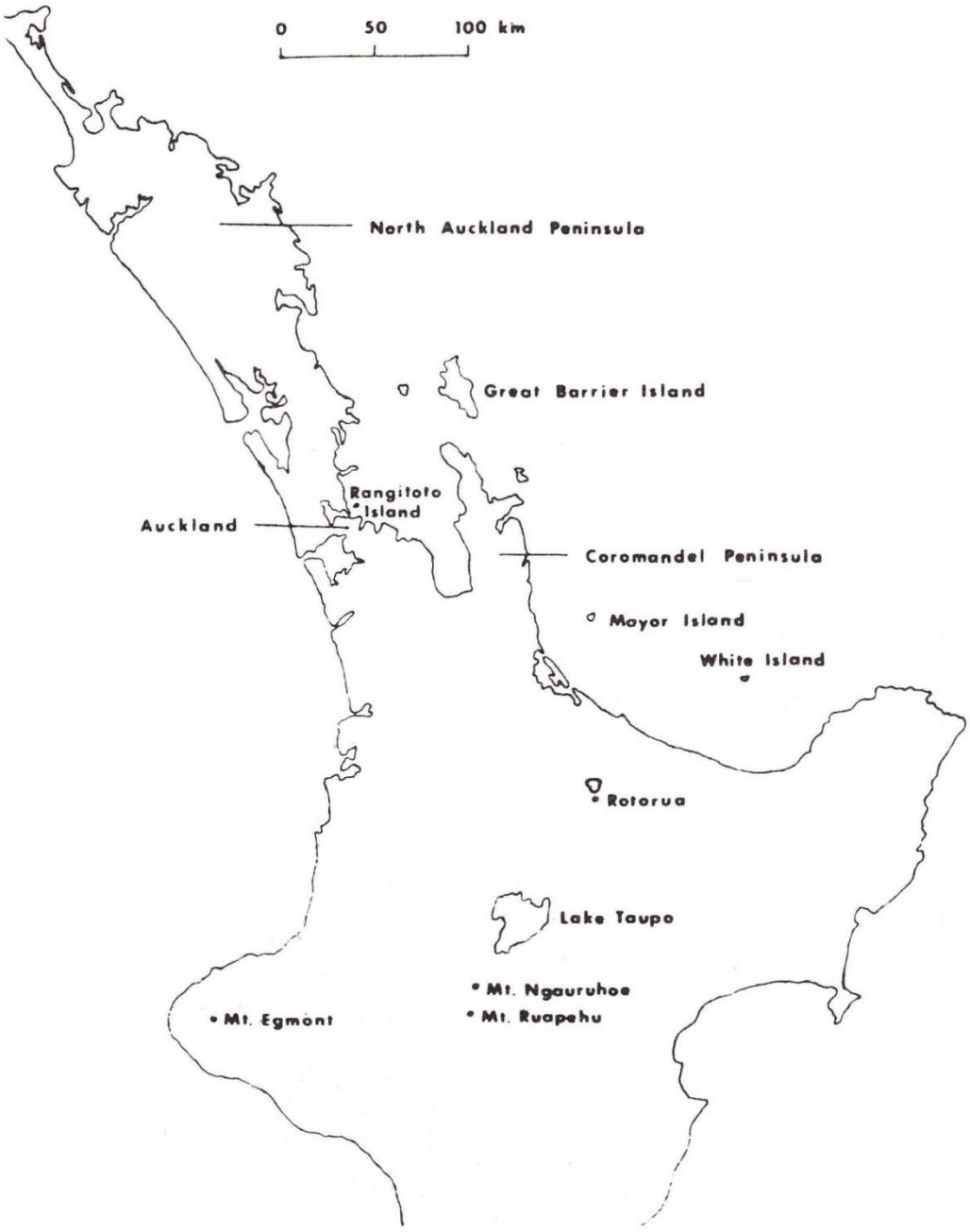

Figure 1. Map of part of the North Island of New Zealand showing some of the centres of Late Tertiary and Quaternary volcanic activity.

[pp.260- 261]

metres of ignimbrite, rhyolite lava and pumice are estimated to have been poured out of this area.

The Pleistocene and Holocene volcanicity of the Zone has been summarized by Healy (1971). Although it is not known when the rhyolitic volcanism began, at least 23 major eruptions from three active centres are believed to have been confined to the last 0.7 million years. The last 40 000 years have seen a total of 25 explosive pumice eruptions from these centres. The rhyolitic volcanics have not proved suitable for potassium-argon dating, but a sample of obsidian from near Taupo has been reported as giving a fission-track age of about 95 000 years.

To the present day, volcanic and hydrothermal activity persists in the Taupo Volcanic Zone, from the andesitic cones of Ruapehu and Ngauruhoe in the southwest to that of White Island in the northeast. Between these volcanoes, three volcanic districts, regarded as still active, correspond to the three centres of earlier rhyolitic volcanism.

In the light of the abundance of rhyolitic and dacitic volcanism, particularly, it is not surprising that the Polynesian settlers, who are believed to have inhabited New Zealand for rather more than 1000 years, discovered obsidian in several localities and made use of it for a variety of purposes. It has become apparent that obsidian was highly prized by the Maori: in some form, it has been found at nearly every archaeological site (Duff 1956). In the absence of various other kinds of artefactual material, especially ceramics, among the prehistoric remains of the southernmost Polynesian culture the study of the ubiquitous obsidian flake has assumed a mantle of importance to New Zealand archaeology.

Exploration of New Zealand by geologists during the period from 1860 to 1930 led to reports of the occurrence of obsidian on Mayor Island, at various localities on the Coromandel Peninsula, in the Taupo-Rotorua region and in North Auckland. These localities were not always pinpointed with sufficient accuracy to enable them to be rediscovered easily, nor was all the obsidian of a quality that would have made it useful to the Maori, the presence of spherulitic inclusions often precluding desirable fracture characteristics.

In 1958, R.C. Green commenced a multifaceted investigation of archaeological obsidian, including hydration dating, source determination and aspects of flake use, designed to elucidate temporal, distributional and technological factors in New Zealand prehistory. The problem of sourcing was outlined as follows (Green 1962):

(a) To locate each source precisely and obtain a representative range of samples.

(b) To demonstrate that flake-quality obsidian can be obtained from the source. (Some sources may have been known to the

[pp.261-262]

Maori, but not used because of poor flaking characteristics.)

(c) To demonstrate the availability of the obsidian to the Maori. (Some sources may have become exposed relatively recently as a result of highway construction, hydroelectric works, etc.)

(d) To show the use of the source, either from the evidence of quarrying at the source or by identifying material at archaeological sites.

(e) To demonstrate that obsidians from one source are not being mistaken for those from another.

It was considered that the sources of quality obsidian might be sufficiently restricted that each part of the problem could be solved.

Location of Obsidian Sources

Mayor Island (Figure 2) has the most extensive deposits of obsidian known in New Zealand. Detailed descriptions have been given by Thomson (1926), Pos (1965) and Ward (1973). The appearance of Mayor Island obsidian varies, but it is usually from black to dark green in reflected light and green to yellow-green in transmitted light. However, a number of flows on the island have produced flake-quality obsidian lacking this green hue. Three areas were reported by Pos to yield high quality flake obsidian; other areas yielding high quality obsidian were noted by Ward. At Taritimi Bay, on the eastern side of the island, there is evidence of a quarry where obsidian has been obtained by tunnelling one to two metres into a seam. The distinctive appearance of Mayor Island obsidian has led to its recognition and differentiation from ‘mainland’ obsidian since the earliest archaeological investigations in New Zealand. Its importance is reflected in the Maori name, Tuhua (‘obsidian’), for the island.

The lack of precise geological and geographical context for many of the other natural-source obsidian samples available for study prior to 1960 led to extensive attempts being made in the following years to dis cover (or rediscover) as many sources as possible. It was hoped that all sources previously known to, and used by, the Maori might be included.

The existence of obsidian deposits in the Whitianga area (Figure 2) and near Lake Taupo had been known to Europeans since the last century, and accurately located samples from these sources became readily available. A deposit near Kaeo was found, as reported by Green (1964), and another North Auckland source, at Huruiki, was documented by Mansergh (1965). It was noted that in some properties the Kaeo obsidian resembled that of Mayor Island. On Great Barrier Island, large boulders of clear grey flake-quality obsidian were found on Te Ahumata Plateau,

[pp.262-263]

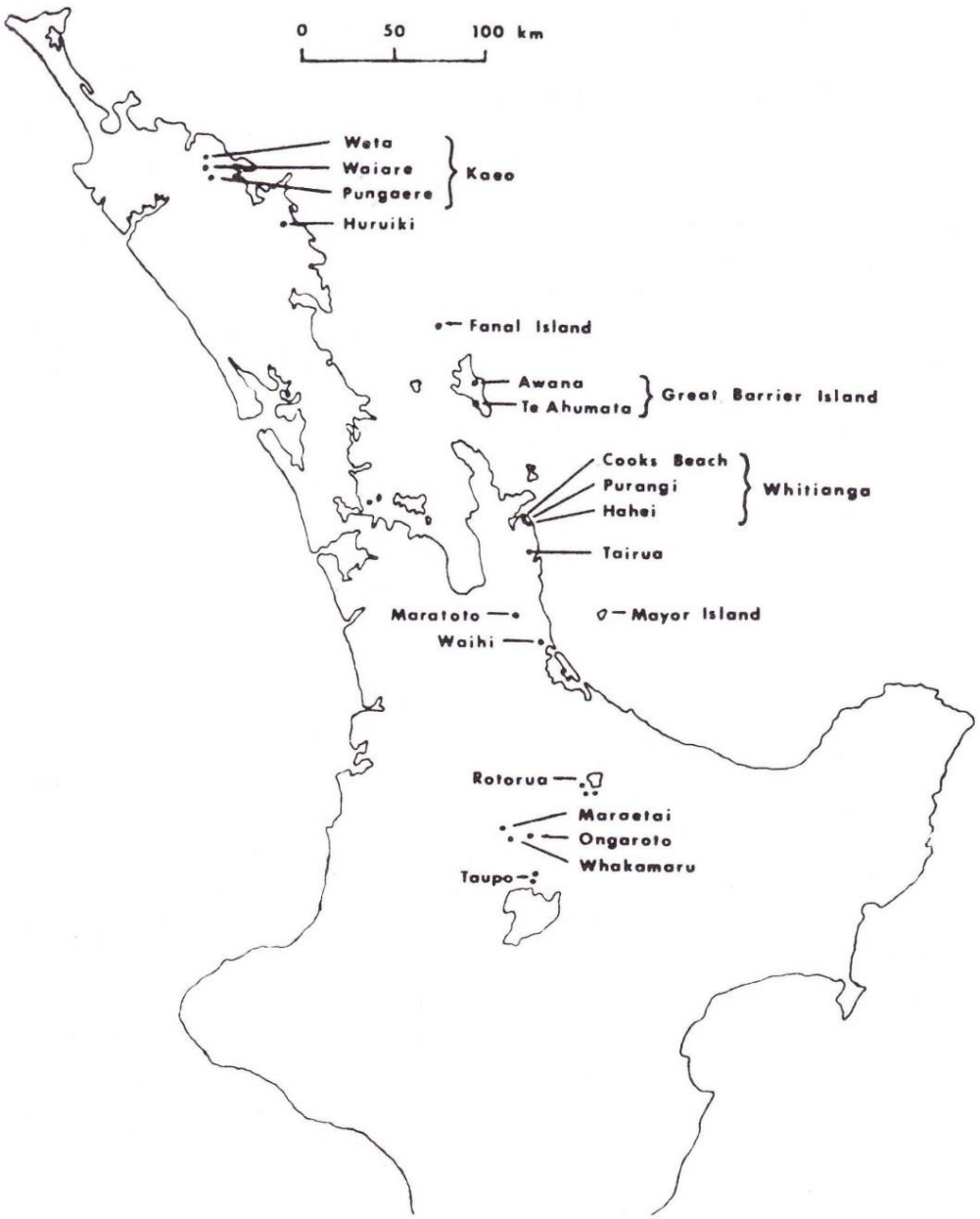

Figure 2. Map of part of the North Island of New Zealand showing location of geological deposits of obsidian.

[pp.263-264]

and poorer quality spherulitic material was also noted (Spring-Rice 1962, 1963).

Obsidian was also found in several places near Lake Maraetai, some thirty kilometres north of Taupo, on the Waikato River. Some samples were taken from naturally-exposed outcrops while others were from a band in a road-cutting. Specimens reported from the Waikato River valley are presumably derived from the Taupo or Maraetai sources and carried down the river (Green 1962). Other sources, generally furnishing material of poorer quality than those listed below, we're also documented. In the Rotorua area specimens came from a road cutting near Lake Rotoiti, from the Hemo Gorge and from Mount Tarawera (Green 1962). Several outcrops of red-flecked and red-coloured obsidian and glassy rhyolite have also been reported from this area (Green 1964). Fanal Island, north of Great Barrier Island, was noted as the source of a green-black obsidian which, because of the presence of spherulites, was not of flake quality (Thompson 1960).

Based on the sources defined by 1966, the first detailed chemical investigation was carried out by Green, Brooks and Reeves (1967). Only those sources yielding flake-quality obsidian were investigated, these being described as follows: (1) Kaeo (two locations), (2) Mayor Island (two locations), (3) Huruiki, (4) Great Barrier Island, (5) Whitianga (two locations), (6) Maraetai (two locations), and (7) Taupo (two locations).

The most extensive search for source material yet undertaken has recently been described by Ward (1972, 1973). This work modifies the above list by defining three locations near Kaeo, ten on Mayor Island, two on Great Barrier Island, and three in the Maraetai area. Nine distinct bomb deposits at Huruiki were sampled, detrital material and boulders were obtained from five locations on the Coromandel Peninsula, a Fanal Island specimen was added, and non-flake- and semi-flake-quality obsidian from three locations in the Rotorua area was included. The inclusion of material of lesser quality was justified by the possibility of its being associated with flake-quality obsidian of similar composition in another part of the deposit. A full description of the obsidians from all of these areas, with maps showing the discrete sampling localities, is given by Ward (1973). The location and nomenclature of the sources known to the present time are indicated in Figure 2.

Characterization of Obsidian Sources

The early literature contains little information useful for characterizing known sources. There is an isolated report of the density of Mayor Island obsidian (Marshall 1936). Chemical analysis for major constituents showed higher concentrations of sodium and potassium in Mayor Island rocks than in the rhyolites and pumices of the mainland, while calcium and magnesium levels were lower (Bartrum 1926). Early analyses of several New Zealand

[pp.264-265]

obsidians for major and minor elements, mainly by wet-chemical methods, are included in the summary by Challis (1971).

Attempts made since 1960 to characterize the various sources have involved the examination of both physical properties and chemical constitution. These studies are summarized in Table 1.

Table 1. Summary of Characterization Studies of New Zealand Obsidian Deposits

Physical Properties
Refractive index (Green 1962)
Density (Reeves and Armitage 1973)
Chemical Composition
Emission spectrography (Green et al. 1967)
Atomic absorption/flame photometry (Armitage et al. 1972)
Proton-induced γ-emission (Coote et al. 1972)
X-ray fluorescence (Ward 1974a)

Refractive index

Refractive indices were reported by Green (1962, 1963) for obsidians from Mayor Island (1.5070 to 1.4970), Maraetai (1.4940 to 1.4866) and Taupo (1.4894 to 1.4867). Samples provided from Arid Island (Rakitu), east of Great Barrier Island, showed refractive indices of 1.4873 to 1.4857. These samples, however, were not clearly defined as being from a natural source on the island, and later work by Armitage (1971) established the identity of their chemical composition with that of the Taupo source material.

Emission Spectrography

By 1966 sufficient well-documented natural-source samples were available to make chemical investigation worthwhile. Green, Brooks and Reeves (1967) used emission spectrography following the success of Cann and Renfrew (1964) in applying this technique to the study of Mediterranean obsidians. Of the elements detected and measured, particular attention was paid to Mn, Zr, Be and Ca, all of which enabled discrimination to be made between at least some of the seven sources. In order to minimize uncertainties arising from matrix effects and other variables associated with the arcing of samples, the data analysis was made not in terms of absolute concentrations but on the basis of the relative intensities of various emission line pairs, such as Be 313.0 nanometre/Ca 315.8 nm and Zr 327.3

[pp.265-266]

nm/Mn 279.8 nm. The degree to which such intensity ratios enable the sources to be distinguished is illustrated in Figure 3. The areas shown for each source indicate the fields containing the values for 90% of the samples from that source (1.645 standard deviations about the mean). Satisfactory characterization can be achieved by this method for all the sources investigated except Huruiki and Great Barrier Island, which show some overlap at the 90% confidence limit. Archaeological samples were not studied at this stage, and the emission spectrographic technique was later superseded by other analytical methods.

The coefficients of variation for the line intensity ratios in the analysis of obsidians for anyone source were typically in the seven to 20% range. This variation is due partly to the relatively poor precision of emission spectrography and partly to the natural variation of element concentrations within a source. Characterization work elsewhere, by emission spectrography (Cann and Renfrew 1964) and neutron activation analysis (Gordus *et al*. 1968), also indicated some large variations in element concentrations within a source, much of which might be attributable to the analytical techniques used.

Atomic Absorption – Flame Emission

An investigation using atomic absorption spectroscopy and flame photometry was carried out by Armitage (1971) with the following objects: (a) to establish accurately the concentrations of several elements in obsidians from each source, (b) to determine the variation due to the analytical method for these elements, (c) to obtain a measure of the natural variation of element concentrations within each source, and (d) to apply the analysis to samples from eight archaeological sites. The analytical methods were chosen because of their potential for giving results of high precision. Samples of 200 mg were

dissolved in concentrated nitric and hydrofluoric acids, and the residue from evaporating the solution to dryness was taken up in hydrochloric acid (Armitage *et al*. 1972). Manganese, zinc and iron were determined by atomic absorption, and sodium and potassium were found by flame photometry.

An extensive series of replicate analyses established the precision of the analytical method. Coefficients of variation were as follows: Na, 1.3%; K, 0.7%; Fe, 1.7%; Mn, 0.8%; Zn, 1.1 % (at the 200 to 400 ppm level), 4.3% (at the 30 to 60 ppm level). It was then possible to investigate the variations of element concentrations within each source. A high degree of intrasource homogeneity was indicated by the fact that the coefficient of variation for Na, K, Fe and Mn nowhere exceeded 4% and was usually less than 3%. For Zn the coefficients of variation were 2.0 to 6.3%, depending on the zinc levels involved; this was predominantly an analytical variation rather than an inhomogeneity of the samples. With

[pp.266-267]

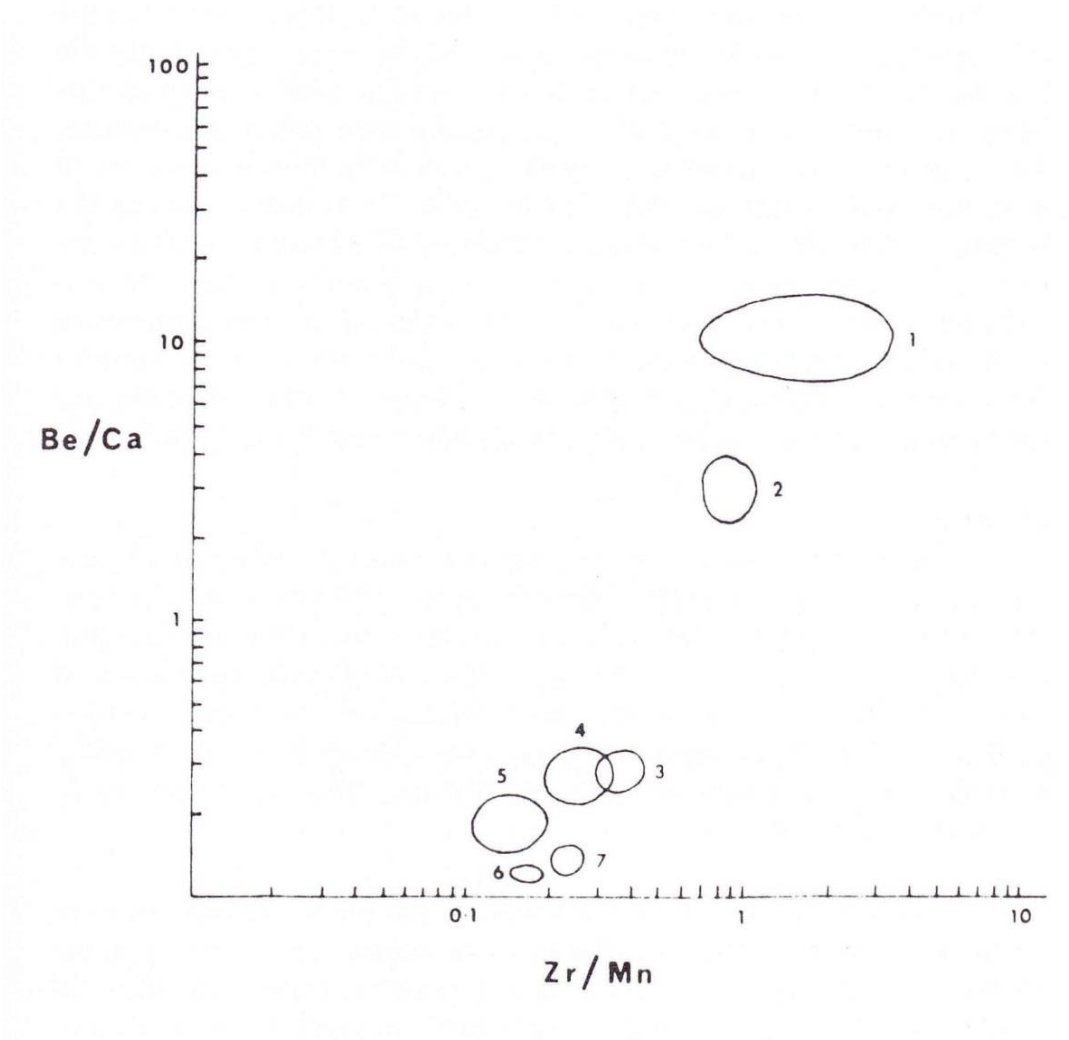

Figure 3. Characterization of sources by emission spectrography using line intensity ratios Be 313.0/Ca 315.8 and Zr 327.3/Mn 279.8 nm. Sources: (1) Kaeo (2) Mayor Island (3) Huruiki (4) Great Barrier Island (5) Whitianga (6) Maraetai (7) Taupo. Areas are defined by 1.645 standard deviations about the mean, except for Maraetai where the area includes all three samples. (Redrawn from *New Zealand Journal of Science* 10 [1967]: 680.)

[pp.267-268]

respect to sodium and potassium no effects due to surface weathering were observed, the samples being large enough that any weathered surface layer constituted an insignificant part of the total mass.

Analytical data are summarized in Table 2a. It was noted that the manganese levels were the most useful for characterization. Only the Huruiki and Great Barrier Island sources showed some overlap on this basis, and they were easily distinguished by their potassium content. Two Mayor Island samples showed significantly greater amounts of iron, zinc and manganese than did the other 18 samples, and did not belong to the normal distribution shown by those samples. The existence of at least three distinguishable Mayor Island compositions was indicated, and strong confirmation was produced in subsequent work with archaeological material. Analysis of the latter included samples from sites at Motutapu (Davidson 1972; Reeves and Armitage 1973), at Skipper's Ridge II, Mangakaware and Otakanini (Armitage *et al*. 1972) and at Hamlins Hill, Foxton Beach and Tiwai Point (Reeves and Armitage 1973).

Density

In the hope of finding a simple physical method of obsidian characterization that might be applied directly under field conditions, the densities of sixty-one New Zealand obsidians from six major sources were measured by Reeves and Armitage (1973). Densities could be measured rapidly with an accuracy better than 0.001 g/cm^3 by a free flotation method and by hydrostatic weighing, the former being particularly suitable for small flakes weighing 50 to 500 mg. The results are summarized in Table 3.

It was concluded that: (a) the Kaeo and Mayor Island sources were separable from the others on the basis of density; they are separable from one another by the characteristic colour of Mayor Island obsidian; (b) the Mayor Island subgroups previously distinguished by chemical analysis did not have distinctive densities; and (c) the extent of overlap among the other sources is considerable, and the confidence with which assignments could be made is very much less than that given by chemical analysis for appropriate elements, such as manganese and potassium.

The claim that Mayor Island and Kaeo obsidians are separable by their colour is subject to the qualification that some Mayor Island flows are of colours other than green, while obsidian from deposits at Waiare and Pungaere near Kaeo do show a greenish tinge in transmitted light which might be mistaken for that of Mayor Island obsidian (Ward 1973:85).

[pp.268-269]

Table 2a. Analyses of Obsidians from Geological Deposits by Atomic Absorption and Flame Photometry

Source	No. of Samples	Na %*	S.D.**	K %*	S.D.	Fe %*	S.D.	Mn, ppm*	S.D.	Zn, ppm*	S.D.
Kaeo	24	4.72	0.15	3.53	0.08	3.04	0.06	585	17	323	10
Huruiki	11	3.98	0.11	3.14	0.04	1.02	0.02	222	7	49	3
Gt. Barrier I.	8	3.32	0.04	3.92	0.06	0.99	0.04	206	7	46	3
Mayor I. (1)	18	4.59	0.09	3.59	0.05	3.29	0.06	682	26	218	4
Mayor I. (2)	1	4.71	-	3.55	-	4.00	-	897	-	256	-
Mayor I. (3)	1	4.82	-	3.59	-	4.40	-	1000	-	231	-
Whitianga	12	3.83	0.09	2.76	0.07	1.02	0.02	454	9	43	3
Taupo	11	3.55	0.07	2.93	0.05	1.06	0.02	362	7	38	2
Maraetai	1	3.35	-	3.12	-	0.78	-	320	-	37	-

* Mean concentration.
**Standard deviation.

[pp.269-270]

Table 2b. Analyses of Obsidians from Geological Deposits by X-ray Fluorescence Spectroscopy

Source	No. of Samples	Zr (ppm)	Mn (ppm)	Ti (ppm)	Rb (ppm)	Sr (ppm)
Te Ahumata	5	160 (122)*	180 (53)	621 (35)	303 (15)	28 (4)
Awana	5	166 (34)	276 (45)	639 (81)	303 (26)	36 (5)
Huruiki	45	152 (11)	211 (11)	605 (35)	228 (28)	41 (4)
Waiare	5	1297 (199)	812 (61)	993 (34)	871 (44)	4 (2)
Pungaere	6	1662 (86)	901 (69)	1013 (20)	838 (16)	3 (3)
Weta	5	83 (1)	144 (14)	384 (17)	562 (4)	6 (2)
Mayor Island	52	916 (22)	946 (41)	1624 (23)	189 (2)	3 (1)
Cooks Bay	10	133 (15)	473 (32)	782 (16)	176 (21)	77 (9)
Purangi	6	200 (7)	505 (28)	702 (65)	207 (6)	85 (3)
Tairua	5	209 (9)	411 (26)	1415 (21)	192 (3)	139 (8)
Hahei	5	177 (1)	498 (6)	634 (20)	227 (2)	105 (0)
Waihi	12	181 (9)	414 (19)	2023 (172)	186 (5)	174 (3)
Maratoto	6	90 (2)	318 (57)	398 (50)	275 (7)	41 (5)
Rotorua	20	145 (5)	390 (11)	799 (16)	221 (3)	86 (3)
Maraetai	10	143 (7)	336 (17)	1023 (28)	218 (5)	101 (5)
Ongaroto	5	171 (8)	375 (26)	1024 (51)	213 (8)	101 (7)
Taupo	25	171 (7)	372 (12)	1258 (19)	200 (5)	101 (3)
Fanal Island	6	212 (8)	170 (37)	1338 (60)	320 (9)	59 (3)

*Mean concentration (standard error of the mean)

[pp.270-271]

Table 3. Density Measurement of Obsidians from Geological Deposits

Source	Samples	Mean Density, g/cm^3	Range of Density, g/cm^3
Kaeo	12	2.410	2.403 – 2.420
Mayor Island	14	2.401	2.375 – 2.432
Huruiki	10	2.362	2.358 – 2.364
Whitianga	9	2.355	2.351 – 2.358
Taupo	10	2.352	2.346 – 2.354
Great Barrier Island	6	2.349	2.235 – 2.354

Proton Inelastic Scattering

An alternative analytical method was illustrated by Coote, Whitehead and McCallum (1972) who studied the γ-radiation emitted following proton bombardment. A beam of 2.2 Mev protons from a Van de Graaff accelerator was directed on to a portion of the sample surface (diameter 1.5 mm)and the γ-radiation resulting from inelastic proton scattering was measured with a Ge(Li) detector and multichannel analyser. Significant peaks from obsidian samples were found for ^{19}F (110, 197 kev), ^{23}Na (439 kev) and ^{27}Al (842, 1013 kev). This method possesses a major advantage over emission spectrography, flame emission and atomic absorption, and some techniques of X-ray fluorescence, in being non-destructive.

Replicate analyses of fragments from a single piece of obsidian showed a standard deviation of 2% for the F/Na ratio taken from the areas of the peaks at 110 and 439 kev. The standard deviation for a range of samples from a given source averaged less than 4%, confirming the high degree of homogeneity found previously.

The ratio F/Na was shown to be a better discriminator than the ratio Al/Na, but there was some overlap in the F/Na values for Mayor Island and Rotorua obsidians, and considerable overlap for the geologically related Maraetai and Taupo sources. The proton inelastic scattering technique is essentially one of surface analysis, the penetration of the sample being 20 to 50 pm, depending on the proton energy. The possibility of anomalous results arising from weathered surfaces was investigated, but the F/Na ratios were found to be independent of proton energy for both types of surface, indicating that this effect is not significant. No artefact samples have yet been analysed using this technique.

[pp.271-272]

X-Ray Fluorescence

Samples from the extensive collection of source material described by Ward (**1973**)were analysed by X-ray fluorescence. Samples were ground by a standardized procedure that ensured the preparation of a powder with reproducible grain size. The powder was compressed into a disc with a boric acid support. Analysis was made with Philips X-ray fluorescence spectrometer using a tungsten anode. Scintillation counting was used for four elements (Zr, Sr, Rb, Mn) and a flow-proportional counter was used for Ti. Pulse-height discrimination was used in the measurement of Sr and Rb. All measurements were made with the spectrometer path evacuated to two torr pressure. The technique was non-destructive in the sense that the prepared sample could be preserved for repeated counting.

Conversion of count rates to concentrations was made by comparison with values given by a similarly prepared sample of the USGS Standard granite G-2. Currently accepted best values of the appropriate element concentrations in G-2 were used. Errors from voltage drift and other instrumental variations were minimized by continual reference to the G-2 sample. The standard error of the mean (SEM) for replicate preparations from a single sample was generally less than 10% at the $P = 0.05$ level.

For each of the nearly fifty sampling locations five or six randomly chosen samples were analysed. In about two-thirds of the element determinations the intrasource variations were small enough to maintain the SEM below 10% ($P = 0.05$). Most of the cases where the SEM exceeded 25% were in the determination of low levels (2 to 10 ppm) of Sr. The X-ray fluorescence data of Ward (1974) are summarized in Table 2b.

Of the elements determined by atomic absorption by Armitage (1971) only Mn was included in the X-ray fluorescence measurements. The correlation between the two sets of values for Mn is generally very good, although the XRF values for the Mayor Island samples are 15 to 20% higher than those found by atomic absorption. The group means for Mn from ten Mayor Island localities by XRF ranged from 815 ppm (quarry site) to 1168 ppm. However the extent of overlapping of the five-element data for these ten localities led to their classification as a single cluster (Ward 1974a).

Armitage, Reeves and Bellwood (1972: 408) found a majority of archaeological site samples to correspond to the quarry site material (about 700 ppm Mn by atomic absorption), but obsidian from other Mayor Island localities with about 900 and 1000 ppm Mn was also found. It is possible that material from only three or four of the localities sampled by Ward was in general use by the Maori. In any case, it seems unlikely that any major political significance will prove to be associated with the exploitation

of obsidian from different flows on the island.

A major advance was made by Ward (1972, 1974a) in the treatment of multi-element data. Previous work made use of element concentrations or element ratios, either taken singly or taken in pairs, to give a two-dimensional plot in which fields corresponding to different sources were represented. With a limited number of defined sources and with analytical data of high precision, these methods may be used successfully as illustrated in Figure 4. When the number of sources to be characterized is increased, however, the likelihood of overlap increases in a way that depends on the precision of the analytical data, the extent of intrasource homogeneity, and on the inter-source variation of the elements concerned.

Eventually it is desirable to resort to a multivariate technique. In its simplest form this consists of visual inspection of multi-element data. An alternative approach is a graphical method such as that demonstrated by Key (1968), who plotted the element concentrations in an artefact on the *y*-axis and the concentrations in a source on the *x*-axis, identification being made by finding the source which gave the smallest total deviation from the line $y = x$. In order to make the best of the five-element information, Ward (1974a, 1974b) based his data analysis on the D^2 statistic of Mahalanobis and Rao (Mahalanobis 1930; Rao 1948, 1952) in which functions involving weighted combinations of the *n* measured variables are investigated to find those functions which provide the maximum discrimination between sources (i.e., maximum sum of squares of distances of separation in the *n*-dimensional hyperspace). Clusters of the original groups were then formed by combining groups which were insignificantly discrete.

This analysis led to the delineation of eighteen source-groups that could be regarded as petrographically distinct on the evidence of the five elements investigated; in each case the tentatively defined ‘subsources’ were recombined in such a way that geographical boundaries were not overstepped (Ward 1974a). The eighteen potential sources appear in Figure 2.

For the purpose of making geographical representation of the relationship among sources a canonical analysis was carried out. It was found that the eighteen source-groups could be represented in three dimensions with little stress on the five-dimensional configuration, some 98% of the variance being included. A model portraying the inter-group relationships was constructed (Figure 5). In the identification of artefact unknowns, however, the original five-dimensional matrix was retained. Initially this was tested by replacing each individual set of data representing a geological deposit sample within the original matrix. An ‘incorrect’ assignment, indicating that an individual was significantly different from the group mean, occurred to only five of the 232 original data sets. Subsequently, artefact characterization data were

[pp. 273-274]

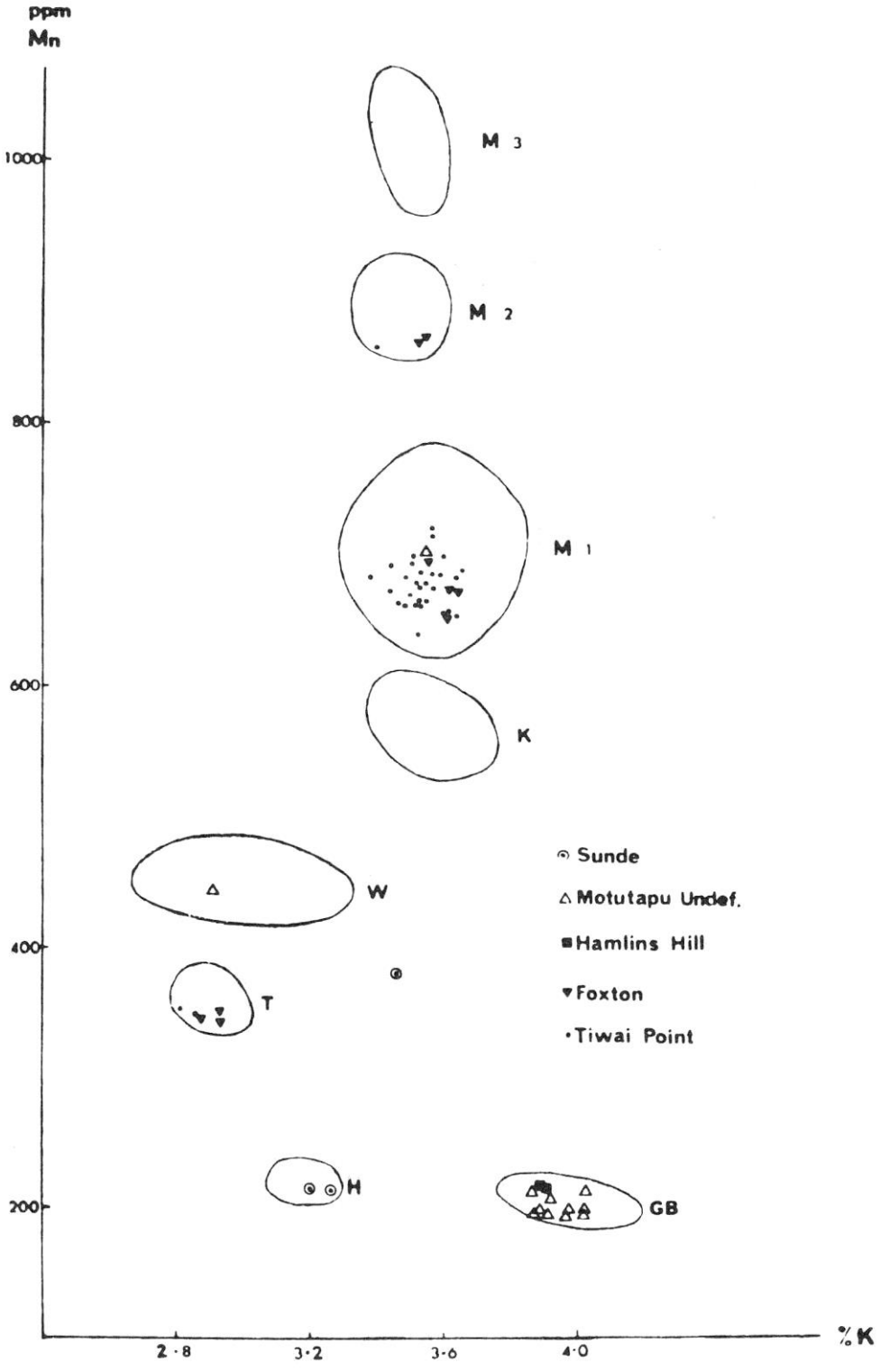

Figure 4. Manganese and potassium in archaeological obsidians from Motutapu Island sites, Hamlins Hill, Foxton, Tiwai Point. M1, M2, M3: Mayor Island subgroups; K: Kaeo; H: Huruiki; W: Whitianga; T: Taupo; GB: Great Barrier Island. (Reproduced from *New Zealand Journal of Science* 16 [1973]: 567)

[pp. 274-275]

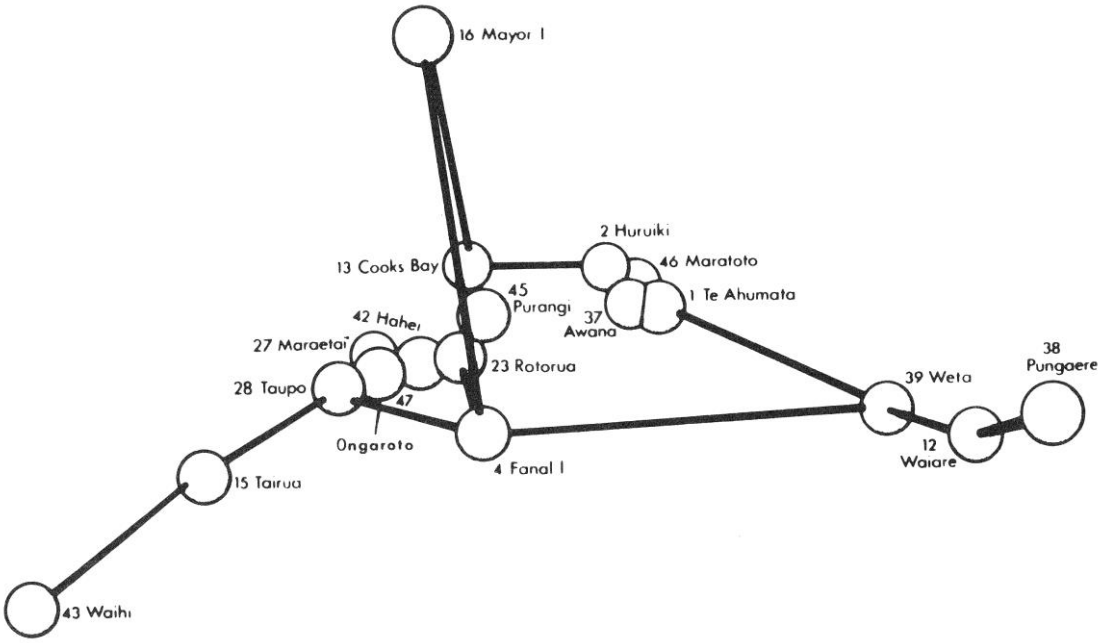

Figure 5. Model showing the spatial interrelationships among eighteen source groups. The separations are proportional to the D^2 distance between pairs of groups. (Reproduced from *Archaeometry* 16 [1974]: 49)

[pp. 275-276]

assigned to the reference matrix in a similar way, and the likelihood of statistically correct association calculated. A high probability indicated the degree of confidence that could be placed upon an individual assignment, whereas a low probability could indicate that the sample had no place in the matrix because data from its actual source had not been included (Ward 1974a).

The three-phase statistical analysis was made practicable by computer processing. A paradigm for use in sourcing New Zealand obsidians was defined, in which comparable data from the analysis of artefact samples could be measured against the available reference matrix using a FORTRAN program (Ward (1974b). The method has been applied to artefactual material from the Chatham Islands (Leach 1973), Palliser Bay (Leach 1973; Leach and Anderson in press [1978]), Southland and Fiordland sites (Ward 1974a) and from Motutapu Island (Ward 1974c).

Investigation of Archaeological Obsidians

General Observations

Obsidian source deposits are restricted to the northern and central parts of the North Island of New Zealand; evidence of prehistoric Polynesian settlement, however, is widespread throughout these islands and the ubiquity of volcanic glass is well attested in site reports since the excavations of von Haast during the 1860s. More than 1500 km separates the northern extremities of the North Island from Stewart Island in the south, while the Chatham Islands are about 800 km east of the New Zealand mainland (Figure 6). Assemblages containing tools made from both flakes and cores, but mostly consisting of apparently unmodified flakes, vary in size from the single piece recovered by Coutts from an isolated southern Fiordland site to the more than 13 000 flakes and fragments counted by Shawcross at the Kauri Point swamp (Coutts 1969; Shawcross 1964).

Apart from the earlier measurements of refractive index made by Green, nearly five hundred analyses of obsidian samples from archaeological contexts have been made by geochemical techniques. These derive from only sixteen excavated sites and often represent only small and unsystematic samples. Considering the great wealth of excavated and unexcavated material remaining to be analysed, any general conclusions drawn from the data available must necessarily be viewed with some scepticism.

Archaeological Inferences from Characterization Data

The initial work of Green was concerned with archaeological material from the Auckland region. The refractive indices measured by him,

[pp. 276-277]

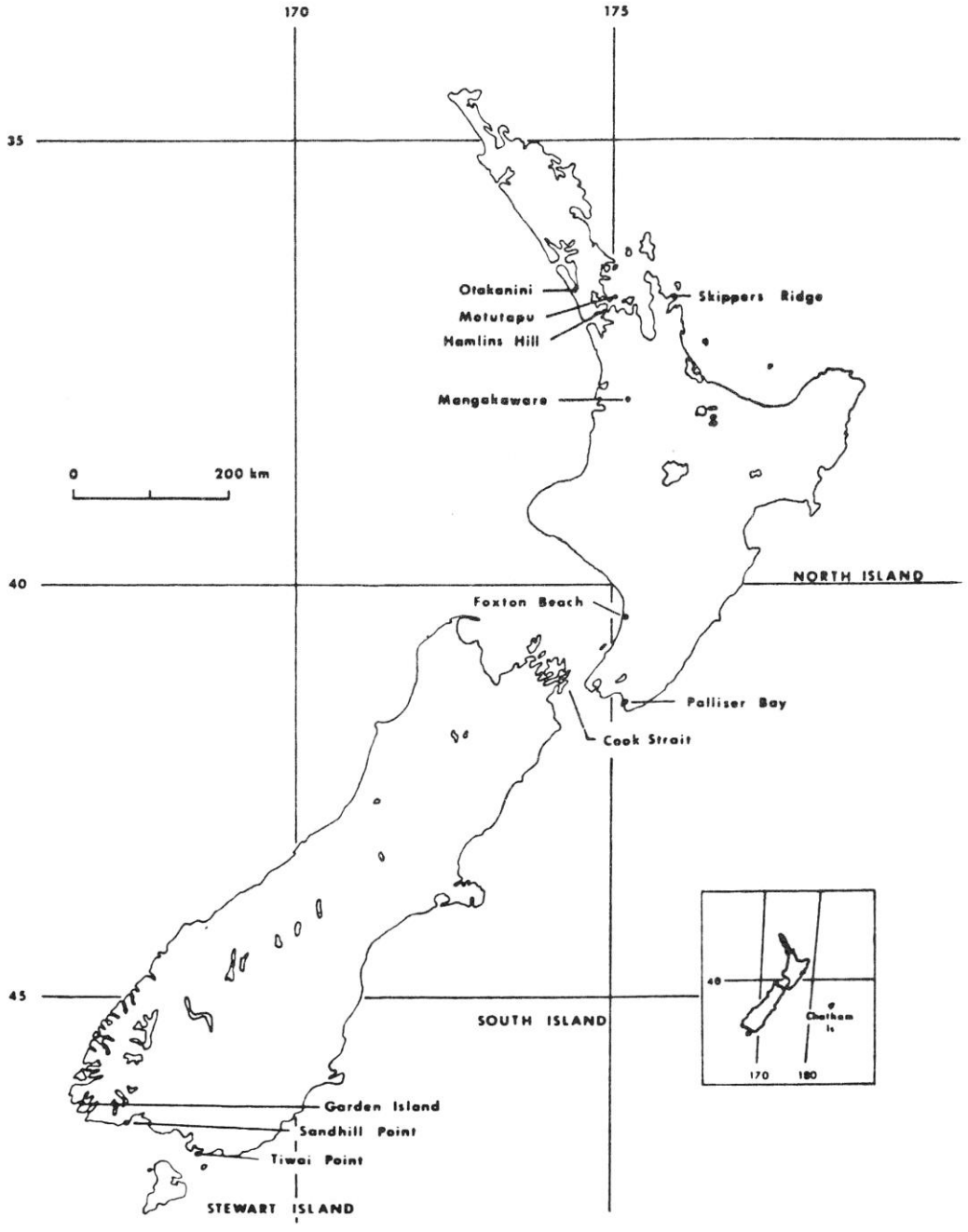

Figure 6. Map of New Zealand showing location of archaeological sites with obsidians identified by chemical analysis.

[pp. 277-278]

combined with hydration rim determinations (Green 1962; Ambrose and Green 1962) of the same excavated obsidian, allowed a number of primary inferences to be drawn regarding the pattern of exploitation of obsidian resources in the northern part of New Zealand (Green 1964, 1970).

One of the first results from this work was the rediscovery of three major obsidian sources – those at Te Ahumata on Great Barrier Island, at Whangamata near Lake Taupo, and at Huruiki in Northland – whose presence had been inferred from the pattern of distribution of archaeological obsidian which was incapable of being assigned to previously known geological deposits. Using the Mayor Island–non-Mayor Island differences in conjunction with the hydration rim measurements, Green established a relative chronology of sites in the Auckland Province showing the proportion of Mayor Island obsidian in their assemblages (Green 1964). From this it was clear that Mayor Island obsidian was the earliest to be widely exploited, and that subsequently, even with the discovery of other sources, it continued to form a large percentage of the obsidian assemblage, particularly in sites close to Mayor Island. In more distant areas, obsidians from closer deposits were discovered and came to constitute an almost exclusive component. The later Auckland sites, for example, contained material tentatively identified as deriving from Great Barrier Island. With the refinement of such a sequence of obsidian exploitation for each area, other sites could be placed within it and thus 'relatively dated'. The lowly obsidian flake was indeed beginning to fill its potential role as "the pottery of New Zealand archaeology" (Green 1964: 134).

Two major difficulties arose at that stage which arrested the development of this promise. The first related to the fundamental difficulties with the obsidian hydration method, particularly with the identification of those factors which influenced the rate of hydration. The suspicion that material of different chemical composition from different sources might hydrate at different rates was countered by using only obsidian from Mayor Island for this purpose; however, the great importance of ground temperature at each individual site was underestimated (Ambrose this volume [1976]). Secondly, the inadequacy of the Mayor Island–non-Mayor Island differentiation proved a severe limitation to the development of archaeological inference, especially when a narrower, regional focus was adopted. As has been seen above, attentions have turned to more accurate methods of characterization and the results from the application of chemical techniques of analysis have recently become available. The results of analyses of archaeological material are best considered on a regional basis, with reference to the site locations shown in Figure 6.

[pp. 278-279]

Auckland Region

Much of the data available relates to sites in the Auckland and Coromandel areas, reflecting the amount of excavation carried out there and the continuing interest in obsidian sourcing studies. A tentative pattern of use can be drawn from the seven archaeological sites studied so far. However, two qualifications must be made. Firstly, with few exceptions only small samples from the total obsidian assemblages have been analysed. Thus it is possible that more complete analyses may lead to modification or negation of the tentative conclusions drawn here. Secondly, temporal placement of sites within New Zealand's brief prehistoric sequence is still often problematical. Green's early multiphase subdivision of the sequence within the Auckland region (Green 1963 /1970) based largely on hydration-rim measurement, has yet to be reviewed systematically in the light of the re-evaluation of the obsidian hydration method, but it is inevitable that some changes will be required if different rates of hydration must be defined for material from each source and each archaeological deposit. Radiocarbon determination is often a grossly inadequate tool for the investigation of many problems of

New Zealand prehistory (Trotter 1968; Shawcross 1969). Nevertheless, attempts continue to be made to add further subdivisions to the basic Archaic/Classic Maori bipartition made by Golson (1959). The Auckland sub-division used here is modified from the discussion by Davidson of the Motutapu Island sites (Davidson 1972), into which other site assemblages have been fitted where temporal control is available.

At the Sunde site on Motutapu (Green 1964; Scott 1970; Davidson 1972), one piece of obsidian was found beneath the Rangitoto ash and attributed by Green to a Mayor Island source. Three pieces from above the ash were analysed chemically; two were identified as Huruiki obsidians, but the third was of unknown geological provenance (Davidson 1972; Reeves and Armitage 1973). Two further fragments were examined only by density measurement and tentatively assigned to Mayor Island and Huruiki. This information is summarised in Table 4.

The Mayor Island source was thus important at an early stage, suggesting that the conspicuous deposits of the island were particularly significant to early communities with a maritime orientation. The Huruiki source deposit is located several kilometres inland in an area showing signs of previous shifting cultivation; the presence of obsidian from here in the lower levels of the Sunde site indicates the significance of the subtropical Northland area to the initial settlement of New Zealand.

Intermediate phase sites in the Auckland area include those at Mangakaware (Bellwood 1969, 1972), and the Undefended Sites N38/30 and N38/37 at

[pp. 279-280]

Table 4. Identification of Archaeological Obsidians-Auckland Region Sources *

Sites		Sources					
		Mayor Island	Huruiki	Great Barrier Is	Whangamata (Taupo)	Cooks Bay (Whitianga)	Unknown
Early phase	**Sunde N38/24** Motutapu Island	2*	3**	-	-	-	-
	Ref: Scott 1970; Davidson 1972; Reeves & Armitage 1973						
Middle phase	**Undefended sites N38/37, N38/30**, Motutapu Island	2	6	52	-	1	-
	Davidson 1970a, 1972; Leahy 1970; Reeves & Armitage 1973; Ward 1974c;						
	Mangakaware N65/35 Waikato Basin 47,41,21	2	-	-	1	-	-
	Bellwood 1969, 1972; Armitage *et al*. 1972						
Late phase	**Hamlins Hill N42/137** Auckland Isthmus	-	-	2	-	-	-
	Davidson 1972; Reeves & Armitage 1973						
	Skippers Ridge N40/7 Coromandel 47,41,21	90	-	-	-	54	3
	Bellwood 1969, 1971; Armitage *et al*. 1972						
Phase unknown	**Otakanini N37/37** Kaipara Harbour	2	3	4	-	-	3
	Bellwood 1969, 1971, 1972; 1973; Armitage *et al*. 1972						

* Includes tentative identifications of one specimen by refractive index and one by density.
** Includes tentative identification of one specimen by density.

[pp. 280-281]

Station Bay on Motutapu (Allo 1970; Davidson 1970a, 1974; Leahy 1970). Mayor Island obsidian was identified at both places, but Whangamata (Taupo) material only at the former, while obsidians from Huruiki, Great Barrier Island and Cooks Bay near Whitianga are found at the Undefended Sites (Table 4). It is clear that a wider number of

sources were being exploited than at the early Sunde site. The Great Barrier Island and Cooks Bay deposits are short distances from their respective coasts and within a small compass of Motutapu (Table 7), but the Whangamata source locality near Taupo is relatively inaccessible in the volcanic plateau area of the central North Island. Perhaps the most significant point about material from various sources in relation to the sites is that the Great Barrier Island, Huruiki and Cooks Bay source localities are those most closely available to the Motutapu sites; the Mangakaware site is inland and closer to the Taupo source localities (Figure 2).

Later sites at Hamlin's Hill (Davidson 1970b) on the Auckland Isthmus and Skipper's Ridge on the eastern side of the Coromandel Peninsula (Bellwood 1969, 1972) show a similar pattern to that noted for the previous phase; the former site has obsidian from the adjacent sources on Great Barrier Island as well as glass (identified from hand specimens) from Mayor Island (Davidson 1970b) while the Skipper's Ridge assemblage, recovered only twelve kilometres from the Cooks Bay deposits, is divided between obsidian from these and from Mayor Island (Table 4).

There are also analyses from another site in the Auckland Region, Otakanini on the southern Kaipara Harbour (Bellwood 1969, 1971, 1972, 1973). Unfortunately, the small obsidian assemblage was recovered from a terrace which was not able to be tied stratigraphically, or chronologically, to the rest of the excavated and radiocarbon-dated deposits (Armitage et al. 1972; Bellwood 1972). The assemblage contained obsidian from the Northland and Hauraki Gulf source localities of Huruiki and Great Barrier Island as well as Mayor Island. Bellwood places adjacent archaeological deposits at ca 1300 A.D. (Period I) and 1427-1631 at one standard deviation (Period II/III). It might be noted that the Motutapu sites of the middle phase contain material from the same three sources; any further chronologically dependent discussion, however, should remain until more data are available.

Wellington Region

When one turns to a discussion of the sites in the Wellington region for which analyses are available, those at Palliser Bay (Leach and Leach 1971, 1972, in press [1979]; Anderson and Pricket 1972) and Foxton (McFadgen 1972), evidence is found of a different situation. For the purposes of this discussion, the Palliser Bay sites are divided, using a break in the dated

[pp. 281-282]

sequence, into those representing two phases of occupation: from the beginning of the twelfth century A.D. to the mid-fourteenth, and from there to within the last two hundred years. Table 5 shows the analyses that were made. Sites falling into the earlier of the two phases contain obsidian from the greatest number of source localities yet analysed, including that at Rotorua from which flake-quality material had not previously been identified, from the sources at Huruiki, Great Barrier Island, and two of the Coromandel source deposits at Cooks Bay and adjacent Purangi; as well as the ubiquitous Mayor Island obsidian, material from Whangamata was also confidently identified (Ward 1974b; Leach and Anderson in press [1978]).

A later phase of the sequence of occupation at Palliser Bay, and that on the southwestern coast of the North Island represented by the Foxton midden (dated 1520-1630 A.D. – Reeves and Armitage 1973: 561; McFadgen 1972) contain glass from fewer source localities. Whangamata, Purangi and Rotorua obsidian is absent from the later Palliser Bay assemblage; Foxton contains only Whangamata and Mayor Island material (Table 5). It is more difficult to know how to interpret these results. Was the Palliser Bay coast during the earlier phase of occupation recipient of visiting groups from several areas to the north, by both inland and coastal routes? Were the more permanent occupants at this distance from the source deposits pleased to trade for material from any area? Perhaps these settlements commanding Cook Strait and a rich hinterland were the centre

of considerable trade or conflict involving groups coming from several areas. The less extensively derived material in the later phase of occupation both here and at Foxton points to a more settled period of occupation. Further speculation must await the publication of reports by Leach and Leach and by others involved in these projects.

Southern Region

Further to the south, the early site at Tiwai Point (Park 1969) contains both Mayor Island and Taupo obsidian. Very small samples (Table 6) from the Southland and Fiordland sites of Sandhill Point, and Garden Island in Chalky Inlet (Coutts 1969, 1970) represent the presence of Mayor Island, Whangamata and Huruiki obsidian, while two obsidian tools from the Chatham Islands in the Otago Museum were found to derive from Mayor Island Deposits (Leach 1973). The widespread occurrence of Mayor Island and Huruiki obsidian no doubt reflects its importance throughout the prehistoric sequence of New Zealand, while the presence of glass from the Whangamata source localities near Taupo point to the greater importance of this obsidian to southern sites, if not to those in the Auckland region where more local sources were available.

[pp. 282-283]

Table 5. Identification of Archaeological Obsidians-Wellington Region Sources

Sites		Sources						
		Mayor Island	Huruiki	Whangamata (Taupo)	Cooks Bay (Whitianga)	Purangi	Rotorua	Unknown
Early phase	**Palliser Bay 1168 – 1313 a.d.**	118	8	5	24	2	1	8
	Ref: Ward 1974b; Leach & Leach 1971, 1972, in press [1978]; Anderson & Pricket 1972; Leach & Anderson in press [1978]							
Late phase	**Palliser Bay 1374 a.d. – < 178 b.p.**	26	2	-	6	1	-	-
	Leach & Leach 1971, 1972, in press [1978]; Anderson & Pricket 1972; Leach & Anderson in press [1978]							
	Foxton Beach 1520 – 1630 a.d.	6	-	3	-	-	-	-
	McFadgen 1972; Reeves & Armitage 1973							

Table 6. Identification of Archaeological Obsidians-Southern Region

Sites		Sources			
		Mayor Island	Huruiki	Whangamata (Taupo)	Unknown
Early phase	**Tiwai Point, Southland**	30	-	2	8
	Ref: Park 1969; Reeves & Armitage 1973				
Late phase	**Sandhill Point, Te Wae Wae Bay, Southland**	1	1	1	-
	Coutts 1969, 1970; Ward 1974b;				
	Garden Island, Chalky Inlet, Fiordland	1	-	-	-
	Coutts 1969; Ward 1974b;				
	Chatham Islands	2	-	-	-
	Leach 1973				

[pp. 283-284]

Table 7. Source-Site Distances Sources (approximate straight-line distances in kilometres)

Sites	Sources					
	Mayor Island	Whangamata (Taupo)	Cooks Bay & Purangi (Whitianga)	Huruiki	Te Ahumata & Awana (Great Barrier I.)	Rotorua
AUCKLAND REGION						
Motutapu sites	140	230	73	150	93	191
Hamlins Hill	132	220	76	158	90	185
Mangakaware	110	90	126	284	127	95
Skippers Ridge	82	215	12	114	57	154
Otakanini	200	285	144	120	112	173
WELLINGTON REGION						
Palliser Bay	485	330	645	680	590	387
Foxton	340	190	394	565	440	271
SOUTHERN REGION						
Tiwai Point	1220	1080	1245	1320	1295	1145
Sandhill Point	1245	1110	1270	1345	1305	1165
Garden Island	1260	1125	1285	1340	1305	1190
Chatham Islands	980	890	1040	1260	1120	920

[pp. 284-285]

Conclusion

The evidence of distribution of volcanic glasses in New Zealand, viewed broadly, points to a pattern of exploitation in which Mayor Island and Huruiki obsidian are widely spread throughout the prehistoric sequence; both provide flaking material of high quality from extensive deposits (Ward 1973) which were of easy access. It should be pointed out that hegemony over access at Mayor Island in particular was probably maintained by extensive fortifications on the island, as suggested by some earlier accounts (Gold-Smith 1885) and by the remains (Pos 1961, 1965) It must be seen as significant that in the earlier phases of the New Zealand prehistoric sequence a number of sources was exploited and distributed widely throughout the country and that, later, more local sources gained prominence. The inferences can be drawn that, following the initial settlement, little time elapsed before a wide area of both main islands was explored and significant resources became known and widely exploited; that subsequently whatever the cause-great territoriality developed, leading to the well-defined if often fluctuating borders observed during the protohistoric phase; and that this greater emphasis on more closely-defined territory promoted the greater utilization of more local resources.

In the evidence of obsidian source utilization there is support for a model of settlement (Green 1975; Golson and Gathercole 1962; Groube 1970; Green 1971) which portrays seafaring people, from a limited tropical small-island eastern Polynesian environment, rapidly developing a pattern of extensive exploitation on the New Zealand continental islands, involving new flora and fauna (including the flightless moa and large sea mammals) and a whole new suite of lithic materials. Following this, there occurs a longer period of consolidation in which larger settlements more fully exploit more local resources, and networks of exchange develop, perhaps involving more the movement of goods through adjacent group territory rather than the extensive ranging of smaller parties which was likely to have been the case earlier.

Core material from which the ubiquitous obsidian flake was struck was an important component of such an exchange network. The analytical data now becoming available will provide significant evidence for the further evaluation of models which seek to elucidate the process of adaptation of a tropical island culture to the very different resources present in the New Zealand continental island archipelago.

Acknowledgements

The permission of the editor of the *New Zealand Journal of Science* to reproduce Figures 3 and 4 is gratefully acknowledged. Figure

[pp. 285-287]

5 is reproduced by permission of the editor of *Archaeometry.* One of the authors (G.K.W.) is indebted to B.F. Leach for access to characterization data from Leach and Anderson (in press) and to Dr Leach, Department of Anthropology, University of Otago and W.R. Ambrose, Department of Prehistory, The Australian National University, for discussions.

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This article was contributed to a collection of papers edited by E. R. Taylor and published in 1976 as Chapter 14 (pp.259-287) of *Advances in Obsidian Glass Studies: Archaeological and geochemical perspectives*, Noyes Press, Park Ridge, NJ, details of which are provided below GKW December 2014

CONTENTS

Introduction
1. Science in contemporary archaeology *R. E. Taylor* 1

Part I: Advances in Hydration Studies

A. Basic Studies

2. Physics and chemistry of the hydration process in obsidians. I: Theoretical implications *Jonathon E. Ericson, John D. Mackenzie and Rainer Berger* 25
3. Physics and chemistry of the hydration process in obsidians. II: Experiments and measurements *Jonathon E. Ericson and Rainer Berger* 46

B. Hydration Rate Studies

4. Obsidian hydration rate determinations on chemically characterized samples *Jerome Kimberlin* 63
5. Intrinsic hydration rate dating of obsidian *Wallace Ambrose* 81
6. Empirical determination of obsidian hydration rates from archaeological evidence *Clement W. Meighan* 106
7. Variation in obsidian hydration rates for Hokkaido, Northern Japan *Yoshio Katsui and Yuko Kondo* 120
8. Basaltic glass hydration dating in Hawaiian Archaeology *Maury Morgenstein and Paul Rosendahl* 141

C. Technical Advances

9. Photographic measurement in obsidian hydration dating *Frank J. Findlow and Suzanne P. De Atley* 165
10. Calculations of obsidian hydration rates from temperature measurements *Irving Friedman* 173

Part II: Advances in Obsidian Characterization Studies

A. Regional Studies: Western Hemisphere

11. Prehistoric obsidian in California. I: Geochemical aspects *Robert N Jack* 183
12. Prehistoric Obsidian in California. II: Geologic and geographic aspects *Johnathon E. Ericson, Timothy A. Hagan and Charles W. Chesterman* 218
13. Chemical and archaeological studies of Mesoamerican obsidians *Fred H. Stross, Thomas R. Hester, Robert F. Heizer and Robert N. Jack* 240

B. Regional Studies: Eastern Hemisphere

14. Characterization studies of New Zealand obsidians: toward a regional prehistory *Roger D. Reeves and Graeme K. Ward* 259
15. Obsidian characterization studies in the Mediterranean and Near East *J. E. Dixon* 288

C. Technical Advances

16. SPECTRA: Computer reduction of gamma-ray spectroscopic data for neutron activation analysis *Philip A. Baedecker* 334

Contributors 351
Index 353
(pp. v-vi)