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The Ages of Pacific Obsidians from Fission Track Analysis

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ABSTRACT

Fission track ages are presented for volcanic glasses from New Zealand and the tropical Pacific. They range from 0.2 to 8.9 million years. Track density and uranium content were evaluated for their potential to identify the original sources of archaeological obsidian which has been transported as artefacts by prehistoric man. Of 33 types of obsidian collected for analysis only 11 could be accurately assessed. The remainder were unsuitable due to partial hydration, annealing or the presence of microlites. The technique therefore has only limited application to sourcing problems in Pacific archaeology but on occasion could be a decisive factor in identifying the source of individual artefacts. The high concentration of uranium in Pungaere obsidian from New Zealand raises the distinct possibility of its use for dating archaeological events during the last millennium with reasonable accuracy.
Keywords: OBSIDIAN, DATING, SOURCING, PACIFIC, NEW ZEALAND, FISSION TRACKS.

INTRODUCTION

Fission tracks are produced in glassy substances from the spontaneous fission of ^{238}U which has a decay constant of about 7.03×10^{-17} emissions per year. Two fragments of masses 70 and 160 are produced, and these are projected with considerable energy in opposite directions, their paths creating damage to the matrix. The number of tracks present varies with the concentration of uranium and the time which has elapsed since the glass was last annealed by heating. These tracks may be detected under high magnification after etching with hydrofluoric acid to increase track diameter. Uranium content in the sample is determined by measuring the track density of fission tracks artificially induced by exposing the sample to a measured dose of thermal neutrons ($^{235}U + n \rightarrow {}^{236}U$, immediate fission produces fragments of masses 95 and 140). The age since the obsidian was last melted may be determined as follows:

$$T = \frac{1}{\lambda_D} \log_e \left[\frac{\rho_s \lambda_D \sigma I \phi}{1 + \rho_i \lambda_F} \right]$$

Where T = Time elapsed in years

λ_D = Decay constant of ^{238}U by normal α emission = 1.552×10^{-10} year^{-1}

λ_F = Decay constant of ^{238}U by spontaneous fission = 7.03×10^{-17} year^{-1}
σ = Cross section of ^{235}U = 580×10^{-24} cm^2
I = Ratio of ^{235}U to ^{238}U = 7.252×10^{-3}
ϕ = Neutron flux dose per unit area (n cm^{-2})
ρ_s = Sample track density due to spontaneous fission (t cm^{-2})
ρ_i = Sample track density due to induced fission (t cm^{-2})

Previous work involving fission track analysis of obsidians in the Pacific has been minimal. In New Zealand there have been some geologically-oriented investigations. For example, Seward used fission track analysis to date a series of tephras in the Wanganui region (Seward 1976). Of more interest to the present discussion is the research by Rutherford in which he reported the results of research dating the Minden Rhyolites of the Coromandel Volcanic Arc using obsidians from deposits on Great Barrier Island, at Hahei, Paku Island, Bowentown and Mt Maunganui in the Bay of Plenty (Rutherford 1978). Some difficulty was experienced with the Paku Island sample because of perlitic fracturing and annealing. The results indicated progressively younger ages for the glasses from north to south along the Coromandel Arc; they concurred with potassium-argon dates, inferences drawn from palynological data and supported geomorphic evidence of succession.

OBSIDIAN AND ARCHAEOLOGY

Volcanic glass suitable for making sharp-edged stone tools during prehistoric times occurs as flows, in isolated bomb deposits, or as detrital deposits in at least 40 locations in the South Pacific (Smith, Ward and Ambrose 1977). The material was so highly valued that it became an important item of trade in both the Western Pacific (Ambrose 1976, 1978) and New Zealand (Leach 1978). This trade in obsidian, which began at least as early as 1500 BC in some areas, has been documented by establishing the source of fragments found in archaeological sites by analysis of properties which distinguish among those sources. Density, minor and trace element composition, and other physical and chemical properties have been utilised (for example, Leach and Fankhauser 1978).

The age at which obsidian tools were manufactured can be assessed by measuring the thickness of an hydration rim formed by water which has diffused into the surface newly exposed by the prehistoric artisan. This has been achieved by thin sectioning techniques and optical microscopy (Friedman and Smith 1960) and more recently by performing various nuclear reactions at the surface to reconstruct the diffusion profile (Leach 1977a), although neither of these methods has proved entirely suitable in New Zealand.

For the Pacific archaeologist, therefore, obsidian can offer a number of opportunities for studying the past: it is a guide to prehistoric technology and the means by which early man fashioned and used stone tools, it provides a means of evaluating prehistoric communication systems and economics, and it has the potential to be used to date directly prehistoric activities and archaeological sites.

To be of use in dating the events of prehistory, fission track dating requires that the stone tool must be annealed by heating to erase earlier tracks which have accumulated over geological time. Fission track analysis has only rarely been performed on Pacific archaeological obsidian. There are several reasons for this – one is that the decay constant for spontaneous fission is so low that the number of fission tracks which might be induced in archaeological samples would be very small.

The geological ages of different sources of obsidian also will vary and, indirectly, this can be of benefit to the archaeologist. If no subsequent overprinting by annealing has occurred, the original source of an obsidian tool may be discerned from fission track analysis given that the ages at which various deposits were formed are distinctive in the first place. There are two variables which are determined for each obsidian sample in the course of fission track analysis – track density and uranium content.

The technique of determining uranium content is not very precise (± 30%) and, if this information is already known by alternative more accurate methods such as "delayed neutron activation analysis" (Wall 1976), greater precision can be introduced into source discrimination. Thus, the identification of a type of obsidian is enhanced by considering separately both track density and uranium content, rather than combining them into an overall assessment of age. A similar conclusion was reached by Susuki, who was able to distinguish reliably among 17 Japanese obsidian sources using a combination of uranium concentrations and fission track age (Susuki 1970). This technique works very well except in the case of obsidians with phenocrysts (which prevent accurate track counting). Only two Japanese sources – Asama and Kozujima – pose this difficulty and, as they have similar uranium contents, alternative sourcing methods have to be applied. Their chemical compositions have been found to differ considerably (particularly in iron and calcium), and so prehistoric stone tools with phenocrysts are subjected to element analysis (Susuki 1974:446).

FISSION TRACK RESULTS

In a discussion of the results of the analyses of Pacific glasses it is useful to employ the differentiation between Oceanic and Circum-oceanic contexts made by Smith, Ward and Ambrose (1977).

Obsidian samples from 33 potential sources of both Oceanic and Circum-oceanic glasses in New Zealand and the tropical Pacific were examined for their suitability for fission track analysis. Localities from which most samples were derived are described by Ward (1973) and Smith, Ward and Ambrose (1977). The results of the analyses are set out in Table 1. Only 11 samples proved to be satisfactory. The remainder had to be rejected for one of several reasons, such as presence of flow banding or a dull appearance on a fresh surface. This latter feature is especially important because it usually indicates that the obsidian is partly hydrated or contains a significant proportion of microlites; this condition prevents accurate determination of fossil track density.

The fission track results are given in Table 2, and in Figure 1 each obsidian type is plotted in terms of its uranium concentration and spontaneous fission track density.

As can be seen from these results a useful degree of discrimination is obtained for six, perhaps seven, of the glasses when both uranium content and track density criteria are used. A relatively tight clustering of the remaining three New Zealand Oceanic glasses with that from the Rapanui source indicates a limitation of the technique.

GEOLOGICAL CONSIDERATIONS

The ages of obsidians and other silicic volcanic glasses are generally considered to be relatively youthful in terms of geological time; not only are they associated with younger volcanics but the glasses hydrate over time, becoming perlitic in character and spalling hydration products. The little evidence currently available would tend to restrict the occurrence of Pacific volcanic glasses to the Pliocene to Recent eras. The geological context in which the Banks Islands glasses occur, for example, called the Central Volcanic Chain of the New Hebrides, is entirely Pliocene to Recent in formation (Mallick 1973, Mitchell and Warden 1971), while those particular areas of andesitic vulcanism producing the glasses date from late in the Quaternary (Mallick 1973).

Some Oceanic glasses are even younger. The areas of peralkaline rhyolites which have produced the D'Entrecasteaux comendites "are Holocene in age and show a close spatial association with Quaternary andesitic volcanoes" (Smith, Chappell *et al.* 1977:231). Similarly, the Mayor Island obsidians derive from Holocene pantelleritic lavas, and the Kaeo pantellerites are found to overlie basalts of Plio-Pleistocene age (Smith, Chappell *et al.* 1977:231–233).

Other New Zealand obsidians are of Circum-oceanic affiliation and may be older, although it is doubtful that many derive from Tertiary strata. Evidence of Early

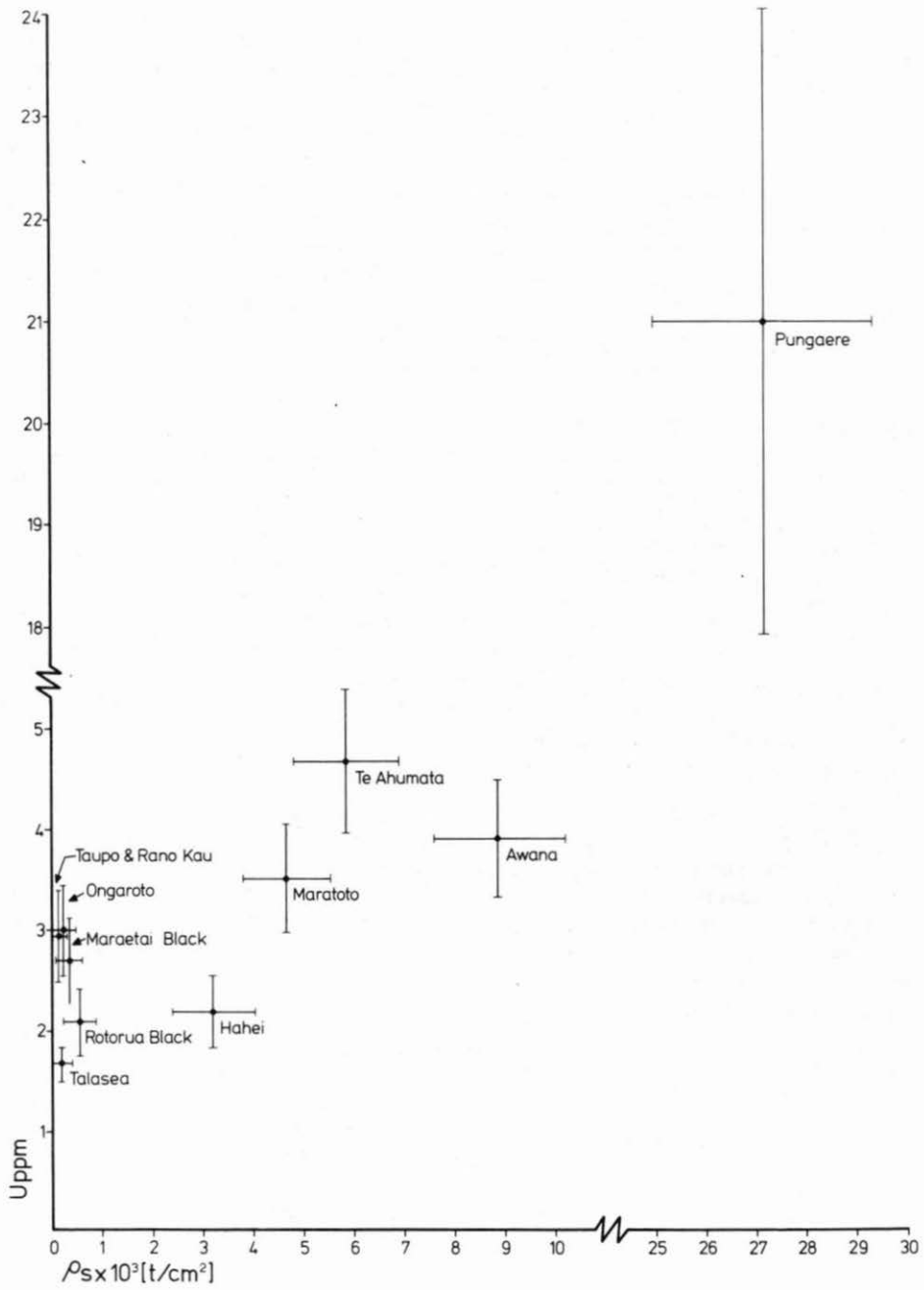

Figure 1: Uranium concentrations plotted against spontaneous fission track density for examples of New Zealand and Pacific island volcanic glasses.

TABLE 1

URANIUM CONTENTS OF NEW ZEALAND AND OTHER PACIFIC ISLAND OBSIDIANS EXAMINED FOR SUITABILITY FOR FISSION TRACK ANALYSIS

AREA	OCEANIC GLASSES		CIRCUM-OCEANIC GLASSES	
	Locality	U ppm	Locality	U ppm
	GROUP A: NEW ZEALAND			
NORTHLAND	Weta	12.0	Huruiki	3.4
	Waiare	28.1		
	*Pungaere	21.0(25)		
GREAT BARRIER			Fanal Island	2.5
COROMANDEL AND BAY OF PLENTY			*Awana	3.9(3)
			*Te Ahumata	4.7(4)
	Mayor Island[3]	4.0	Cooks Bay	2.8
			Purangi	2.8
			*Hahei	2.3(2)
			Tairua	2.8
			*Maratoto	3.5(3)
			Waihi[2]	2.9
TAUPO VOLCANIC ZONE			*Rotorua[2]	2.1(3)
			*Maraetai[2]	2.7(3)
			*Ongaroto	3.0(3)
			*Taupo	3.0(1)
	GROUP B: EASTERN PACIFIC			
RAPANUI	Maunga Orito	2.2		
	Motu Iti	2.1		
	*Rano Kau	3.0(3)		
	Te Manavai	2.6		
MARQUESAS ISLANDS	Tamaka, Ua Pou	?		
HAWAII	Puu Waawaa	1.5		
PITCAIRN	Down Rope	3.3		
	GROUP C: CENTRAL PACIFIC			
TONGA			Hala'utu, Tafahi	1.0
	GROUP D: WESTERN PACIFIC			
VANUATU			Tanna	?
BANKS ISLANDS VANUA LAVA			Losa Bay	2.7
			Lalngetak	2.7
BANKS ISLANDS GAUA			Lesalau	3.0
ADMIRALTY ISLANDS			Lou Island	3.9
NEW BRITAIN			*Talasea	1.7(1)
D'ENTRECASTEAUX	Igwageta	3.4		

Notes: Only those obsidians marked with an asterisk (*) were found to be suitable for dating (see text). Uranium concentrations appearing in the main body of the table were determined by neutron activation analysis by Leach and Warren (n.d.), and are averages of multiple samples (>5) from a source. Final values are ± 15%. In the case of Group D, however, the figures given are those obtained by delayed neutron activation analysis by Wall (1976) and are ± 10%. The value for Tafahi is that obtained by Smith, Ward and Ambrose (1977:191, Table 3). Figures appearing in parentheses (3), were obtained in the present study

by neutron induced fission track analysis. Some obsidian sources have several distinct varieties, and are indicated thus: [3] = 3 types.

Miocene andesitic vulcanism has been found in Northland and the Coromandel Peninsula; more extensive areas of Late Miocene dacite and rhyolite exist in eastern Northland along the Coromandel Volcanic Arc. Early in the Quaternary, andesitic vulcanism was succeeded by rhyolitic eruptions resulting from the propagation of the zone of deep faulting extending from south of Lake Taupo to White Island in the Bay of Plenty. In the last two thousand years there have been periodic eruptions from the andesite volcanoes in the central North Island (Grindley *et al.* 1959:10–11). Thus the three main areas of late silicic vulcanism (Northland, Great Barrier-Coromandel-Mayor Island and Rotorua-Maraetai-Taupo) are predominantly of Pliocene to Holocene age.

More recently, the silicic volcanics of the Coromandel-Bay of Plenty region have been relatively well dated by potassium argon determination and fission track analyses. Andesitic eruptives, over which lie the Minden Rhyolites, have K-Ar ages ranging from 16 to seven million years, and the results obtained from fission track analyses confirmed that the more recent rhyolites date to between approximately nine and two million years ago (Rutherford 1978). Again, the predominantly rhyolitic vulcanism of the Taupo Volcanic Zone is generally accepted to have been confirmed as Quaternary by recent evidence (for example, Nathan 1976).

The geological context of the Lou Island obsidians of the Admiralty Islands is very young, being the scene of major eruptions in the middle of this century, and most volcanics there have been described as being probably of Late Pleistocene to Recent ages (Smith 1974:334). The available evidence does not suggest anything other than Lower Tertiary or Quaternary derivations for other glasses from both Oceanic islands and Circum-oceanic volcanic areas (Smith, Ward and Ambrose 1977).

The lower boundaries of the Pliocene and Pleistocene are usually accepted as being of the order of seven and one million years ago respectively and the Holocene a mere ten thousand years ago. Against this background the fission track analyses presented in Table 2 can be evaluated. The data for the majority of the eleven suitable specimens place these glasses securely within the Quaternary but restrict them to the Pleistocene rather than the Holocene. The remaining results place five North Island glasses (ranging in age between 4.6 and 8.9 million years) into the Pliocene or even the Miocene. As predicted from the geological considerations outlined above, fission track dates provide a fairly consistent pattern in which the Coromandel Arc obsidians – those from the Awana, Te Ahumata, Hahei and Maratoto deposits – are the oldest, followed by the materials from the Taupo Volcanic Zone – the Rotorua-Maraetai-Ongaroto-Taupo area. The fission track age for the Pungaere obsidian is anomalous in light of the discussion by Smith and others (1977) of the probable Holocene age of the Kaeo glasses. Both the Oceanic glass from Rano Kau on Rapanui and the Circum-oceanic obsidian from Talasea are of the expected Pleistocene age.

The data derived here for uranium content (Table 1) also warrant comparison with previous results. In their review of potential sources of volcanic glasses throughout Oceania, Smith, Ward and Ambrose found that Oceanic glasses generally were high in uranium content (>5ppm), while Circum-oceanic glasses tended to be lower (<5ppm) (Smith, Ward and Ambrose 1977:190–191, Tables 1 and 2). This division can be usefully employed in summarizing comparisons in the present context. In Table 1, Oceanic glasses derive from the Kaeo area (Weta, Waiare and Pungaere), Mayor Island, Rapanui, Marquesas, Hawaii, Pitcairn and D'Entrecasteaux Islands; the bulk of the New Zealand obsidians and the remaining Western Pacific glasses are Circum-oceanic. The data for the uranium content of each as derived from the neutron activation analysis reported here shows that the Circum-oceanic glasses are typically low in uranium, ranging from 2 to 5ppm. The Oceanic glasses tend, on the average, to have a higher proportion of uranium but the results vary widely, from 28 to only 2ppm; the three Kaeo sources showing particularly high concentrations.

TABLE 2

FISSION TRACK RESULTS

Sample	A	B	C	D	E	F
Awana GT-831/1/1 DF-1659	8.9 (50)	1.3	57.5 (373)	9.60	8.9	1.30
Hahei GW-363 DF-1660	3.2 (18)	0.8	26.3 (166)	9.57	7.0	1.80
Maratoto GT-847 DF-1661	4.63 (26)	0.87	51.3 (157)	9.54	5.2	1.10
Maraetai Black GT-295 DF-1662	0.36 (2)	0.25	43.1 (122)	9.51	0.5	0.35
Ongaroto GT-367 DF-1663	0.36 (2)	0.25	40.9 (116)	9.48	0.5	0.35
Pungaere GS-561 DF-1664	27.20 (153)	2.20	423.0 (1264)	9.45	3.6*	0.30
Rano Kau 17503 DF-1665	0.18 (1)	0.18	48.9 (138)	9.42	0.2	0.20
Rotorua Black GS-959 DF-1666	0.53 (3)	0.31	50.7 (144)	9.40	0.6	0.30
Talasea 287 DF-1668	<0.20 (0)	0.20	19.4 (55)	9.34	<0.5	0.50
Taupo GT-440 DF-1669	0.18 (1)	0.18	43.3 (122)	9.31	0.2	0.20
Te Ahumata GS-148/1 DF-1670	5.87 (33)	1.02	70.3 (214)	9.28	4.6	0.90

Notes

A = $\rho_s \times 10^3$ tracks cm^{-2}

B = $\pm\sigma$ tracks cm^{-2}

C = $\rho_i \times 10^3$ tracks cm^{-2}

D = $\phi \times 10^{14}$ neutrons cm^{-2}

E = T x 10^6 Years

F = $\pm\sigma \times 10^6$ Years

( ) = Number of tracks counted

* = Annealing probable as the diameter of fossil tracks is less than that of induced tracks

DATING ARCHAEOLOGICAL ARTEFACTS

The key factor in using fission track analysis in New Zealand for archaeometric dating is whether there is a significant accumulation of tracks in the time involved. In New Zealand, there is little evidence for a prehistoric period older than a millennium, and in this time few tracks would be formed in normal types of obsidian artefacts. For

example, glass with 1ppm uranium which was annealed one thousand years ago would have a track density of approximately 500 tracks per cm^3 and, since during a microscopic scan only a few microns from the surface are observed, the scanning density would be about 0.3 tracks per cm^2 (Tite 1972:102). Because of this very low density a large area of the artefact would need to be searched to find sufficient tracks to yield reasonable dating statistics. This can, however, be done without massive damage to an artefact by removing a small fragment and carrying out repeated scanning of the sample after successive rounds of polishing and etching.

This technique has been successfully employed on Japanese obsidian tools and pottery glaze (Table 3). With one possible exception (where the putative true age could be incorrect), the results in this study were in close agreement with those predicted on other archaeological grounds. The statistical errors are high, however, even for the large areas scanned, largely due to the relatively low concentrations of uranium in the artefacts (approximately 3ppm). At the other end of the spectrum, some artefacts can have extremely high uranium content, notably uranium enriched glasses or pottery glazes. Some glasses have as much as 2.5% of uranium oxide (UO_3) added to the mix to induce desirable colours (Brill *et al.* 1964, Sheilagh and Haggith 1973). Table 4 shows the remarkable dating accuracy which can be achieved in these circumstances.

The fission track results for the obsidian types investigated here suggest that glasses from the Kaeo group of deposits could form the basis of an effective dating technique for New Zealand archaeologists since they have a moderately high concentration of uranium (12 to 28ppm). However, of the three potential sources of obsidian from this area, only the Pungaere glass was found suitable for fission track analysis (Table 1).

A further consideration is the definition of the baseline from which the analysis of fission tracking is made. To date a cultural event, as opposed to the geological origin, the glass must have been heated sufficiently to obliterate evidence of tracks before its use as an artefact. Artefacts which were accidentally annealed during their cultural life could be used for dating. Accidental annealing of glass occurs quite commonly in domestic situations; it may be detected readily by the microscopic surface crazing which results (Trembour 1976).

TABLE 3

JAPANESE ARCHAEOLOGICAL FISSION TRACK DATES

(Extracted from Suzuki and Watanabe 1968, and Watanabe and Suzuki 1969)

Specimen	A	B	C	D	E	F	G	H	I	J
1	15	3.2	350–400	37.9	175	4.62	1.00	1.8	5080 ± 400	3240–3900
2	15	3.1	350–400	47.6	44	0.92	0.16	0.3	1060 ± 160	990–1420
3	15	3.1	350–400	7.0	7	1.00	0.16	0.3	1150 ± 440	990–1420
4	25	3.3	350–400	71.0	25	0.33	0.75	1.8	520 ± 110	640– 780

Specimen 1: Obsidian spearhead. Specimen 2: Obsidian arrowhead. Specimen 3: Obsidian flake. Specimen 4: Pottery glaze.

A = Etching time (seconds) in 48% HF at 23°C
B = Uranium content (ppm)
C = Track Fading Temperature (°C)
D = Area Searched for fission tracks (cm^2)
E = Total Number of tracks recorded (N)
F = ρs (tracks per cm^2)
G = ρi (tracks per $cm^2 \times 10^{-5}$
H = ϕ (thermal neutron dose. neutrons per $cm^2 \times 10^{-15}$)
I = Age (years B.P.) using the simplified formula $T = 6.12 \times 10^{-3} \phi (\rho s/\rho i)$. The statistical error is simply $100 \sqrt{N}/N$
J = Expected Age (years B.P.) from C14 dates from similar or close cultural provenance.

Examples are recorded where obsidian tools have been vitrified in the intense blaze of early prehistoric house fires in New Zealand (Prickett 1974). In addition, annealing can take place on surfaces exposed to bright sunlight, and for this reason natural obsidian flows should be sampled from a fresh surface if fission track analysis is to be

performed (see Naeser, *et al.* 1980:2). In the course of its useful life, much exposure to sunlight of an obsidian tool can be expected and, in some, significant anealing might have resulted. There is good cause to believe that a reasonable proportion of obsidian artefacts will have the potential for archaeometric dating from fission tracks. After their incorporation into an archaeological site, further annealing effects can be discounted as soil is an excellent thermal insulator.

TABLE 4

FISSION TRACK DATES FOR URANIUM ENRICHED GLASSES
(after Brill *et al.* 1964:155)

Sample	A	B	C
1	0.61	139 ± 20	119–129
2	0.44	119 ± 18	79–104
3	2.50	55 ± 07	51– 54
4	1.21	41 ± 06	>40
5	5.30	34 ± 04	36*

Notes
Sample 1 New England Candlestick
2 French or Bohemian footed beaker
3 Steuben "Topaz" wineglass
4 Commercial glass tubing
5 Experimental uranium enriched glass

Column A Uranium (UO_3) content (wt %)
B Fission Track Age (Years B.P.)
C Expected Age in years B.P.
* Certain age

APPLICATION TO NEW ZEALAND ASSEMBLAGES

In applying this analysis to the New Zealand situation, it is first necessary to screen any archaeological assemblage for artefacts made from Pungaere obsidian. This can be done in two steps. Firstly, the entire assemblage may be sorted for those with high uranium content. Secondly, Pungaere material must be separated from the other two Kaeo glasses high in uranium content. The first step can be accomplished fairly rapidly by using a scintillation counter to detect the β particles deriving from the breakdown of uranium (Leach *et al.* 1977), and for most archaeological sites this will reduce the assemblage by 90 to 100%. The three types of Kaeo obsidian all have high uranium contents; their chemical compositions, however, differ in significant aspects. In the second step the Pungaere material can be identified, using energy dispersive XRF analysis, by its distinctive rubidium and arsenic values (Leach 1977b). All remaining artefacts can then be examined using a low power microscope for evidence of surface crazing and these can be used for fission track determination.

In Figure 2 the statistical dating error is plotted for the New Zealand prehistoric period using the two search areas of 7 and 71cm² which constitute the range used by Watanabe and Susuki (1969) in their study of archaeological artefacts.

It can be seen from the figure that for the higher of these search areas, the errors range from about ± 16 to ± 50 years over the age range 100 to 1400 years. This of course would be very acceptable, although the length of time required in microscopic scanning is considerable (approximately 1cm² per hour).

CONCLUSION

Using fission track analysis, New Zealand and other Pacific obsidians are not as easy to distinguish among as their counterparts in Japan – only six of the eleven sources assessed are clearly different from one another and the remaining five are tightly clustered together. The Pungaere obsidian stands out on its own, largely as a result of

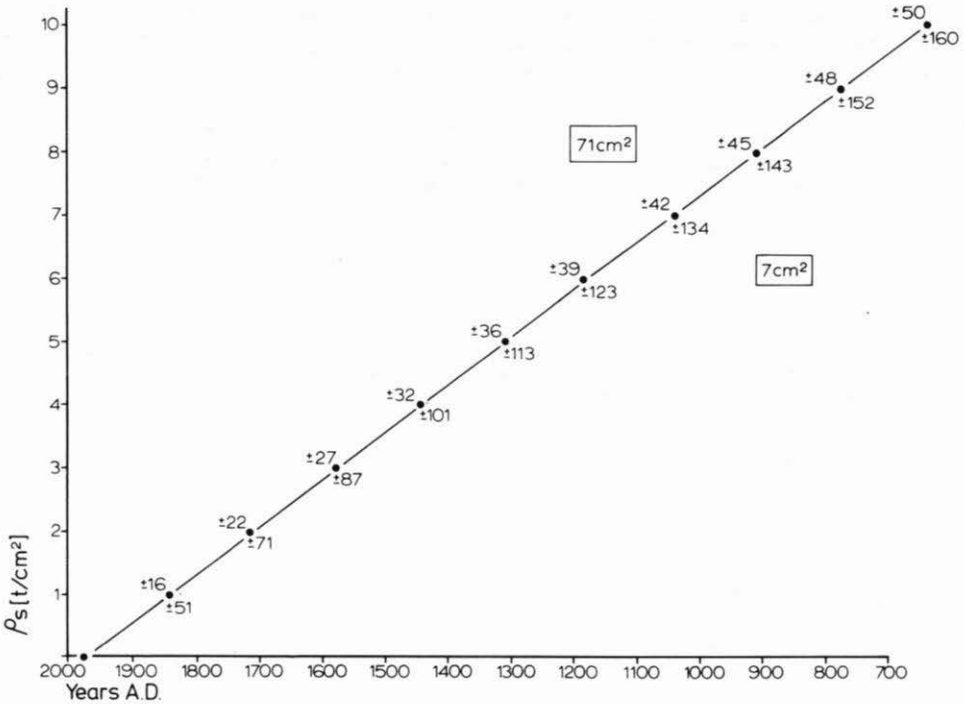

Figure 2: The theoretical dating error in years for Pungaere obsidian artefacts for two different areas searched for fission tracks. These areas correspond to the range searched on artefacts by Watanabe and Suzuki (1969).

its high uranium content. Artefacts made from this source of obsidian which were accidentally annealed during prehistory can be dated with reasonable precision by fission track analysis.

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