Journal of the Royal Society of New Zealand

ISSN: 0303-6758 (Print) 1175-8899 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzr20

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To cite this article: (1991) The age and stratigraphic significance of sea-rafted Loisels Pumice in northern New Zealand, Journal of the Royal Society of New Zealand, 21:4, 357-371, DOI: 10.1080/03036758.1991.10420833

To link to this article: http://dx.doi.org/10.1080/03036758.1991.10420833

© *Journal of the Royal Society of New Zealand,*
Volume 21, Number 4, December 1991, pp 357–371

The age and stratigraphic significance of sea-rafted Loisels Pumice in northern New Zealand

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Loisels Pumice is a sea-rafted pumice of uncertain origin, found on the east coast of the North Island of New Zealand. Since a radiocarbon age range was compiled from different and indirectly dated pumice layers by McFadgen (1982), Loisels Pumice has been used as a stratigraphic marker layer of known age in late Holocene coastal deposits. We contend that the date of primary deposition has been incorrectly determined and applied. We examined field sections from the far north of the North Island to identify and date the primary deposition of Loisels Pumice and to describe the physical characteristics and value of such a deposit. We also critically examined sites identified in the literature. Only one deposit was potentially primary, and the age of pumice deposition could be closely bracketed. From this section, we propose an age range of 915-1030 cal AD for the first stranding of Loisels Pumice in northern New Zealand. Analysis of sections shows that stratigraphic and geomorphic interpretation may be used to identify sites with the potential to be primary, but primary and secondary deposits cannot be identified by descriptive statistics. We conclude that the age of first stranding of Loisels Pumice cannot be reliably derived by compiling an age range bracket using maximum and minimum dates from different sections. Loisels Pumice should not be used as a coastal marker layer to establish synchrony between sites, and recent interpretations based on this method should be re-appraised.

Keywords: coastal landforms, pumice layers, marker layers, radiocarbon dating, geomorphology, archaeology, Holocene, deposition

INTRODUCTION

Loisels Pumice is a late Holocene sea-rafted pumice identified in coastal locations of the North Island (Wellman, 1962). It is distributed from Twilight Beach near Cape Reinga in Northland, along the length of the east coast of the North Island, to west of Cape Palliser in south east Wairarapa (McFadgen, 1985; Fig. 1). It is found as deposits in coastal dune sections, as lag deposits in dune deflation hollows, or as reworked material lying at or above high water mark. The pumice was first described and named by Wellman (1960, 1962) after Loisels Beach on the East Coast where it was first recognised, but it is most abundant at the extreme north of the North Island (McFadgen, 1985). It is typically dense, hard and grey in colour, with dark and light banding (Pullar *et al.*, 1977). It has a hypersthene-augite-labradorite mineralogy quite distinct from New Zealand-sourced pumices such as Taupo Pumice or Kaharoa Ash (Froggatt and Lowe, 1990) (Table 1).

Despite previous attempts (Wellman, 1962; Pullar *et al.*, 1977; McFadgen, 1982), the age of primary Loisels Pumice has not been conclusively determined. Furthermore, a volcanic source for the pumice has not been found. One potential source for Loisels Pumice is one of the active seamounts on the Tongan ridge. These are known sources of drift pumice (Smithsonian Institution, 1981) and pumice believed to be from the March 1984 eruption of Home Reef (31° 31'S, 177° 11'E) (Volcanological Society of Japan, 1987) has been found on

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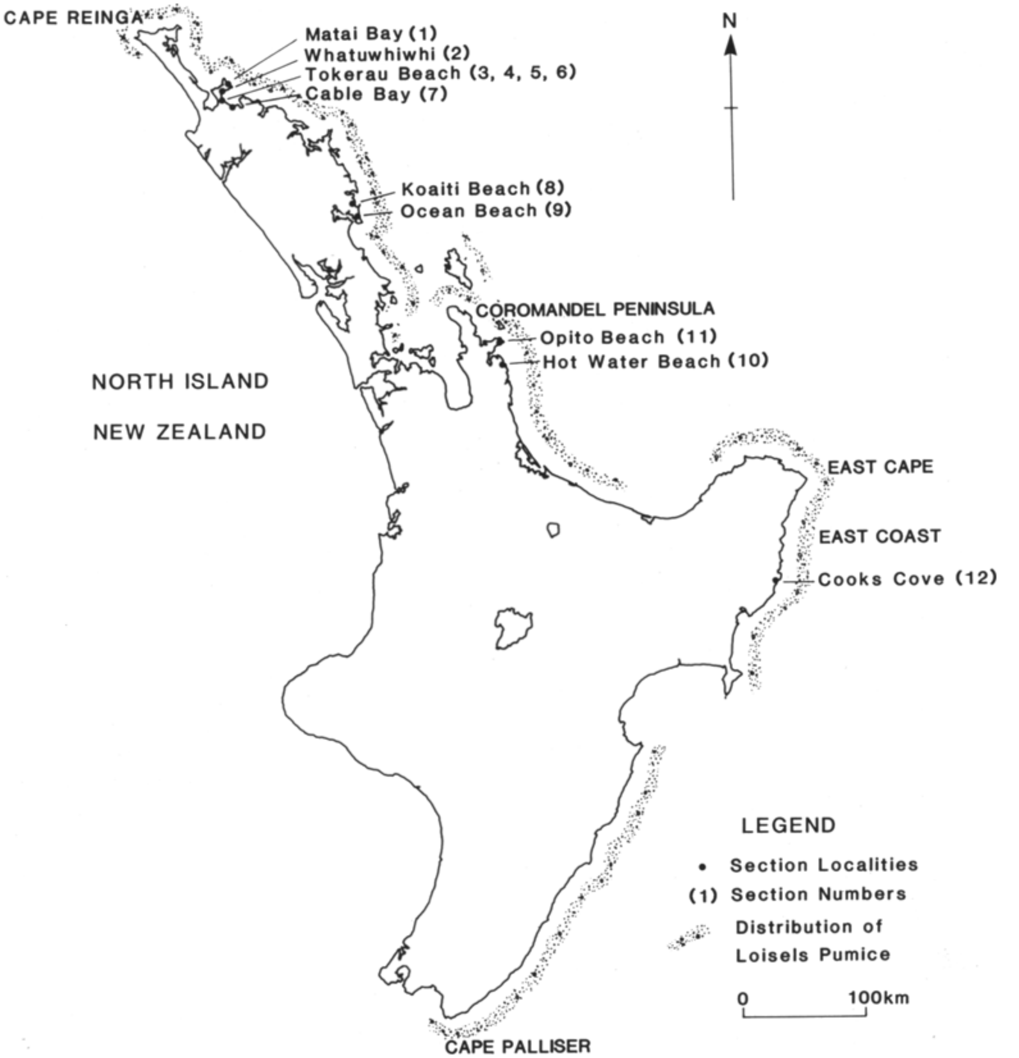

Fig. 1 – The distribution of Loisels Pumice (following McFadgen, 1985), and locations of sections, North Island , New Zealand.

beach strandlines on the east coast of the North Island since late April, 1985. Yet the distribution of Loisels Pumice differs from Home Reef Pumice, as the latter was rafted to many locations in the Pacific and Loisels Pumice has been found only in New Zealand. Loisels Pumice may have originated from another, unidentified Pacific Ocean source to the east of New Zealand from which currents did not carry pumice rafts to land masses other than the North Island.

Following the publication of a date for the arrival of Loisels Pumice by McFadgen (1982), it has been used in geomorphology and archaeology as a stratigraphic marker layer of known age in late Holocene coastal deposits. McFadgen (1985) employed Loisels Pumice layers to produce a generalised chronostratigraphic relationship between sea-rafted pumices, buried soil sections and evidence of human habitation in the form of occupation layers. McFadgen (1989) considered sea-rafted pumices invaluable for correlation between coastal deposits, and provided the best evidence for chronostratigraphic interpretation for the east coast of the North Island, south of Auckland. The use of Loisels Pumice was advocated by McGlone

Table 1 – Microprobe analyses on glass from pumice samples (%) (mean of 'n' separate analyses), undertaken and reported by Dr P. Froggatt, Research School of Earth Sciences, Victoria University of Wellington

	Tokerau Sample[1]	Loisels Pumice[2]	Kaharoa Ash[3]	Taupo Pumice[4]
SiO_2	72.38	68.23	78.21	77.23
Al_2O_3	14.54	17.20	12.53	13.27
TiO_2	0.49	0.59	0.06	0.26
FeO	3.70	3.44	0.75	1.93
MnO	0.15	0.12	-	-
MgO	0.64	0.75	0.07	0.25
CaO	3.50	5.19	0.50	1.20
Na_2O	3.54	3.66	3.81	3.32
K_2O	0.85	0.66	4.02	2.52
Cl	0.23	0.17	-	-
Water	3.50	0.65	2.63	2.05
n	21	6	11	9

[1] Mean of analyses on three pumice clasts from Tokerau Beach
[2] "Typical" Loisels pumice from Wairarapa coast
[3] Sample from near source (Mt Tarawera)
[4] Sample from type section, Taupo

(1989) to provide more reliable synchrony between late Holocene buried soils than direct dating of the soils themselves. The depositional chronosequence of selected eastern Coromandel coastal embayments were interpreted by Abrahamson (1987) from stratigraphies containing Loisels Pumice and other tephra.

McFadgen (1982) derived an age range of 1270 AD to 1441 AD for Loisels Pumice (note: dates used by McFadgen have here been updated to new calibrations; McFadgen and Manning, 1990). Information was compiled from four different coastal sections containing Loisels Pumice, at which the relationships between depositional events were recorded stratigraphically. Radiocarbon dates from material found above or below pumice in coastal dune deposits indirectly dated the stranding of the pumice at that particular site. Material found above pumice was used as a minimum age for the pumice, that found below was used as a maximum age. The oldest minimum date and the youngest maximum date of the combined sites were used to bracket the age-range of Loisels Pumice. Overlap in the age-range of these dates best defined the age of Loisels Pumice.

Wellman (1962), while describing a coastal reconnaissance of the North Island, first made the distinction between *primary pumice*, which came onto the shore suddenly and in abundance shortly after eruption events, and *secondary* (or *reworked) pumice* which was deposited later as a result of erosion of pumice layers stored in coastal deposits. Although primary and secondary deposits were noted by both Wellman (1962) and Pullar *et al.* (1977), this distinction was not made by McFadgen (1982) when deriving his age bracket on the first arrival of Loisels Pumice. He states that "*all indirect dates are considered*" to procure the age range of an indirectly dated event.

The conceptual distinction between primary and secondary deposits is, however, critical when deriving a date for the arrival of sea-rafted pumice. It is preferable that primary, and not secondary, pumice deposits are dated. A radiocarbon age bracket on a secondary deposit at best dates the time of secondary deposition. Viewed simply, secondary deposits are liable to form at any time between primary deposition and the present.

A radiocarbon date from material with a negligable inbuilt age, which is stratified above any Loisels Pumice deposit, will provide a minimum date of primary deposition. But this age will not represent the primary deposition of pumice if reliable older minimum dates exist at other sites. McFadgen (1982) correctly states that, for the purpose of dating drift pumice, all reliable minimum ages should be appraised and then all but the oldest minimum date discarded.

A date from material stratified below any Loisels Pumice deposit will provide a maximum age for pumice deposition at that site. However, not all maximum ages date primary Loisels Pumice, as assumed by McFadgen (1982). If all indirect ages are taken into account, maximum dates on some secondary deposits may significantly post-date older minimum dates at other sites. In such circumstances, bracketing of sea-rafted pumice by indirect dating is quite impossible. Furthermore, the risks of dating a secondary deposit which does not represent primary deposition are compounded by selecting the youngest maximum date for use as a bracketing parameter without considering that it might be secondary.

To derive the best estimate of the age of Loisels Pumice, a primary (or as close as possible to primary-aged secondary) deposit must be dated. The oldest minimum age, is then, the critical variable in bracketing the pumice layer. The best minimum ages will be from datable material directly ovelying the pumice layer with a negligable inbuilt age.

The most reliable maximum age bracket of sea-rafted pumice dates the same depositional event as the oldest minimum age. Thus the best maximum date is derived from the same section as the oldest minimum date, has a negligable inbuilt age and is located closely beneath the pumice deposit. Only by making the assumption that pumice from different sections were concurrently deposited can maximum dates from other sections can be employed.

We suggest that Loisels Pumice should not be used as a stratigraphic marker layer for coastal deposits as was done by McFadgen (1985) and others. As sea-rafted pumices are reworked, a range of ages will develop between sites. Potentially, there are many secondary Loisels Pumice layers on the northern coast of New Zealand, with many different ages of deposition represented in the sections in which they are found. This pattern presents grave difficulties for anyone hoping to use such deposits as marker layers. It is exactly this type of variability which led Pullar *et al.* (1977) to state that "Because sea-rafted pumices can be moved again by the sea after their initial deposition on the shore they are of much less value than air-fall tephras as time markers". Variability in the stratigraphic position of Loisels Pumice between coastal sections is demonstrated by its ambivalent and confusing stratigraphic relationship with the late Holocene air-fall tephra Kaharoa Ash (Pullar *et al.*, 1977).

We are concerned that, since the general adoption of McFadgen's (1982) age-range of Loisels Pumice, the problem recognised earlier by Pullar *et al.* (1977) appears to have been dismissed or forgotten. Loisels Pumice has subsequently been used as a easily identified coastal marker layer of an assumedly uniform age between sites of deposition (McFadgen, 1985, 1989; Abrahamson, 1987).

We consider that Loisels Pumice cannot be used as a marker layer between sites, and that an accurate estimation of the date of the first arrival of Loisels Pumice has not been made. The only value of indirect radiocarbon dating on Loisels Pumice layers is thus to define the time of its primary or secondary deposition at the specific location being investigated.

The aims of this paper are: (1) to identify the earliest deposition of Loisels Pumice; (2) to date this deposition in order to determine its primary arrival in northern New Zealand; (3) to describe the geomorphic and stratigraphic characteristics of primary and secondary deposits; and (4) to determine the value of Loisels Pumice as a marker layer in coastal sequences.

METHODS

Field investigation of sections containing Loisels Pumice was undertaken on the east coast of Northland where the pumice is abundant. We identified from a literature review the sites of sections described as primary or interpreted as potentially primary (Wellman, 1962; Pullar *et al.*, 1977; Millener, 1981; McFadgen, 1982), and re-examined them. We also located and investigated new Loisels Pumice layers with primary potential. All field locations are listed in Table 2. We re-appraised the sections used by McFadgen (1982) to derive a date on the arrival of Loisels Pumice through critical examination of the literature.

Table 2 – Location, classification and analyses of Loisels Pumice sections. Section classification: A. Site field-inspected and described in this paper; B. Site cited in literature, not field-inspected, radiocarbon date(s) used; C. Site cited in literature, but not located in the field.

Section No.	Location	NZMS 260 Grid Ref	Reference	Classification of Section	Mineralogical analysis	^{14}C dated
1	Matai Bay, Northland	O03 485078 (1983)	Wellman (1962)/This paper	A	X	X
2	Whatuwhiwhi, Northland	O03 485022 (1983)	Wellman (1962)	C	X	-
3	Tokerau Beach, Northland	O04 448983 (1984)	Millener (1981)	B	-	X
4	Tokerau Beach, Northland	O04 449982 (1984)	This paper	A	X	X
5	Tokerau Beach, Northland	O04 449981 (1984)	This paper	A	X	X
6	Tokerau Beach, Northland	O04 470934 (1984)	This paper	A	X	X
7	Cable Bay, Northland	O04 558899 (1984)	Wellman (1962)	C	X	-
8	Koaiti Beach, Northland	Q07 495084 (1984)	Pullar *et al.* (1977)	C	X	-
9	Ocean Beach, Northland	Q07 514979 (1984)	Pullar *et al.* (1977)	C	X	-
10	Hot Water Beach, Coromandel	T11 621753 (1983)	Leahy (1966)	B	-	X
11	Opito Bay, Coromandel	T10 598952 (1983)	Green (1963)	B	-	X
12	Cooks Cove	Z17 763997 (1983)	Wellman (1962)	B	-	X

During October, 1988, four sections containing Loisels Pumice were surveyed, described and sampled. Horizontal and vertical distances were surveyed by theodolite to mean high water (M.H.W.), estimated by the position of storm strand-lines. In the laboratory, mean particle roundness was determined using the classification of Powers (1953). Graphical grain size statistics (Folk and Ward, 1957) of pumice deposits were calculated after sieving. Pumice identification was determined mineralogically by P. Froggatt, Research School of Earth Sciences, Victoria University of Wellington, using electron microprobe analyses of glass in pumice samples and verified by the observation of distinctive macroscopic characteristics.

Radiocarbon analysis of marine shell was undertaken by the Radiocarbon Laboratory, Institute of Nuclear Sciences. All radiocarbon dates are corrected to produce a calibrated years AD estimation for comparison with dated material from other sections (Stuvier and Reimer, 1986; Stuvier *et al.*, 1986; McFadgen and Manning, 1990). Calibrated radiocarbon dates are presented in the form of a 95% confidence interval to allow for the statistical uncertainty of radiocarbon ages over the relatively short time frame being examined (following McFadgen, 1982). The age of a Loisels Pumice deposit was deemed to be unknown until it had been dated indirectly at that site. Sampling for radiocarbon dating was undertaken, where possible, by bracketing above and below each pumice layer as the most accurate method of determining the age of the depositional event. Where it was not possible to bracket, datable material within the pumice deposit was sampled for radiocarbon dating.

RESULTS

Field Sections

Section 1. Matai Bay

The section at Matai Bay (Table 2; Fig.2) was first identified and examined by Wellman (1962) and a radiocarbon date of 1205-1295 AD (Table 4, N.Z. 396) was obtained on charcoal within an occupation layer immediately beneath Loisels Pumice. This date was adopted by McFadgen (1982) to derive a maximum age bracket for the first arrival of Loisels Pumice. However, Wellman (1962) considered the section unreliable, as it extended laterally for less than 3.5 m. Pullar *et al.* (1977) interpreted Wellman to mean that the section was secondary. We decided to re-examine the section.

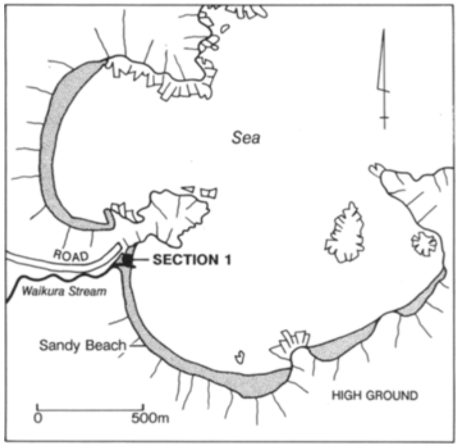

Fig. 2 – The location of Section 1 at Matai Bay.

Matai Bay is a 1.5 km wide headland-bay system on the northeast coast of Karikari Peninsula. The section is located at the northern end of Waikato Bay (the southern of the two bays), bordering a small stream and within a soil profile incised into a low bank. Hand specimens of pumice in this section conformed with the descriptive characteristics of Loisels Pumice, and samples were mineralogically identified as Loisels (Froggatt *pers comm.*, 1989). In stratigraphic section (Fig.3) soil overwash covers the pumice. An occupation layer of soil, small fragments of shell and hangi stones grade directly into the top of the main deposit. The pumice deposit is 20 cm thick, contains sparse shell fragments and is perched on sand above the backshore. The base of the pumice is low with respect to sea level, and it could have been

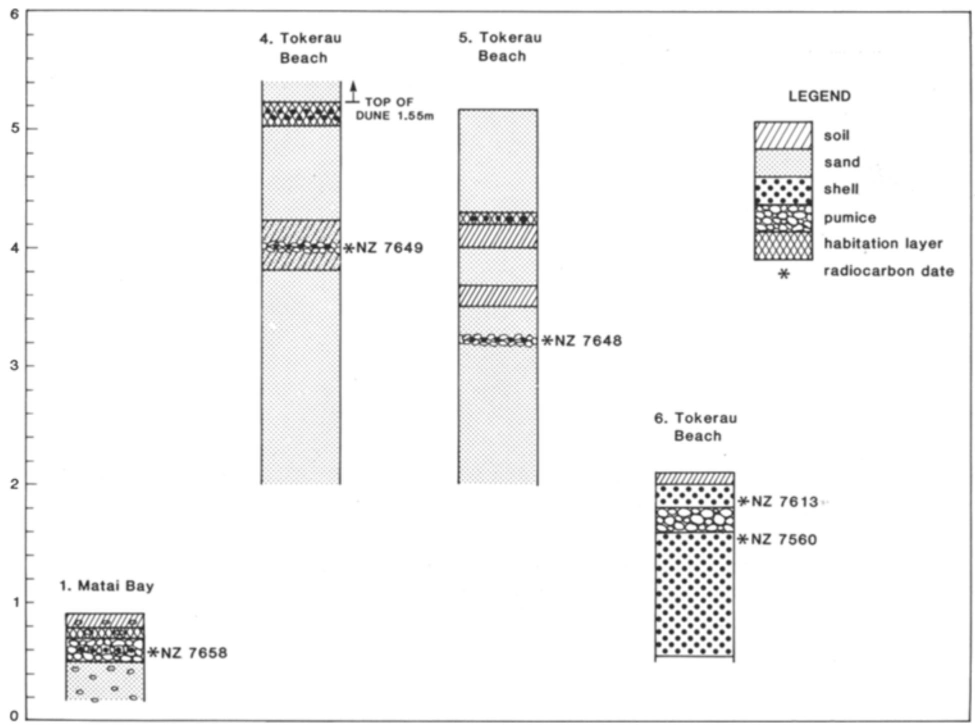

Fig. 3 – Simplified stratigraphy of field-inspected sections, and positions of radiocarbon date samples.

Table 3 – Descriptive statistics of pumice layers in field sections. Roundness classified by Powers (1953); mean grain size, sorting and skewness as defined by Folk and Ward (1957). [phi = $-\log_2$ (mm)]

Section no.		Distance to est. MHW (m)	Height above est. MHW (m)	Mean roundness class	Range of grain size by class (phi)	Mean grain size (phi)	Sorting	Skewness	Deposit thickness (cm)
1	Matai Bay	25	1.0	round	-7.0 to -0.5	-6.56	1.39	1.91	20
4	Tokerau Beach	29	4.0	sub-round	-5.5 to -1.0	-3.97	0.90	-0.02	5-10
5	Tokerau Beach	33	3.2	round	-6.5 to 0.0	-4.45	1.62	-0.34	5-10
6	Tokerau Beach	39	1.6	sub-round	-6.0 to -1.0	-4.44	1.13	0.02	20-22

deposited under wave conditions of moderate magnitude. The location and level of the deposit make it prone both to fluvial and marine erosion and to reworking. Small particles of pumice, identified as Loisels (Froggatt, *pers comm.*, 1989), are distributed throughout the whole section, both above and below the main pumice layer. This pattern indicates that the pumice layer is unlikely to be primary, as the smaller pumice particles spread throughout the lower area of the section chronostratigraphically pre-date it.

The main pumice layer contains some of the largest documented individual clasts of Loisels Pumice. A few very coarse clasts in the section leads to a coarse mean grain size. Grain size is strongly positively skewed, reflecting a tail of fine material. Sorting is poor and pumice sub-rounded in mean form (Table 3). Wellman (1962) suggested that sea-rafted Taupo Pumice which was deposited immediately after its eruption was generally much thicker and coarser than younger, reworked deposits. If this interpretation is adopted, the coarser clasts found in this section could be primary. Alternatively the presence of coarse clasts in Section 1 could be due to the relatively low level of the deposit above M.H.W., irrespective of whether they are primary or reworked. The stratigraphic location of fine particles of Loisels Pumice below the main pumice layer is a strong indicator that the deposit has been disturbed and is secondary.

Shell from the pumice layer was radiocarbon dated to 1425–1675 AD (Table 4, N.Z. 7658). Dated shell comprised small, scattered fragments of mixed species which may have died some significant time before incorporation in the pumice horizon. Such broken shell assemblages are potentially poor sources of radiocarbon dates, due to their uncertain depositional history (Neilson and Roy, 1981).

Tokerau Beach

Tokerau Beach is a 10 km long, arcuate beach on the eastern flank of Karikari Peninsula. It is backed by a Holocene-aged system of aeolian sand dunes and marine deposited shell ridges. This area was identified by Wellman (1962) as valuable for potentially primary Loisels Pumice. Millener (1981) noted pumice lag up to 200 m inland of the present beach. Sections of Loisels Pumice are present in many foredune exposures lacking datable material.

Section 4, Tokerau Beach

The section is located in a foredune 60 m north of a stream, near D.Urlich Road and approximately midway along the beach (Table 2; Fig.4). The location is conceivably within the range of fluvial meandering, but it is likely to have been exposed by wave-cutting of the dune base. Oxidisation of sand comprising the dune core suggests that it has been stable and the pumice layer emplaced for some time.

The section (Fig.3) contains a habitation layer above the pumice deposit, from which shell and rock have spilled down the dune face. There is no indication that this material has contaminated the pumice, and no evidence of anthropogenic disturbance within the pumice layer. A thin band of pumice, typically dense, hard, banded and grey, and mineralogically identified as Loisels (Froggatt *pers comm.*, 1989), is enveloped within a weak, buried soil horizon which can be traced for 8 m along the dune. This enveloping horizon is interpreted as a natural dune surface, which remained stable long enough for soil development to commence before it was buried under fresh sand. Storm-tossed shell mingles with and immediately underlies the pumice.

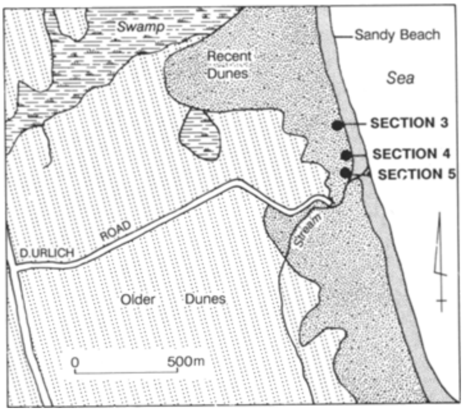

Fig. 4 – The locations of Sections 3, 4, and 5, central Tokerau Beach.

The pumice deposit is homogeneous; skewness is near-symmetrical and sorting is moderate; mean grain size is relatively fine and coarse clasts are absent (Table 3). The range of grain sizes is also small compared with other sites. Clasts are sub-rounded in mean form. Finer mean grain size does not preclude the deposit from being primary. The high-magnitude wind or wave conditions required to deposit the pumice at almost 4 m above M.H.W. would have preferentially transported and deposited fine material. The section is prone to coastal erosion in that it is protected from wave attack only by a small incipient foredune.

We cannot reach any conclusion as to whether the pumice layer is primary or secondary on the basis of geomorphic evidence. A maximum age is derived from shell identified as *Paphies (Mesodesma) subtriangulata* (Powell, 1976) from within the pumice layer. This was radiocarbon dated to 805-1040 AD (Table 4, N.Z. 7649). Shell valves are well preserved, probably not reworked, and may have been deposited in the same event as the pumice.

Section 5, Tokerau Beach

The section is 30 m north of the stream next to D.Urlich Road, midway between the stream and Section 4 (Table 2; Fig.4). It is in the dune disturbance zone bordering the stream. The section is located within a vegetation-topped foredune hummock, possibly remnant of a linear foredune. Past disturbance may have been caused by stream meandering, coastal erosion or anthropogenic activity.

The section (Fig.3) comprises three distinct horizons separated by layers of sand. The highest horizon is a midden and habitation layer comprising an admixture of shell and charcoal on a charcoal-stained buried soil. A weaker buried soil lies 80 cm below the habitation layer. These two horizons represent phases of dune stability and instability. A thin pumice layer containing sparse shell fragments is located 30 cm beneath the weak buried soil. Pumice was traced laterally for only 2 m, not enough to be reliably recognised as a sea-rafted stranding. Initial pumice samples were identified as Loisels Pumice (Froggatt *pers comm.*, 1989), but a further clast proved to be Taupo Pumice. Mixing of pumice types indicates disturbance of stratigraphic units. With two different pumices represented in the same deposit, there is a good chance that one or both may not be primary (following Pullar *et at.*, 1977).

The range of grain sizes within the deposit is large. Grains are poorly sorted and strongly coarse-skewed although rounded in mean form (Table 3). The pumice is well above M.H.W. but within the range of high-magnitude storm deposits, and the layer is thin. The section is directly exposed to marine and fluvial erosion.

Preliminary interpretation supports the contention that the pumice layer is secondary. It is found within a zone of periodic coastal instability which is prone to disturbance. The identification of Taupo Pumice is a strong indicator that there has been some reworking. The layer is not laterally extensive. Shell identified as *Paphies (Mesodesma) subtriangulata* (Powell, 1976) from the pumice layer was radiocarbon dated to 250 BC–70 AD (Table 4, N.Z. 7648).

Table 4 – Radiocarbon dates used to define the age of Loisels Pumice (LP). Ranges are expressed as a 95% confidence interval using the New Zealand Delta -R = -30 correction for marine shell and Southern Hemisphere terrestrial calibration for charcoal and wood.

NZ Radio-carbon Number	Conventional radiocarbon age (BP 1950)	Calibrated age range (AD) at confidence level 95%	Potential signifi-cance of date	Section number and locality	Author	Dated layer & position
NZ 7658 *	762 ± 74	1425-1675	unknown	1, Matai Bay	This paper	Shell inLP
NZ 396	778 ± 40	1205-1295	maximum	1, Matai Bay	Wellman (1962)	Charcoal below LP
NZ 4726*	973 ± 40	1300-1440	minimum	3, Tokerau Beach	Millener (1981)	Shell below LP
NZ 4727*	1233 ± 28	1060-1240	maximum	3, Tokerau Beach	Millener (1981)	Shell below LP
NZ 7649*	1449 ± 52	805-1040	unknown	4, Tokerau Beach	This paper	Shell in LP
NZ 7648*	2383 ± 54	250 BC-70 AD	unknown	5, Tokerau Beach	This paper	Shell in LP
NZ 7291*	1030 ± 60	1240-1430	minimum	6, Tokerau Beach	This paper	Shell bank seaward of LP
NZ 7613*	1441 ± 34	850-1030	minimum	6, Tokerau Beach	This paper	Shell above LP
NZ 7560*	1360 ± 45	915-1145	maximum	6, Tokerau Beach	This paper	Shell below LP
NZ 1296	761 ± 44	1455-1640	minimum	10, Hot Water Beach	Leahy (1974)	Midden shell above LP
NZ 1297	832 ± 44	1395-1570	minimum	10, Hot Water Beach	Leahy (1974)	Midden shell above LP
NZ 354 A	689 ± 40	1270-1325 (49%)	maximum	11, Opito Beach	Green (1963)	Charcoal below LP
NZ 354 B		1335-1395 (46%)				
NZ 632	1008 ± 60	1261-1441	minimum	12, Cooks Cove	Wellman (1962)	Shell, lowest occupation layer above LP
NZ 651	1111 ± 41	890-1020	maximum	12, Cooks Cove	Wellman (1962)	Wood belowLP

* Denotes previously unpublished dates.

Section 6, Tokerau Beach

Located 2 km south of Tokerau Beach Road (over 6 km south of Sections 3, 4 and 5), Loisels Pumice is within a compacted marine shell ridge on the landward face of a frontal dune (Table 2; Fig.5, Fig.6). This shell ridge was exposed by a local company excavating shell for lime. Accordingly, it differs from the other field sections in this study, which were exposed on the dune face adjacent to the beach, and is physically distanced from marine erosion. The shell ridge was formed as a backshore storm deposit. Horizontal laminae at the base of the deposit are paralleled in trenches dug into the present backshore. Periodic storm stranding of similar deposits adjacent to the active beach have been noted over the past five years. Dune progradation followed formation of the shell bank containing Section 6 and excluded further exchange of marine shell. A radiocarbon date of 1240-1430 AD (Table 4, N.Z. 7291) on further shell ridge material 7.3 m seawards of the pumice section provides a maximum age for dune progradation, which developed after that shell ridge was formed.

Soil has developed at the top of the section (Fig. 3) indicating long term stability. The pumice layer is directly overlain by shell, and rests on >1m of shell before the section grades into sand. Shell appears to have been deposited directly from the marine environment, with no indication of post-depositional disturbance other than the compaction and horizontal lamination typical of shell ridges. Both the degree of weathering and the species composition are consistent above and below the pumice layer. There is little abrasion or fragmentation of shell valves, and whole, mature valves are common. There is no evidence of anthropogenic disturbance in the stratigraphic sequence. Pumice was mineralogically identified as Loisels (Froggatt *pers comm.*, 1989), and is typically dense, hard and grey with dark and light banding. The layer can be traced for 6 m, and forms a distinct horizon within the shell ridge. The pumice layer is comparatively thick (Table 3). The base of the horizon is 160 cm above M.H.W., where deposition may have been possible during storm events of a lesser magnitude than the ones responsible for Sections 4 and 5. Horizontal distance to M.H.W. is the greatest of all the field sections. Coastal erosion and reworking of the section is impossible, due to intervening topography. Mean grain size is within the central range of values for this study. The range of grain size classes is also moderate. Particles are near-symmetrically distributed without the tail of fine material found at Section 1. Sorting is poor. Clasts are sub-rounded in mean form. When viewed as a whole, the pristine condition of shell material, the clearly defined envelopment of the pumice layer by shell material and the lack of other evidence of reworking, all justify the adoption of a negligable inbuilt age for radiocarbon dates in this situation.

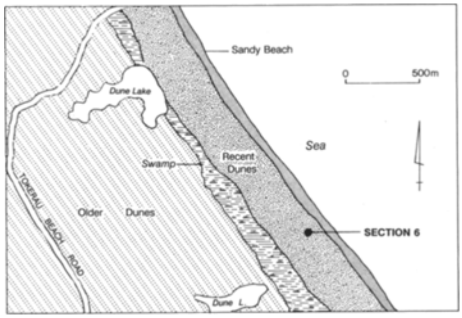

Fig. 5 – Location of Section 6, southern Tokerau Beach.

Radiocarbon dates were taken on shell directly above and below the pumice layer (Table 4). Whole and mature valves of *Paphies (Mesodesma) subtriangulata* and *Chione stuchburyi* (Powell, 1976) were selected for radiocarbon dating. A minimum age of 850-1030 AD (N.Z. 7613) and a maximum age of 915-1145 AD (N.Z. 7560) was returned.

Sections from the Literature

Section 3, Tokerau Beach

Millener (1981) recorded a section, just north of Sections 4 and 5 at Tokerau Beach (Table 2; Fig.4). Coastal erosion had exposed a metre thick, compacted marine deposited shell ridge in a wave-cut foredune. The shell ridge enveloped a thin layer (5-10 cm) of Loisels Pumice beneath midden deposits and unconsolidated sand.

Uniform compaction of the shell horizon demonstrates minimal stratigraphic disturbance by coastal processes from the time of deposition to the point of its exposure. With no stratigraphic indication of reworking, the section should provide a reasonable estimate of the deposition of Loisels Pumice at that site. Without field examination, we cannot determine the inbuilt age factor of shell dated for the minimum age bracket. However, lag deposits of Loisels Pumice were located in dune deflation hollows landward of the section, and these may pre-date it. The thinness of the section at a low elevation above sea-level may be further evidence that the deposit is potentially secondary.

Shell (*Paphies (Mesodesma) subtriangulata*) immediately above and below the pumice was radiocarbon dated (Table 4). A minimum age of 1300–1440 AD (N.Z. 4726) and a maximum age of 1060–1240 AD (N.Z. 4727) was returned.

Section 10, Hot Water Beach

Excavation of a dune midden site by Leahy (1971, 1974) at Hot Water Beach, Coromandel Peninsula, exposed Loisels Pumice (Table 2). Six layers were identified and labelled 1 to 6 from top to bottom. Layer 4 was a habitation layer containing shell and artifactual material. Loisels Pumice was scattered through the site, but concentrated in yellow sand in layer 5. Maori occupation remains were found from the lower part of Layer 3 through to Layer 6. The section showed upward mixing of Loisels Pumice, but the base of the pumice layer was generally found either on sand or concentrated above Layer 6.

Fig. 6 – Section 6, southern Tokerau Beach, showing the pumice layer (20-22cm thick) bounded by shell.

Two radiocarbon dates (Table 4) on midden shell in layer 4 returned ages of 1455-1640 AD (N.Z. 1296, *Amphibola crenata*) and 1395-1570 AD (N.Z. 1297, *Amphidesma australe*). These dates were averaged and employed by McFadgen (1982) to derive a minimum age for the first arrival of Loisels Pumice in Layer 5. No maximum age bracket for pumice deposition on material beneath the pumice layer was taken. No conclusive interpretation of whether pumice is primary or secondary can be made from an analysis of the published stratigraphy. Pullar *et al.* (1977) considered that Loisels Pumice at Hot Water Beach was probably secondary, having been mixed with other pumice types and either reworked or anthropogenically deposited. Radiocarbon dating is inadequate to bracket the age of the pumice deposit.

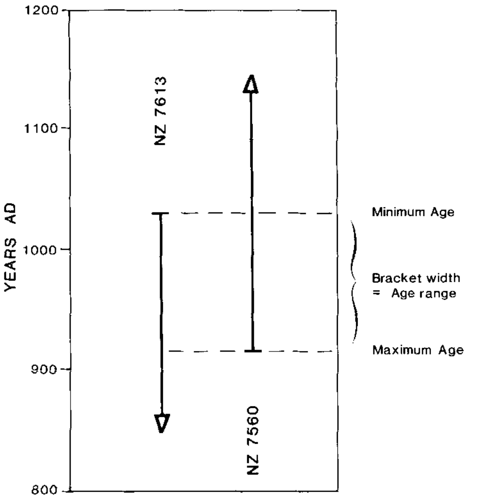

Fig. 7 – Radiocarbon age bracket for Section 6 used to derive the age of Loisels Pumice. Each arrow length = 95% confidence interval for corrected dates.

Section 11, Opito Beach

Green (1963) recorded a section containing Loisels Pumice at Opito Beach, Coromandel Peninsula (Table 2). The site was exposed in a wave-cut foredune but excavated within the dune further back from the beach. The section comprises four layers. Layer 4 contained three sub-layers, two cultural horizons (4a and 4c) separated by a zone of sand (4b). Pumice is found within the upper half of 4b and the layers above.

Radiocarbon dating of charcoal in 4c, the lowest occupation layer directly beneath the pumice returned an age of 1270-1325 AD (49% of material) and 1335-1395 AD (46% of material) (Note: the percentages represent the probability of the date falling into the stated age ranges) (Table 4, N.Z. 354). The date was used by McFadgen (1982) to derive a maximum age bracket for the first arrival of Loisels Pumice. There has been no attempt to close the dating bracket on pumice within the section with a minimum age. We conclude that, as for Section 10, no interpretation of whether the pumice layer is potentially primary or secondary in age can be made from radiocarbon dating.

Section 12, Cooks Cove

Wellman (1962) described a section containing Loisels Pumice, exposed by extensive dune erosion at Cooks Cove, East Coast (Table 2). Two occupation layers were found above the pumice. It was located directly beneath the lower occupation layer, comprising charcoal, stone, shell and fish bones. The base of the Loisels Pumice Layer was well defined, and rested on shelly beach sand with sparse charcoal and bones. This overlay horizons of silty sand and then pumice and tephra thought by Wellman to be from Taupo. This layer covered estuarine sand containing totara logs.

Radiocarbon dates were taken from logs underneath the lowest tephra deposit and shell immediately above Loisels Pumice (Table 4). Wood dated at 890-1015 AD (N.Z. 651), was employed by McFadgen (1982) to derive a maximum age bracket for the arrival of Loisels Pumice. The shell date of 1261-1441 AD (N.Z. 632) was used to derive a minimum age bracket. The date on wood is a poor maximum date for the Loisels Pumice layer, as the two horizons are separated by three other stratigraphic layers. Shell directly beneath Loisels Pumice, which may have provided a closer maximum age bracket, was not dated. Stratigraphic interpretation does not indicate whether the pumice is primary or secondary. The radiocarbon dating age bracket of the pumice layer is only loose.

Other Sections

Of sections identified in the literature as being potentially primary, only Section 1 at Matai Bay was located in the field (Table 2). We could not locate; Sections 2 at Whatuwhiwhi, 3 at Tokerau Beach, 7 at Cable Bay, 8 at Koaiti, and 9 at Ocean Beach. We presume that all these sections, except for section 7, have been either destroyed by coastal erosion or reburied by dune accretion. Section 7 at Cable Bay is probably located under infill behind a sea wall.

DISCUSSION

It is clear that McFadgen's (1982) failure to make the important conceptual distinction between primary and secondary sea-rafted pumice deposits has meant that his estimation of the first arrival of Loisels Pumice is inadequate. When compiling the age-range of Loisels Pumice, he considers the youngest maximum date as a bracketing parameter, instead of the most likely maximum date taken from a secondary pumice deposit which is not primary-aged. Furthermore, McFadgen has derived maximum and minimum age brackets from disparate sections, and then assumed they represent the same, primary-aged depositional episode. This assumption is not tenable when dealing with sea-rafted pumices which can be, and are, reworked. The date of primary deposition has been incorrectly determined and applied. In order to best define the age of primary deposition, potentially primary sites need to be identified and radiocarbon-dated by bracketing pumice layers. The oldest individual bracket of radiocarbon dates at any one site provides the best estimate of primary deposition. However, even this date may still be taken from a secondary deposit. Primary deposits may be reworked by coastal erosion and redeposited in dune environments. There is, therefore, no unequivocal evidence that the earliest-dated Loisels Pumice layer is primary.

In order to produce sound estimates of the age of Loisels Pumice within any coastal section, it is vital that datable material immediately adjacent to the pumice layer is used. The best dates are from sections which bracket the pumice with suitable material both above and below the deposit at the same site, and where the potential for unknown inbuilt ages is minimal. Changes in substrate between dated layers and those containing the pumice may signal chronological breaks in the depositional sequence, and thus may not provide a close bracketing age. Individual dates from material within the pumice layer are only of secondary value, as this material can be reworked and its date of origin will be quite unrelated to the date of deposition of the pumice.

The sections employed by McFadgen (1982) to derive a date on Loisels Pumice do not provide a good basis for dating pumice within those sections. Sections 1 and 10 were probably reworked. More important is the objection that at only one location, Section 12 at Cooks Cove, is the pumice layer bracketed, and even then the maximum age bracket is not from material adjacent to the Loisels Pumice layer. Stratigraphic interpretation of sections may identify pumice layers with the potential to be primary, but is inadequate to evaluate the age of the pumice.

The sections we inspected in the field, 1 at Matai Bay, and 4 and 5 at Tokerau Beach, with shell dates from within the pumice layer, cannot be considered as primary-aged sections, because there is a real possibility that material of a different age has been mixed with the pumice layer. Section 1 is further discounted because Loisels Pumice particles were found underlying the dated pumice layer. Similarly, Section 5 is discounted because its pumice is mixed Taupo and Loisels in composition. Both these sections are at locations prone to erosion and reworking. Section 4 may be a primary-aged deposit, but this remains a speculation without bracketing radiocarbon dates, and only one date from within the pumice is available.

Using the sole criterion of a section providing a radiocarbon date bracket likely to yield the age of primary deposition, then only Sections 3 and 6 at Tokerau Beach can be considered. Both sections are compacted, marine deposited shell ridges enveloping layers of Loisels Pumice. Close radiocarbon date brackets were taken from abundant shell material adjacent to the pumice layers. Section 3 was exposed by coastal erosion, and contains a thin layer of pumice. The location of Loisels Pumice lag deposits in antecedent dunes suggest that this layer could be reworked. Without field inspection of Section 3 we could not determine whether the shell dated for the minimum age bracket might contain an inbuilt age factor representing the time interval between the death of the molluscs and their subsequent deposition at the site. However, the thinness of the layer and its proximity to modern marine erosion indicates potential for reworking of shell and pumice. In contrast, the Loisels Pumice layer in Section 6 is comparatively thick. The site has been protected from any marine reworking for a long time, as it is far from the active coast. Any reworking of shell or pumice would have had to happen quite quickly after initial deposition and before the development of subsequent coastal landforms. Interpretation of the section suggests no reworking. Soil development within the section demonstrates stratigraphic stability. Buried soils, anthropogenic activity or other indices of periodic instability are absent. There is evidence of coherent, ordered depositional stratigraphy, and the shell is homogeneous and well preserved throughout the section. Consequently, we assume a negligable inbuilt age for marine shell radiocarbon dates in Section 6.

CONCLUSIONS

We propose that Section 6 at Tokerau Beach represents the best example of a primary-aged sea-rafted Loisels Pumice deposit reported to date. The section reveals no evidence of reworking and much evidence of long term stability after pumice deposition within the shell ridge. It provides the oldest reliable radiocarbon age of Loisels Pumice. Bracketing radiocarbon dates overlap at 915-1030 AD (Fig.7). We consider this date to be the best estimate for the age of primary deposition of Loisels Pumice.

Stratigraphic and geomorphic interpretation may identify sites where pumice is potentially primary. However, Section 6, which we conclude is primary in age, does not have grain size or roundness characteristics clearly different from the other field sections (Table 3). Furthermore, the presence of large clasts of pumice in a section such as Section 1 may be due to the preferential stranding of coarse size grades in locations with restricted depositional elevation. We conclude that it may be impossible to separate primary and secondary deposits by using descriptive statistics.

Investigators in coastal locations need to exercise prudence in interpreting sections containing sea-rafted pumice. To apply the age of primary Loisels Pumice to other sites containing Loisels Pumice is clearly wrong. The age at any one site depends on the depositional history of the pumice at that site. Loisels Pumice (or other sea-rafted pumices for that matter) should not be relied upon as a stratigraphic marker layer for coastal deposits in the same manner as air-fall tephras. Where Loisels Pumice layers have been employed to establish chronostratigraphic synchrony between sites (*e.g.* by McFadgen, 1985), errors may have been introduced into the literature. We consider that these interpretations should be re-appraised. Such deposits are of little value to investigators of the geomorphology or archaeology of coastal sites.

The possibility also remains that there has been more than one eruption, of similar type, from the source of Loisels Pumice. This possibility only reinforces the point that sea-rafted pumice should not be used as a stratigraphic marker layer. The real value of dating primary sea-rafted Loisels Pumice is to date the first eruption and arrival of ejecta on the northern coast of New Zealand.

ACKNOWLEDGEMENTS

The University of Auckland is acknowledged for a research grant funding fieldwork and analyses. Dr. P.C. Froggatt, Research School of Earth Sciences, Victoria University of Wellington undertook mineralogical analysis. Dr. P.R. Millener, National Museum of New Zealand gave permission to use and interpret unpublished data. The trouble taken by two referees is acknowledged with thanks. Graeme Silver provided the photograph of Section 6. Keri Parnell provided assistance with fieldwork.

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Received 2 July 1990; accepted 24 July 1991