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A review of late Quaternary silicic and some other tephra formations from New Zealand: their stratigraphy, nomenclature, distribution, volume, and age

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Abstract The stratigraphic relationships and distribution of 36 named late Quaternary (≤c. 50 000 yr B.P.) silicic tephra formations, erupted from 4 volcanic centres—Okataina, Taupo, Maroa, and Tuhua (Mayor Island)—are presented. The stratigraphy and status of several other named late Quaternary tephras are also discussed. This compilation brings together all the data, currently scattered through many publications, to make tephrostratigraphy more accessible and more easily used. The nomenclature of tephra formations is discussed and some rationalisations are suggested. The term **"tephrology"** is suggested as an appropriate title for the field of tephra studies. The deletion of grain-size (ash, lapilli), shape (breccia), and lithologic (pumice) terms from all formation names is recommended, as is standardisation on a **"Tephra Formation"** format. Several tephra layers not previously formally named, or without designated type sections, are defined. The dominant ferromagnesian mineral assemblage of each tephra formation has been compiled as an aid to tephra identification. All available radiocarbon ages (384) on each tephra formation are presented, and each age is assessed for reliability in dating the eruption of that tephra. The standard-deviation weighted mean age of the reliable ages has been determined as the best current estimate of the age of each tephra. At least 10 tephra formations have no reliable ages, and efforts should be made to date these.

Keywords tephra formation; nomenclature; stratigraphy; mineralogy; C-14 ages; pyroclastics; volume

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INTRODUCTION

Quaternary silicic tephras have been studied extensively in New Zealand for over 50 years, leading to a detailed understanding of their stratigraphy, distribution, and processes of eruption. The value of identifiable tephra layers as stratigraphic time-planes has been demonstrated by their role in a great diversity of Quaternary studies. Our present knowledge of tephrostratigraphy is due mostly to the dedicated field work of two people, C. G. Vucetich and W. A. Pullar, and is embodied in three benchmark papers (Vucetich & Pullar 1964, 1969, 1973). Recent additions and amendments to their framework, largely as a result of better exposures, have resolved finer details of stratigraphic relationships. These refinements are scattered through many publications, and there has been an obvious need to produce a definitive review of the stratigraphy of the late Quaternary silicic tephras. Many radiocarbon ages have been published for dating the tephras, especially recently (Hogg et al. 1987), and a compilation and review of all available ages is provided.

Here, we present a compilation of the interfingering stratigraphy of tephras erupted since c. 50 000 years ago from four silicic volcanic centres, namely Tuhua (Mayor Island), Okataina, Maroa, and Taupo (Fig. 1), with a revision of the formal tephra nomenclature as developed in New Zealand. We have also compiled the history of naming of each layer, references to published isopach maps, estimates of the erupted volume, the location of type sections, and all relevant radiometric ages. We present our best estimate of the age of eruption of each tephra. The stratigraphy of andesitic tephras from Taranaki and Tongariro Volcanic Centres has been excluded as further work on them is in progress.

This review is complementary to that of Lowe (1990) which describes the history of tephra studies in New Zealand.

TEPHRA NOMENCLATURE

Tephra

"Tephra" (derived from the Greek *tephra* ash) is a collective term for all the unconsolidated, primary pyroclastic products of a volcanic eruption. The term, an ancient one used by Aristotle in an account of the eruption on Hiera in the Lipari Islands, was reinstated and first defined by the Icelandic volcanologist, S. Thorarinsson, in his doctoral thesis published in 1944 (Thorarinsson 1944, 1981). He originally described tephra as "all the clastic volcanic material which during an eruption is transported from the crater through the air, corresponding to the term lava to signify all the molten material from the crater" (Thorarinsson 1954, p. 2). The term was subsequently modified by Thorarinsson (1974), and by Howorth (1975) and Schmid (1981), to include all unconsolidated pyroclastic deposits irrespective of their origin or nature of emplacement. This broader, morphological meaning is adopted here because it negates the need to

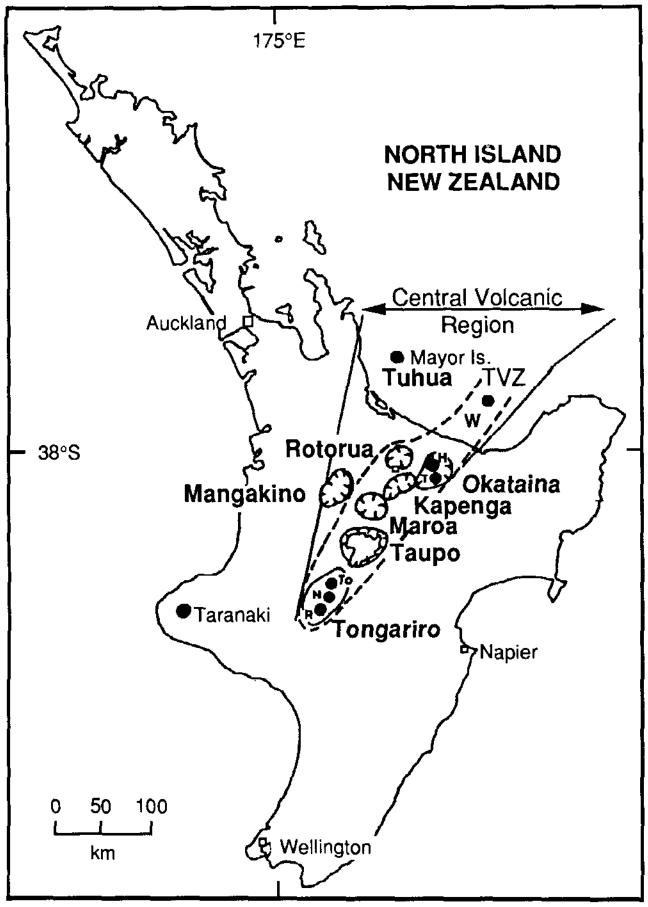

Fig. 1 The central North Island of New Zealand with the volcanic centres from which late Quaternary silicic tephras have been erupted (adapted from Cole 1979 and Wilson et al. 1984). Okataina Volcanic Centre is subdivided into two parts: Haroharo (H) to the north and Tarawera (T) to the south. W, White Island; To, Mt Tongariro; N, Mt Ngauruhoe; R, Mt Ruapehu. Wilson et al. (1986) postulated the existence of "Whakamaru caldera" in the northern Taupo – Maroa area in addition to those shown here.

distinguish pyroclastic flow deposits from airfall deposits, and it encompasses primary pyroclastic deposits generated or emplaced subaqueously or subglacially. Thorarinsson (1974) noted that this usage complements rather than replaces terms such as ignimbrite and welded tuff.

We emphasise that "tephra" denotes essentially unconsolidated material, thus welded (or hardened) pyroclastic materials, of either flow or airfall origin, should not normally be described as "tephra". It is also our intention that unconsolidated pyroclastic deposits that originate from explosions resulting from the interaction of lava with either groundwater (e.g., forming pseudocraters: Thorarinsson 1979) or seawater (e.g., forming littoral cones: Fisher 1968), and thus originating from rootless vents, may be described as tephra.

The adjective "**pyroclastic**" (Greek *pur* fire, *klastos* broken in pieces), a collective term for clastic or fragmentary materials ejected from a volcanic vent (Fisher & Schmincke 1984), is a more comprehensive term than tephra and is not necessarily synonymous with it.

The stratigraphic entity composed of tephra is often loosely referred to in New Zealand as a "tephra" or collectively as "tephras", but "tephra layer" or "tephra bed" is etymologically more correct and this use is encouraged here. Although tephra as a collective noun may be singular or plural, we consider it sensible that an "s" should be appended to form the plural if it avoids ambiguity. In the derivative terms "tephrostratigraphy" and "tephrochronology" the "a" is replaced with an "o".

Although "tephra" is deliberately defined as a nongenetic term, it has often been found useful to distinguish between three (or more) fundamentally different mechanisms of transport and emplacement of tephra: airfall, pyroclastic flow, and surge. The last term is usually distinguished from fall or flow processes (Wright et al. 1980). Vucetich & Pullar (1973) suggested "fall-tephra" and "flow-tephra" but although these terms were adopted by some workers they have not been widely used. The genetic term "ignimbrite" (see below) adequately suits the products of a pyroclastic flow (e.g., Sparks et al. 1973; Sparks & Walker 1977; Froggatt 1981d), but there is no equivalent word for the airfall phase. "Plinian tephra" or "Plinian pumice" (Walker 1980) may be appropriate in a volcanological sense, but are here regarded as being too specific genetically as stratigraphic terms, requiring the establishment that the eruption was truly Plinian in nature. These terms are then applicable only to tephra from Plinian eruptions and exclude other mechanisms such as phreatomagmatic. The term "airfall tephra" or perhaps "fall-tephra" or "fallout tephra" are probably still the most appropriate where an indication of genesis is required.

The adjective "**tephric**" (meaning related to, or of, tephra) has been applied informally to various deposits derived from tephra by reworking or chemical weathering. There is considerable merit in a term that denotes the origin or major constituent of a strongly weathered or secondary deposit, and we find "tephric" preferable to the use of "tephra" for material not of primary origin.

The use of "tephra" for epiclastic sediments dominated by volcanic detritus (e.g., Seward 1976) is not consistent with the definition of tephra as primary volcanic material. Rationalisation of the nomenclature of these types of deposits (Schmid 1981) recommends the use of "**tuff**" for friable deposits, and tuffaceous sandstone or siltstone for lithified deposits; we suggest that "tephric" (e.g., "tephric sand" or "tephric alluvium") could also be applied to unconsolidated sediments of the sort described by Seward (1976).

Ignimbrite

"**Ignimbrite**" (Marshall 1932, 1935) is a genetic term for the primary deposit of a pyroclastic flow or flows. The etymology of the term is uncertain (Froggatt 1984) but is probably from the Latin *ignis* (fire) and *imbrex -imbris* (stormcloud), rather than *nimbus* (cloud) which does not contain an "r". As ignimbrite has two common lithological states it is usually convenient to qualify the term with welded or unwelded as appropriate. Welding involves the adhering together of hot, glassy fragments under the influence of a compactional lithostatic load (Cas & Wright 1987). Some ignimbrites, typically known as sillar, may be hardened by vapour phase crystallisation and, although having the appearance of being welded, are better described as cemented (Fisher & Schmincke 1984; Cas & Wright 1987).

Tephra formation

The need for the formal definition of a stratigraphic layer of tephra as a "formation" was argued by Gregg (1961), who also recommended the use of "tephra formation". Formation naming was adopted by Vucetich & Pullar (1964, 1969, 1973) and adapted to "tephra formation" by Howorth (1975). The products of one eruption sequence may contain coarse, well-sorted airfall pumice, thick unsorted ignimbrite, surge deposits, and distal, thin, fine ash layers. On the scale of a regional geological map such lithological variations may be minor and encompassed by a single formation, but at the millimetre scale of detailed tephrostratigraphical or volcanological studies they are important. By definition, a "tephra formation" is strictly neither a chronostratigraphic nor lithostratigraphic term as defined by the International Stratigraphic Guide (Hedberg 1976), but contains elements of both (Gage 1977). It could be classed as an allostratigraphic unit under the revised North American Code (North American Commission 1985). The base of a tephra formation is essentially an isochronous plane and is of fundamental importance in tephra stratigraphy. The top of a formation may be time transgressive, and may have additions of material from other sources (e.g., loess, andesitic tephra), and is of less importance in a stratigraphic sense. For rhyolitic tephra layers, a tephra formation contains all the primary pyroclastic products of one eruptive episode, each separated by significant time intervals that are often marked by paleosols. It may be divided into named members where appropriate. Andesitic tephra formations in New Zealand have commonly been defined to include the products of more than one eruption and hence may span a considerable time period as a consequence of the more intermittent eruptive nature of these types of volcanoes (e.g., Neall 1972; Topping 1973).

Formations composed of tephra, as defined above, are a special type of formation, but their naming should conform to the accepted stratigraphic guide. A formation name should be composed of geographical and lithological components, and we would argue that tephra is the most appropriate lithological term for these formations. This also emphasises their unique nature, particularly as isochronous stratigraphic marker beds, and distinguishes them from other lithological formations.

Volcanic formation and eruptive episode

Cole (1970a) mapped lavas and pyroclastic deposits (tephra) erupted from Tarawera and demonstrated their coeval nature. He grouped both types of deposits into "volcanic formations". Nairn (1980, 1981, 1986) has mapped coeval lava and tephra in Haroharo caldera as separate formations, but has indicated the close time and genetic links between the tephra and the lava by grouping both into an informal "**eruptive episode**". Such an eruptive episode (e.g., Kaharoa eruptive episode) consists of all the primary volcanic material produced during a relatively short-lived eruption sequence.

Ash, lapilli, and breccia in formation names

The original formal definitions of many late Quaternary tephra layers (Baumgart 1954; Baumgart & Healy 1956; Vucetich & Pullar 1964, 1969) included a grain-size term denoting the dominant or most frequently observed grain size (for instance Kaharoa Ash, Taupo Lapilli), or the dominant grain shape or texture (Oruanui Breccia, Rotoiti Breccia). Since the definition of these, the term "tephra" has gained widespread acceptance and has been incorporated by preference into formation names (e.g., Howorth 1975; Vucetich & Howorth 1976b; Hogg & McCraw 1983). General consensus, together with the continuing use of "tephra", suggests that most of these grain-size and clast shape or textural terms are not appropriate and should be replaced. However, the names of members of formations may contain a grain-size or lithological term if the member is dominantly of this grade or lithology. Such names also serve to distinguish the member status of the deposits from that of formations (denoted by "Tephra").

The opportunity has been taken to rename some tephra layers when recently redefined (e.g., Hinemaiaia Tephra Formation: Froggatt 1981c). We propose here to formally rename those formations with an "Ash" suffix as "Tephra Formation" and those members with a "Breccia" suffix as "Ignimbrite" where appropriate. We also propose to rename Taupo Pumice Formation as Taupo Tephra Formation, because some members of the formation are not pumiceous (e.g., Rotongaio Ash). Our redefined names are listed in Table 1. Other new names are defined below.

Tephrology

No single term adequately describes the scientific discipline currently informally called "tephra studies" (e.g., Self & Sparks 1981). "Tephrostratigraphy" and "tephrochronology", as specialist subjects within "tephra studies", are unsuitable. Consequently, we suggest that "**tephrology**" (Greek *tephra* ash, *logos* discourse or subject of study) may be an appropriate term for the science of "tephra studies", which includes the stratigraphy, chronology, correlation, and petrology of tephra layers.

VOLCANIC CENTRES AND TEPHROSTRATIGRAPHY

The central North Island has had silicic eruptive activity since at least the early Quaternary, but the sites of volcanism have varied with time. A broad, wedge-shaped zone containing all Quaternary volcanism was defined as the ***Central Volcanic Region*** (CVR) by Thompson (1964). A narrower zone of presently or recently active volcanoes is ***Taupo Volcanic Zone*** (TVZ) (Healy 1961), and volcanoes within this zone were placed in "volcanic centres" (see below).

Subsequently, Rogan (1982) and Wilson et al. (1984) inferred a sixth centre, south of Rotorua, mostly from geophysical evidence, which they named Kapenga Volcanic Centre. However, the activity of this centre and its relationship to Okataina is unclear. Whether any of the late Quaternary eruptives considered here have originated from Kapenga has not been definitively stated, but Earthquake Flat Tephra Formation is a likely candidate, although it has close chronological associations with Rotoiti Tephra Formation from Okataina (I. A. Nairn pers. comm. 1988).

We have included the widespread silicic tephra from Mayor Island (Tuhua Tephra) in this review, so we here propose a seventh centre: **Tuhua Volcanic Centre**, from the Maori name for the island. This centre encompasses all the eruptive vents on the pantelleritic Mayor Island volcanic edifice. Buck et al. (1981) classified all the lavas on the island as Tutaretare Rhyolite Formation and all pyroclastic deposits on the island as the Oira Pyroclastite Formation, both formations constituting the Mayor Island Group. Houghton et al. (1985) named the Ruru Pass Tephra on the island without defining its stratigraphic status, but the stratigraphy of this and other eruptives on the island is currently under review (Houghton & Wilson 1986; B. F. Houghton pers. comm. 1988).

Table 1 The formal stratigraphic name of each tephra formation and members, as proposed here, followed by the abbreviation used for the tephra; references to where the name was first defined or modified; references to isopach maps; the location of the type section (grid references based on the national 1:50 000 map series); the error-weighted mean age and pooled error (old half life basis), and the number of ages (*N*) in the mean, based on the data in Appendix 1. Provisional estimated ages (italics) are given where no dates are available, or where dates are uncertain. The tephra formations derived from each volcanic centre are listed in stratigraphic order.

Formation and members	Symbol	Ref 1	Ref 2	Type section	Age	*N*
Okataina Volcanic Centre						
Tarawera Tephra	Tr				1886AD	
Rotomahana Mud	Trm	13	24	V16/128206*		
Tarawera Scoria	Trs	13,5	24,32,28,5,40	V16/185257*		
Kaharoa Tephra	Ka	5,13,32	24,32,26,5	V16/174198*[b]	770 ± 20	15
Rotokawau Tephra[a]	Rw	13,32	32,2	U15/054336	3440 ± 70	1
Whakatane Tephra	Wk	27,32	24,32	V17/322989	4830 ± 20	21
Mamaku Tephra	Ma	13,32	24,32,20	U16/945315	7250 ± 20	22
Rotoma Tephra	Rm	32	24,32,20	V16/141154	8530 ± 10	45
Waiohau Tephra	Wh	32	24,32,20	V16/141150	11 850 ± 60	12
Rotorua Tephra	Rr	13,22,32	24,32,20	U16/018316	13 080 ± 50	10
Rerewhakaaitu Tephra	Rk	32	24,32,20	V16/141150	14 700 ± 110	3
Okareka Tephra	Ok	33	24,33	U16/065306	c. *18 000*	
Te Rere Tephra	Te	33	33	V16/252179	21 100 ± 320	2
Omataroa Tephra	Om	16	16	V15/351361	28 220 ± 630	3
Awakeri Tephra	Aw	16	16	V16/351361	c. *29 000*	
Mangaone Tephra	Mn	33, 16	16	V15/368461	27 730 ± 350[d]	10
Hauparu Tephra	Hu	16	16	V15/396548	35 870 ± 1270	2
Te Mahoe Tephra	Tm	16	16	V15/396548	c. *39 000*	
Maketu Tephra	Mk	16	16	V15/396548	c. *41 000*	
Tahuna Tephra	Ta	16	16	V16/410256	c. *43 000*	
Ngamotu Tephra	Nt	16	16	V16/410256	c. *45 000*	
Earthquake Flat Tephra†					c. *50 000*	
Rifle Range Ash*	Ra	23	#	U16/833119*		
Earthquake Flat Ig.	Ea	38,39,23	#	U16/955279*		
Rotoiti Tephra					c. *50 000*	
Rotoehu Ash	Re	33,42	24,33,19,41	W15/623519		
Rotoiti Ignimbrite	Rb	39,42	#	U15/051631		
Matahi Scoria	Mb	25	#	V16/355390*		
Taupo Volcanic Centre						
Taupo Tephra	Tp	1,14,9	24,26	U18/798728	1850 ± 10	41
Taupo Ignimbrite	Tpi	13,9	32	U18/792617[c]		
Taupo Lapilli	Tl	1	1,32,35	U18/798728		
Rotongaio Ash	Rn	1	1,37,32,44	U18/798728		
Hatepe Ash	Hta	9	37,32	U18/798728		
Hatepe Lapilli	Htl	1	1,32,36	U18/798728		
Mapara Tephra	Mp	34	34	U18/798728	2160 ± 25	6
Whakaipo Tephra	Wo	34	34,20	U18/798728	2685 ± 20	13
Waimihia Tephra	Wm	14	24,32	U18/899574*	3280 ± 20	17
Waimihia Ignimbrite	Wmi	39		U18/899574		
Waimihia Lapilli	Wml	1	1,24,32,34,36	U18/899574		
Hinemaiaia Tephra	Hm	8,34,18	8,34,18	U18/743531	4510 ± 20	12
Motutere Tephra	Mt	8	8	U18/743531	5430 ± 60	3
Opepe Tephra	Op	34	34,20	U18/798728	9050 ± 40	10
Poronui Tephra	Po	34	34	U18/839535	9810 ± 50	3
Karapiti Tephra	Kp	7,34	7,10,34	U18/798728	9820 ± 80	4
Kawakawa Tephra	Kk	30	4,24,33,	T17/619830	22 590 ± 230	4§
Oruanui Ignimbrite	Ou	33,39,11	29,43,44	T17/619830		
Aokautere Ash	Ao	6,30	6,12	T24/343877		
Poihipi Tephra	P	31	#	T17/658890	c. *23 000*	
Okaia Tephra	O	31	31	T17/619830	c. *23 500*	
Tihoi Tephra	Ti	31	31	T17/575881	c. *46 000*	
Waihora Tephra	W	31	#	T17/678866	c. *47 000*	
Otake Tephra	Oe	31	#	T17/678866	c. *48 000*	
Maroa Volcanic Centre						
Puketarata Tephra	Pk	17,34	17	U17/753902	c.*14 000*	
Tuhua Volcanic Centre*‡						
Tuhua Tephra	Tu	15,21	15,20	T12/636403	6130 ± 30	10
Unnamed tephra		20	#		c. *14 500*	

* Defined here
\# No isopach map published
† May derive from Kapenga Volcanic Centre (see text)
‡ Tephra layers occuring on mainland North Island
a Strictly outside Okataina Volcanic Centre—hypostratotype (reference section) defined at U15/071442 (Beanland 1981, 1982)
b Hypostratotype defined at V16/175197
c Hypostratotype defined at U15/799535
Ref1 References where first named or formally defined or redefined
Ref2 References where isopach maps published
§ Mean of the 4 charcoal dates in Wilson et al. (1988). Pooled mean of all 16 dates is 20 685±100 yr
d See text

References

1 Baumgart 1954
2 Beanland 1981, 1982
3 Berry 1928
4 Campbell 1986
5 Cole 1970a
6 Cowie 1964
7 Froggatt 1981b
8 Froggatt 1981c
9 Froggatt 1981d
10 Froggatt & Solloway 1986
11 Froggatt et al. 1988
12 Geddes et al. 1981
13 Grange 1929, 1937
14 Healy 1964b
15 Hogg & McCraw 1983
16 Howorth 1975
17 Lloyd 1972
18 Lowe 1986
19 Lowe 1987
20 Lowe 1988a
21 Lowe et al. 1980
22 Nairn 1980
23 Nairn & Kohn 1973
24 Pullar & Birrell 1973a,b
25 Pullar & Nairn 1972
26 Pullar et al. 1977
27 Taylor 1953
28 Thomas 1888
29 Self 1983
30 Vucetich & Howorth 1976a
31 Vucetich & Howorth 1976b
32 Vucetich & Pullar 1964
33 Vucetich & Pullar 1969
34 Vucetich & Pullar 1973
35 Walker 1980
36 Walker 1981a
37 Walker 1981b
38 Grindley 1959, 1960
39 Healy et al. 1964
40 Walker et al. 1984
41 Walker 1979
42 Nairn 1972
43 Self & Healy 1987
44 Self & Sparks 1978

At the northern end of TVZ, a group of andesitic to rhyolitic eruptives, including White and Whale Islands, Mt Edgecumbe, and Manawahe, exhibit close affinities to one another and were informally grouped into the "Bay of Plenty volcanic centre" by Duncan (1970). Insufficient is currently known about these volcanoes and their relationships to other areas to justify formalising this term.

Named volcanic centres and the standard abbreviations we propose are shown in Table 2. Cole (1979) and Wilson et al. (1984) have presented the location and extent of each centre, and Fig. 1 is based on their maps.

The post-50 000 year tephra formations erupted from each centre are listed in Table 1. There are no known eruptives from Mangakino in this time range (Wilson et al. 1984). Those from Okataina can be further subdivided according to the site of eruption. Tarawera, Kaharoa, Waiohau, Rerewhakaaitu, and Okareka Tephras are from Tarawera (Vucetich & Pullar 1964; Cole 1970a); the remainder are from the Haroharo complex (Nairn 1981, 1986) to the north.

Detailed mapping of individual tephra layers, supplemented by distal stratigraphic and chronological studies (Vucetich & Pullar 1964, 1969, 1973; Vucetich & Howorth 1976a, b; Howorth 1975; Howorth & Topping 1979; Froggatt 1981a, c; Froggatt & Solloway 1986; Lowe 1986, 1988a, b) has enabled the interbedded stratigraphy of 38 formations from the 4 silicic volcanic centres to be elucidated (Fig. 2).

HIERARCHY OF STRATIGRAPHIC NAMES

The definition of a tephra formation allows for the establishment of members within that formation. With most tephra formations this is unnecessary, but five formations (Taupo Tephra, Waimihia Tephra, Kawakawa Tephra, Rotoiti Tephra, and Earthquake Flat Tephra) have such widespread or distinctive units that definition of members has been found useful. This is especially the case for formations with both airfall and ignimbrite components. Other formations may eventually be subdivided where necessary.

At a broader level, a stratigraphic term encompassing several tephra formations has value. Healy (1964b) proposed an Arawa Group comprising Taupo Subgroup and Rotorua Subgroup (Vucetich & Pullar 1964). This subdivision has not found widespread favour, perhaps being too general for practical use. A useful amalgamation into four subgroups (Fig. 3) delineated by the widespread formations at c. 22 500 and c. 50 000 years ago was proposed by Howorth (1981) and we recommend adoption of this proposal. Formations within each group are shown in Fig. 2. All the formations derived from one eruptive centre (e.g., Okataina, Taupo) are deemed to constitute a group. For example, the Lake Taupo Group presently comprises Taupo Subgroup, Kawakawa Tephra Formation, and Okaia Subgroup; the Okataina Group comprises Rotorua Subgroup, Mangaone Subgroup, and Rotoiti Tephra Formation.

Table 2 Named volcanic centres, the standard abbreviations we propose, and the authors of the names.

Volcanic centre	Abbreviation	Reference
Tuhua Volcanic Centre	(TuVC)	(this paper)
Rotorua Volcanic Centre	(RVC)	(Cole 1970b)
Okataina Volcanic Centre	(OVC)	(Healy 1962)
Kapenga Volcanic Centre	(KVC)	(Rogan 1982)
Maroa Volcanic Centre	(MVC)	(Healy 1962)
Taupo Volcanic Centre	(TVC)	(Healy 1964a)
Mangakino Volcanic Centre	(MkVC)	(Wilson et al. 1984)
Tongariro Volcanic Centre	(TgVC)	(Healy 1964a)

DEFINITIONS OF NEW NAMES

1. ***Taupo Tephra Formation*** comprising ***Taupo Ignimbrite***, ***Taupo Lapilli***, ***Rotongaio Ash***, ***Hatepe Ash***, and ***Hatepe Lapilli*** members

Taupo Pumice Formation and some members were named by Grange (1931), but formalised by Baumgart (1954) with the type section at the "Terraces pumice pit". Further members were named by Healy (1964b) and Froggatt (1981d). We consider "pumice" inappropriate for use as a name for a formation of such diverse character and grain size, so we propose Taupo Tephra Formation, as suggested by Froggatt (1979). The member names and their stratigraphic relationships are shown in Fig. 2.

2. ***Waimihia Tephra Formation*** comprising ***Waimihia Lapilli*** and ***Waimihia Ignimbrite*** members

Waimihia Lapilli is a widespread airfall tephra layer, composed of coarse pumice lapilli in the Taupo area, and was first named by Baumgart (1954). Healy (1964b) recognised the multiple nature of the eruption and proposed Waimihia Formation with Waimihia Lapilli as a member. Vucetich & Pullar (1964) recognised the presence of a typically thin fine ash unit above the lapilli, and they referred to the two units as Wm1 and Wm2, respectively. Later, Vucetich & Pullar (1973) recognised the upper ash unit (Wm1) as part of an unwelded ignimbrite of restricted distribution and included it within their Waimihia Formation.

We propose the establishment of Waimihia Tephra Formation, composed of two members: a lower Waimihia Lapilli (Wml) and an upper Waimihia Ignimbrite (Wmi). The type section and type area for "Waimihia Formation" were defined by Healy (1964b) at Iwitahi, east of Taupo. Vucetich & Pullar (1973) designated the De Bretts section, Taupo, as a reference section because the Iwitahi section had been partly destroyed. Within the type area near Iwitahi, a section at Mere Rd (U18/899574*) is suggested as a new type (neostratotype). An additional reference section for Waimihia Ignimbrite is proposed on State Highway 1 at Hatepe Hill (U18/735567).

Waimihia Lapilli is characterised by grey-banded pumice, oxidised lithic clasts, and rare basaltic clasts in the upper half of the deposit. None of these types of clasts appear to be present in the overlying ignimbrite unit.

3. ***Kawakawa Tephra Formation*** comprising ***Oruanui Ignimbrite*** and ***Aokautere Ash*** members

The ongoing nomenclature difficulties of the c. 22 500 year old eruptive products from Taupo require clarification. These products were originally named Oruanui Formation, comprising Oruanui Ash and Oruanui Breccia (Vucetich & Pullar 1969). The recognition of miscorrelations, and the inclusion of an older unit (Okaia Tephra) at the base,

*Grid references are based on the metric 1:50 000 topographical map series NZMS 260.

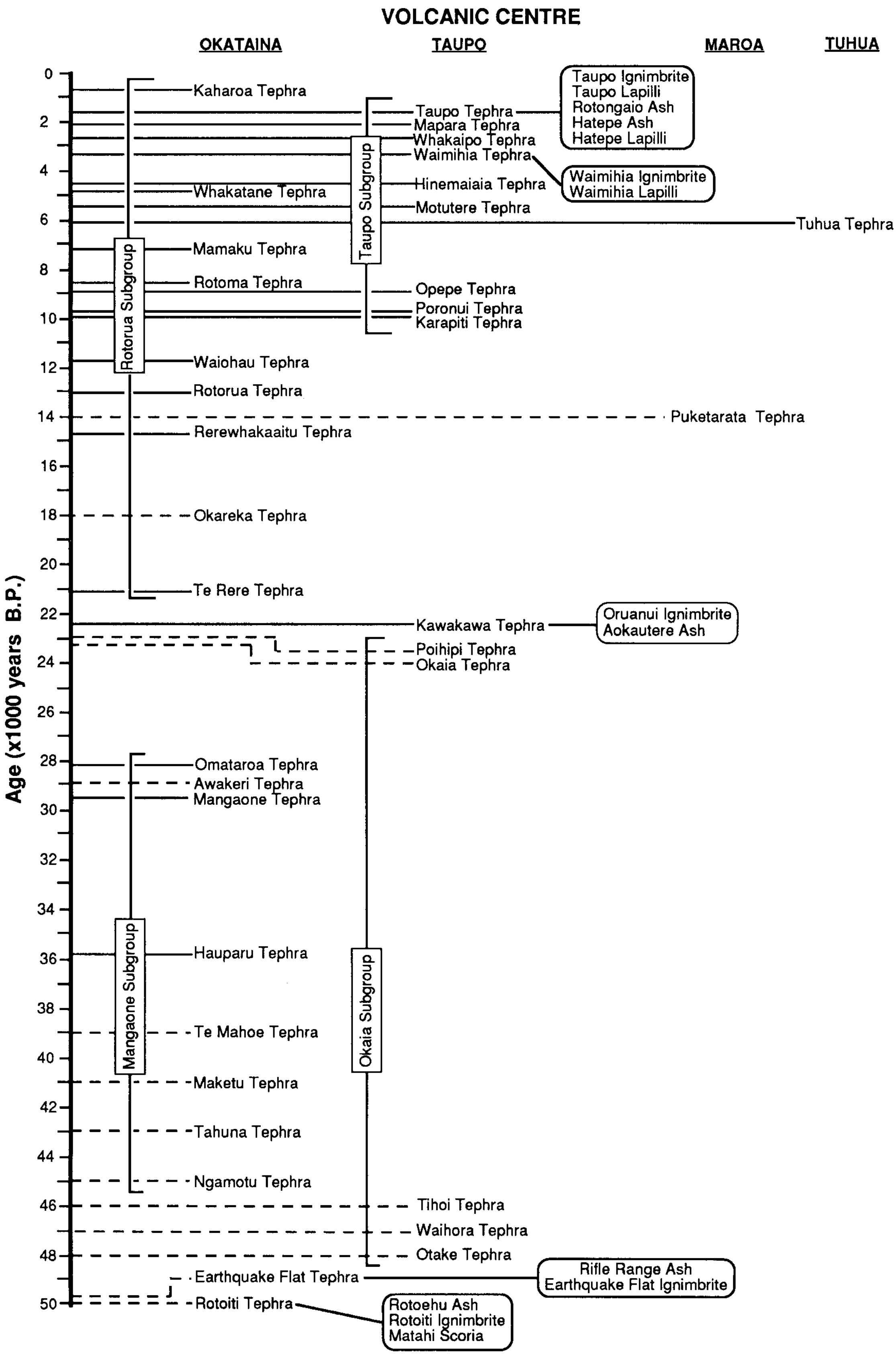

Fig. 2 The stratigraphic relationships of the named late Quaternary silicic tephras in time and space, showing the interfingering of tephras from four volcanic centres and the grouping of some into four subgroups (Taupo, Okaia, Rotorua, and Mangaone). Solid tie lines to the chronology scale are based on mean conventional radiocarbon ages from Table 1 and Appendix 1. Dashed lines indicate no date is available; a relative chronology is suggested from stratigraphic relationships and the degree of paleosol development on undated tephras. The age of c. 50 000 years given for the oldest formation (Rotoiti) is assumed, as discussed in the text.

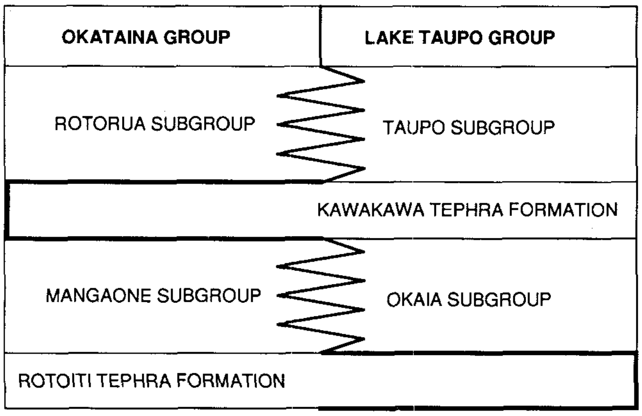

Fig. 3 The hierarchy of group and subgroup names for late Quaternary silicic tephra deposits as proposed by Howorth (1981). The zig-zag line separating the subgroups indicates the spatial and stratigraphic interfingering of the tephra formations. The individual formations within each subgroup are shown in Fig. 2.

led Vucetich & Howorth (1976a) to the definition of Kawakawa Tephra Formation containing three members: Aokautere Ash, Scinde Island Ash, and Oruanui Breccia. Oruanui Breccia was defined by Vucetich & Pullar (1969), Scinde Island Ash was named by Berry (1928) for a layer of ash found at Napier and containing in part accretionary lapilli (for which he coined the term "chalazoidites"), and Aokautere Ash was defined by Cowie (1964) as a bedded unit of fine and coarse white ash, without appreciable accretionary lapilli, at Aokautere, near Palmerston North. Vucetich & Howorth (1976a) correlated parts of the two distinctively different distal ash layers with near-source layers of similar character at the type section on Whangamata Road, and argued that the original names should become member names.

An unwelded ignimbrite, described from drill cores at Wairakei, was named Wairakei Breccia by Grindley (1965). Vucetich & Pullar (1969), in naming Oruanui Breccia, recognised its similarity of stratigraphic position and appearance to Wairakei Breccia. Correlation between the two is now widely accepted (e.g., Self 1983; Wilson 1988). In a detailed volcanological study of the c. 22 500 yr B.P. deposits, Self (1983) referred informally to the whole formation as the Wairakei formation, and has more recently argued for its formalisation (Self & Healy 1987). The term Wairakei is probably invalid for both Wairakei Breccia and Wairakei Formation (Froggatt et al. 1988), having been previously applied to Wairakei Ignimbrite (Beck & Robertson 1955). Wilson (1988) has proposed that Oruanui Formation should be reinstated as the sole formation name, but it, too, has prior usage.

We propose to retain Kawakawa Tephra Formation, as defined by Vucetich & Howorth (1976a) at the Whangamata Road type section (T17/619830). We have renamed Oruanui Breccia as Oruanui Ignimbrite, and propose that Aokautere Ash as defined by Cowie (1964) be used for all the airfall ash within Kawakawa Tephra Formation, including the lower airfall beds at the Kawakawa Tephra type section on Whangamata Road. This usage is analogous to Rotoehu Ash within Rotoiti Tephra Formation.

Oruanui Ignimbrite is invariably overlain by an erosion surface, in turn overlain by Mokai Sand (Vucetich & Pullar 1969). Mokai Sand is a sequence of aeolian deposits derived from Kawakawa Tephra, which range from coarse well-bedded pumice sands to fine tephric dunes with massive to fine, undulose bedding.

4. ***Earthquake Flat Tephra Formation*** comprising ***Earthquake Flat Ignimbrite*** and ***Rifle Range Ash*** members
Earthquake Flat Breccia Formation has been described and mapped by Grindley (1960), Healy et al. (1964), and Nairn & Kohn (1973). It consists of unwelded, crystal-rich pyroclastic flow units with interbedded and mantling biotite-rich airfall tephra units. It was erupted from explosion craters centred on Earthquake Flat to the south of Rotorua. Nairn & Kohn (1973) demonstrated that the Earthquake Flat eruptions immediately followed those of the Rotoiti Tephra Formation (see below), and thus ascribed them the same age. The widespread, biotite-rich, pinkish-grey airfall tephra units were informally named "Rifle Range ash" by Nairn & Kohn (1973).
In line with our proposals for nomenclature of the Rotoiti tephra deposits, we propose that the Earthquake Flat Breccia Formation be renamed Earthquake Flat Tephra Formation, and comprise two members: Earthquake Flat Ignimbrite for the pyroclastic flow deposits and Rifle Range Ash for the intercalated and mantling airfall tephra deposits. Type sections have not previously been designated for these units so we propose the reference sections described in Nairn & Kohn (1973, p. 272) on State Highway 5, 4 km south of Hemo Gorge (U16/955279) for Earthquake Flat Ignimbrite, and at Maleme Road (p. 274) (U16/833119) for Rifle Range Ash.

5. ***Rotoiti Tephra Formation*** comprising ***Matahi Scoria, Rotoehu Ash***, and ***Rotoiti Ignimbrite*** members
The widespread pyroclastic unit from Okataina, with an estimated age of c. 50 000 years or more (see Chronology section below), has an initial basaltic airfall phase (Matahi Basaltic Tephra: Pullar & Nairn 1972), a rhyolitic airfall phase (Rotoehu Ash), and an unwelded ignimbrite (Rotoiti Breccia), which were all grouped under Rotoiti Breccia Formation by Vucetich & Pullar (1969). The relationships between the two rhyolitic phases are complex with the airfall ash found both beneath, and interbedded within, the ignimbrite (Nairn 1972; Walker 1979). We consider the term "Rotoiti Breccia Formation" as inappropriate for such a diverse formation, not withstanding the undesirability of a grain-shape term. Rotoiti Tephra Formation is here proposed, comprising three members: Matahi Scoria, Rotoehu Ash, and Rotoiti Ignimbrite.

TYPE SECTIONS

To formally define a formation, a single outcrop or section must be designated the type section (holotype), and should be supported by a type area and perhaps reference sections (Hedberg 1976). Many of the current names of tephra formations originated before formal stratigraphic nomenclature was formulated. Some formation names have not been formalised and still do not have type sections.

Type sections for all formations, including those newly proposed, are compiled in Table 1. The 10 new sections defined here (Table 3) are based on previously described stratigraphic sections. In addition, a new reference section for Taupo Tephra Formation in support of the type (hypostratotype: Hedberg 1976) is defined on State Highway 1 south of Taupo at U15/799535. Similarly a hypostratotype for Kaharoa Tephra Formation is defined on Crater Road near Mt Tarawera at V16/175197.

OTHER NAMED LATE QUATERNARY TEPHRA DEPOSITS

In addition to the tephra formations listed in Table 1, several other late Quaternary tephra layers, other than those from Tongariro and Taranaki, have been named. Four of these are basalts, and although limited in distribution, have stratigraphic value where found. Other named tephra layers have proved to be correlatives of known tephra formations and the status of these names is discussed here.

Basaltic tephras

(1) *Tarawera Tephra Formation*

The material erupted from Tarawera on 10 June 1886 was first named Tarawera Ash and Lapilli by Grange (1929, 1931, 1937) for the coarse basaltic tephra, and Rotomahana Mud (Grange 1929; Nairn 1979; Walker et al. 1984) for the phreatic ash. The former unit was renamed Tarawera Basalt (Cole 1970a) as a member of his Tarawera Formation. We propose a Tarawera Tephra Formation comprising **Tarawera Scoria** (Trs) (to replace both Tarawera Ash and Lapilli and Tarawera Basalt) and **Rotomahana Mud** (Trm) members. The term Tarawera Tephra was first proposed by Gregg (1961).

Neither of the members of Tarawera Tephra Formation have been designated type sections. For Tarawera Scoria, we propose the adoption of the section through the southeast wall of the Tarawera Crater (Chasm) opposite Wahanga dome (V16/185257) as the type section. This corresponds to the section described at "Reference site A" by Walker et al. (1984, p. 64), and is near to that described by Cole (1970a, p. 100). The type area is designated as the entire chasm on Mt Tarawera. Proximal deposits of Rotomahana Mud are well exposed in cliffs around the shore of Lake Rotomahana, and we propose the type section to be at V16/128206, a lakeshore cliff section described at "Reference site A" by Nairn (1979, p. 366). The type area extends in a circle of 3 km radius centred on the type section.

Table 3 The locations of the 10 newly defined type sections. Detailed section descriptions have been published in the references cited.

Tephra Formation	Type section location*	Reference
Tarawera Tephra		
Rotomahana Mud	V16/128206	Nairn (1979)
Tarawera Scoria	V16/185257	Walker et al. (1984)
Rangitoto Tephra	R10/808928	Brothers & Golson (1959)
Kaharoa Tephra	V16/174198	Cole (1970a)
Waimihia Tephra	U18/798728	
Rotokawau Tephra	U15/053436	Vucetich & Pullar (1964)
Ohakune Tephra	S20/176974	Houghton & Hackett (1984)
Earthquake Flat Tephra		
Rifle Range Ash	U16/833119	Nairn & Kohn (1973)
Earthquake Flat lg.	U16/955279	Nairn & Kohn (1973)
Rotoiti Tephra		
Matahi Scoria	V16/355390	Pullar & Nairn (1972)

*(NZMS 260 grid ref.).

(2) *Rotokawau Tephra Formation*

A basaltic airfall tephra, originally named Rotokawau Ash, lies between Whakatane and Kaharoa Tephra (Vucetich & Pullar 1964) and was erupted from a line of craters northeast of Rotorua (Beanland 1981, 1982). It is immediately overlain by a Taupo-derived tephra at Holdens Bay (Kennedy et al. 1978), either Whakaipo or Waimihia Tephra (Green 1987). A single reliable radiocarbon age on the formation is 3440 ± 70 yr B.P. (NZ7356: N. M. Kennedy pers. comm. 1988). Other ages are given in Appendix 1. We propose to rationalise the name to **Rotokawau Tephra Formation**, and suggest that the reference section of Beanland (1981) at U15/071442 is adopted as a hypostratotype in support of the section given in Vucetich & Pullar (1964).

(3) *Matahi Scoria*

The basal member of Rotoiti Tephra Formation, named by Pullar & Nairn (1972), is a basaltic airfall tephra of limited thickness and distribution. We propose altering the name to **Matahi Scoria**. A type section was not designated so we propose that the reference section at V16/355390 (=N77/161093 of Pullar & Nairn 1972, p. 448) becomes the type section.

(4) *Rangitoto Tephra Formation*

Rangitoto Tephra was erupted from Rangitoto Island (Auckland) around 750 years ago (NZ220, 750 ± 50 and NZ222, 770 ± 50 yr B.P.; Grant-Taylor & Rafter 1963). It was informally named Rangitoto Ash by Taylor (1953) and later described by Brothers & Golson (1959). We propose the formal definition of the tephra as **Rangitoto Tephra Formation** (Ro) with the type at the section at "Pig Bay" (in Administration Bay) on Motutapu Island (R10/808928) as described by Brothers & Golson (1959, p. 570).

Ohakune Tephra Formation

A tephra layer of limited areal extent originated from craters near Ohakune (Houghton & Hackett 1984). Near-vent exposures of tuff-ring-forming tephra are found in several large quarries, with distal material in several road exposures. The tephra is a two-pyroxene, olivine, low-silica andesite with SiO_2 about 56% (Houghton & Hackett 1984). We propose the name **Ohakune Tephra Formation** (Oh), with the type section in a road cutting at S20/176974 (see Houghton & Hackett 1984, fig. 9), where the stratigraphic position of the tephra beneath Kawakawa Tephra is clear. The type area is within 1 km of this site. Reference sections are located in the quarries west of Ohakune (at S20/175976; S20/174979), as described by Houghton & Hackett (1984). The tephra layer lies within loess overlying fluvial sediment and is closely overlain by Kawakawa Tephra. A single radiocarbon age on charred twigs collected from the coarse lapilli layer in the middle of the formation (the middle Pa+Pb bed of Houghton & Hackett 1984) is 31 500 ± 300 yr B.P. (WK1260: P. C. Froggatt & D. J. Lowe unpubl. data 1988).

Loisels Pumice

Loisels Pumice (Wellman 1962) is a distinctive, dense, grey-white banded rhyolitic pumice found in beach deposits throughout the east coast of New Zealand and on Chatham Island (B.G. McFadgen pers. comm. 1987). Its identity and relationship to some other sea-rafted pumices was discussed by Pullar et al. (1977). Loisels Pumice has proved particularly valuable for coastline and archaeological studies (e.g., McFadgen 1985). The pumice is highly vesicular with a honeycomb texture resembling a foam, and has a mineralogy of hypersthene-augite-labradorite. The appearance of the pumice and its glass chemistry (P. C. Froggatt unpubl. data) are unlike anything known from New Zealand volcanoes, and strongly resemble pumice erupted from some Pacific islands (e.g., Metis Shoal: Melson et al. 1970) or the pumice washed ashore from the South Sandwich Island eruption in 1962 (Coombs & Landis 1966). The exact source of Loisels Pumice is unknown, but is probably in the Pacific, judging from ocean current patterns. Radiocarbon ages on material associated with Loisels Pumice are listed in Appendix 1. The ages form two clusters with pooled mean ages of 610 ± 20 yr B.P. and 1250 ± 40 yr B.P. The older cluster of ages are on shell associated with a drift pumice of Loisels-like appearance and chemistry (P. C. Froggatt unpubl. data) from Tokerau Beach, Northland (N. Osborne pers. comm. 1989) suggesting there may be an older drift event. Sea-rafted pumices can be moved again by the sea after their initial deposition on the shore. They should be regarded as less reliable time markers than airfall tephra layers (Pullar et al. 1977).

Status of other named tephra deposits

(1) Ohui Ash, Papanetu Tephra
Ohui Ash (Wellman 1962) found at Ohui Beach on the Coromandel Peninsula is sea-rafted Taupo pumice (Pullar et al. 1977). Papanetu Tephra is distal Karapiti Tephra (Froggatt & Solloway 1986). Both names have lapsed.

(2) Leigh Pumice
Leigh Pumice is a sea-rafted pumice deposit named by Wellman (1962). Because the original type section is in doubt, Pullar et al. (1977) were unable to examine it in relation to other sea-rafted pumices. It thus has uncertain status and no value as a stratigraphic marker, and the name should lapse.

(3) Stent Ash
The Stent Ash (Wellman 1962) is a 1 cm thick, pink fine ash found within estuarine and peaty muds at the mouth of the Onaero River (Neall & Alloway 1986) and other coastal sections in north Taranaki. A sample collected from the central 5 mm of the layer, and sieved to exclude grains coarser than 0.25 mm, has a hypersthene-dominant mineralogy and a glass chemistry typical of a Holocene, Taupo-source tephra (P. C. Froggatt unpubl. data). It is probably Waimihia Tephra, based on stratigraphic grounds and ^{14}C ages on peat from beneath the tephra at several localities in Taranaki (Alloway et al. 1988; B. V. Alloway and D. J. Lowe unpubl. data).

(4) Named soil-forming "Ash" deposits
A number of terms, including "Tirau Ash", "Mairoa Ash", Waihi Ash", "Gisborne Ash", and "Whangamata Ash", were introduced during reconnaissance soil mapping in central North Island (Grange 1931; New Zealand Soil Bureau 1954). These terms were used to describe the composite parent materials of tephra-derived soils in different regions and are essentially geographical "hold-all" names, not geological formations. Subsequent studies on the parent materials of these soils have identified many of the constituent tephra formations (Pullar & Birrell 1973c; Hogg & McCraw 1983; Lowe 1988a). We thus recommend that the early terms be discontinued to avoid confusion, and suggest that soils with composite tephra parent materials are described instead, for example, as "post-Kawakawa Tephra deposits" or "post 20 000 year old tephra deposits including ... Tephra", as appropriate.

FERROMAGNESIAN MINERAL ASSEMBLAGES

Determination of the dominant ferromagnesian mineral assemblage is the best initial laboratory guide to tephra identification. The relative abundance of each mineral species, determined by point counting, is useful for identification, but experience has shown that the presence (but not absence) of key minerals is of most value. We stress, however, that positive correlations of tephra can commonly only be made using multiple criteria (e.g., Froggatt 1983; Lowe 1988a, b).

The observed mineral assemblages fall into six main groups, first recognised in part by Ewart (1963, 1968, 1971) and developed by Kohn (1973). These assemblages are listed below, with mineral species in usual order of abundance, followed by minerals that may or may not be present in small amounts (±). The diagnostic or dominant mineral in each assemblage is underlined:

(1) <u>hypersthene</u> ± augite ± hornblende
(2) hypersthene + <u>hornblende</u> ± augite
(3) hypersthene + hornblende + <u>biotite</u>
(4) hypersthene + <u>cummingtonite</u> ± hornblende
(5) hypersthene + <u>augite</u> ± hornblende
(6) <u>aegirine</u> ± riebeckite ± aenigmatite ± olivine ± tuhualite

Assemblage 4 (cummingtonite-bearing) is restricted to eruptives from the Haroharo complex within Okataina Volcanic Centre (Ewart 1968), and assemblage 6 is restricted to pyroclastics from Tuhua Volcanic Centre, Mayor Island (Marshall 1932, 1936; Buck et al. 1981; Hogg & McCraw 1983; Lowe 1988a). Tephra layers classified into each group are listed in Table 4. Some tephra formations show a change in mineral assemblage stratigraphically through the deposit and these have multiple listings.

CHRONOLOGY OF THE LATE QUATERNARY TEPHRA FORMATIONS

Age and date

We have used the term "age" rather than "date" for the chronology produced by the isotopic radiocarbon dating method, as recommended by Colman et al. (1987). A "date" is a specific point in time, whereas an "age" is an interval of time measured back from the present. Colman et al. (1987) and the North American Commission (1985) recommended the use of ***ka*** and ***Ma*** (thousand and million years ago, respectively) for ages, and the use of ***yr B.P.*** for conventional radiocarbon ages measured from A.D. 1950.

Half-lives, secular and reservoir corrections

All ages listed and discussed here are "conventional ages" based on the old (Libby) half life of 5568 ± 30 years, rather than the "new" half life of 5730 ± 40 years. We have not converted any ages to new half life, and have determined calendar ages for only two tephra formations. The recent detailed curves and tables of Stuiver & Pearson (1986) or Stuiver & Becker (1986) can be used for this purpose. The ages obtained on shell samples (marine carbonates) have not been corrected for the reservoir effect.

Numerous ages have become available for nearly all the tephra layers erupted within the range of radiocarbon dating (until recently about 40 000 years). Some of these ages have later proved unreliable for dating a specific tephra. In some cases the tephra identity or exact sample location is in doubt; in others, multiple ages or stratigraphic successions of ages suggest that any single age could be anomalous. The availability of paired ages from above and below a tephra, especially in peat or organic lake sediment, has considerably strengthened the available chronology (e.g., Howorth et al. 1980; Lowe et al. 1980; Lowe 1988a).

Published ages are scattered through many papers, some not dealing primarily with tephrostratigraphy, and it is often difficult to locate all ages for a tephra layer and to assess their value. We have listed in Appendix 1 (updated copies are available from either author) details of all the ages available to us (total 384) for each tephra, together with an assessment of the value of each age for dating that tephra. We have then selected the most reliable ages and calculated the pooled mean, weighted by the standard deviation, on each age determination (Ward & Wilson 1978; Gupta & Polach 1985), assuming the ages are normally distributed. The weighted mean (Ap) and the standard error of the mean of the ages (se_{Ap}) are calculated from the individual ages (A_i) and associated errors (se_i) thus:

$$Ap = \Sigma (A_i / se_i^2) / \Sigma 1 / se_i^2$$

$$se_{Ap} = (\Sigma 1 / se_i^2)^{-1/2}$$

Table 1 lists these mean ages and pooled errors and the number of reliable ages used to calculate the mean. Several tephra formations still require further ages, and some of the older tephras from both Okataina and Taupo remain undated (Table 1 and Appendix 1).

AGES OF SOME TEPHRA FORMATIONS

Kaharoa Tephra Formation

The 15 available ages on Kaharoa Tephra (Appendix 1) range from 610 ± 60 yr B.P. (NZ1765) to 980 ± 60 yr B.P. (NZ7472). The ages are on wood, charcoal, and peat within and bracketing the tephra but there are no consistent differences in age between sample type, nor is there any evidence for a prolonged hiatus in the eruption of Kaharoa Tephra (I. A. Nairn pers. comm. 1984). Consequently, we have treated all ages as valid and representing the same event. They give a pooled mean age of 770 ± 20 years. This age converts to a calibrated (calendar years) date of A.D. 1270 with a 1σ range of A.D. 1264–1275 (Stuiver & Pearson 1986).

Taupo Tephra Formation

Healy (1964b) was the first to calculate a weighted mean age for Taupo Tephra of 1819 ± 17 yr B.P., updated to 1820 ± 80 yr B.P. by Froggatt (1981d). Wilson et al. (1980) claimed literary evidence for this eruption in Roman and Chinese records. Objections were raised by Froggatt (1981e), and Stothers & Rampino (1983) demonstrated errors in the translation of the Roman text used by Wilson et al. (1980) and suggested that the literary reference was to a supernova. There is no evidence that the Chinese reference was to an eruption and, furthermore, it is not dated with sufficient accuracy to constrain the age of Taupo Tephra.

Calendar age

The mean radiocarbon age for Taupo Tephra (Table 1) is 1850 ± 10 yr B.P., based on 41 ages. Conversion of this age to a calendar age is problematic, falling in a period of rapid ^{14}C fluctuation (multiple curve intercepts) and low curve probability (large error). The curves of Stuiver & Pearson (1986), based on a 20 year tree-ring series, convert this age to A.D. 214 with a 1σ range of A.D.138–230 after the 30 year hemisphere correction has been subtracted (Stuiver & Pearson 1986). Curve matching of a sequence of ^{14}C ages on tree rings from trees killed by the Taupo eruption (J. G. Palmer pers. comm. 1988) gives a date of A.D. 177 (1σ range of A.D. 166–195).

Palmer et al. (1988) deduced that the eruption occurred in mid-late summer, because trees destroyed by the eruption do not show an outer latewood ring. This is substantiated by

Table 4 The dominant ferromagnesian mineral assemblages for the late Quaternary silicic tephra deposits, listed by mineral assemblage (see text), volcanic centre, and relative age.

ASSEMBLAGE 1	ASSEMBLAGE 2	ASSEMBLAGE 3	ASSEMBLAGE 4	ASSEMBLAGE 5	ASSEMBLAGE 6
Hyp ± aug ± hbl	**Hyp + hbl ± aug**	**Hyp + hbl + bio**	**Hyp + cgt ± hbl**	**Hyp + aug ± hbl**	**Aegirine**
Taupo VC	**Okataina VC**	**Okataina VC**	**Okataina VC**	**Okataina VC**	**Tuhua VC**
Taupo (all members)	Mamaku	Kaharoa	Whakatane	Hauparu	Tuhua
Mapara	Waiohau	Rotorua (top part)	Rotoma	Te Mahoe	
Whakaipo	Rotorua (lower part)	Rerewhakaaitu	Rotoiti (all members except Matahi)	Maketu	
Waimihia (both members)	Te Rere	Okareka			
Hinemaiaia	Omatoroa	Earthquake Flat			
Motutere	Awakeri	Rotoiti (top part)			
Opepe	Mangaone				
Poronui	Tahuna				
Karapiti	Ngamotu				
	Taupo VC	**Maroa VC**			
	Kawakawa (both members)	Puketarata			
	Poihipi				
	Okaia				
	Tihoi				
	Waihora				
	Otake				

Clarkson et al. (1988) who examined the forest preserved at Pureora and found fruits and seeds only from early fruiting species.

Kawakawa Tephra Formation

Kawakawa Tephra is the most widespread late Quaternary tephra studied and provides an important timeplane near the nadir of the Last Stadial of the Last Glacial (Vucetich & Pullar 1969). All radiocarbon ages summarised by Vucetich & Howorth (1976a), two ages from Buller Gorge (Campbell 1986; Wilson et al. 1988), and four accelerator mass-spectrometry ages on pretreated samples from Westland (Hammond et al. 1988a, b) are on organic sediment associated with the tephra layer. These 12 ages have a pooled mean of 20 220 ± 115 years. Early attempts to date directly the eruption using charred material in Oruanui Ignimbrite have produced four sets of near-infinite ages: >45 000 years, resampled to give 32 320 ± 1750 yr B.P. (NZ3128 and NZ3211; S. Self pers. comm. 1980); >42 100 yr B.P., and >45 600 yr B.P. (NZ4575 and NZ4576; Froggatt 1982a). On detailed examination the material sampled in both cases was found to be charred lignite rather than extant vegetation and thus does not date any eruptive event. A fission-track age on glass sampled from North Canterbury is 20 300 ± 7100 years old (Kohn 1979).

Recently, Wilson et al. (1988) dated four samples of fine charcoal fragments from within the deposit itself (Oruanui Ignimbrite), giving a pooled mean of 22 590 ± 230 yr B.P. This age is significantly older (c. 1290 years) than the optimal pair of ages (21 300 ± 450 yr B.P.) from Buller Gorge (Campbell 1986). Charcoal is considered to give more reliable ages than peat as the charcoal is formed by the eruptive event itself and is generally less susceptible to contamination. The discrepancy in ages may be due to different sample pretreatment procedures, but the peat and sediment may be mildly contaminated by younger carbon. The effects of various pretreatments on contaminants in samples of organic silt and peat associated with Kawakawa Tephra in Westland are currently being assessed (Hammond et al. 1988a, b).

Mangaone, Awakeri, and Omataroa Tephra Formations

The pooled mean age of 27 730 ± 350 yr B.P. for Mangaone Tephra is not significantly different from that of 28 220 ± 630 yr B.P. for Omataroa Tephra (Table 1). However, Awakeri Tephra and Mangaone Tephra both underlie Omataroa Tephra stratigraphically (Howorth 1975), and hence are older. If all the ages on Omataroa Tephra are accepted as valid, then some of the younger ages obtained on Mangaone Tephra (i.e. those less than c. 27 000 years ago) are likely to be underestimates. On this basis, Mangaone Tephra may have been erupted c. 30 000 years ago.

Rotoiti Tephra Formation

Several radiocarbon ages on this formation are close to, or beyond, the current limits of the dating technique (McGlone et al. 1984). As several infinite ages have been returned (Appendix 1) and must be regarded as valid ages, the finite ages of c. 42 000–44 000 years are likely to be minima. The preservation of Rotoehu Ash at Mahia Peninsula on a marine-cut surface thought to be 54 000 ± 4 000 years old (K. R. Berryman pers. comm. 1985), and between the second and third loess units on Mamaku Plateau (Kennedy 1987), suggests an age of c. 50 000– 55 000 years for this formation, by comparison with the oxygen isotope stage chronology.

A U-Th disequilibrium age on whole sample and titanomagnetite separates is c. 71 000 ± 6000 years (Ota et al. 1989b). However, this age should be regarded as provisional because the isochron from which the age is derived (Ota et al. 1989, fig. 4) is essentially based on only one data point, that of the whole rock sample. The other three points are on the equilibrium line or within two standard deviations of it (C. H. Hendy pers. comm 1989). In addition, analyses of at least two mineral species, and of ^{234}U as well as ^{238}U, are desirable in dating pyroclastic deposits such as Rotoehu Ash (Hendy et al. 1980). Other dating methods, such as accelerator mass-spectrometry, low-level scintillation spectrometry, and thermoluminescence dating have not yet produced definitive ages for this formation.

DISTRIBUTION OF LATE QUATERNARY TEPHRA

Isopach maps showing the thickness distribution of most late Quaternary tephras are available. Many of the earlier maps were recompiled and updated by Pullar & Birrell (1973a, b). Maps based on new data for some of the Taupo and Rotorua subgroup tephras and Tuhua Tephra have been published (Walker 1980, 1981a, b; Froggatt 1981b; Froggatt & Solloway 1986; Hogg & McCraw 1983; Lowe 1988a). Table 1 lists the references to published isopach maps for each tephra. The distribution of some of the late Pleistocene tephras from Taupo is poorly known because of inadequate exposure.

Nearly all the isopach maps show a dominant easterly distribution pattern with only a few tephra deposits (Ka, Mk, Re) having a more northerly aspect. Despite the large volume and widespread distribution of Rotoehu Ash, it has not yet been located south of Taihape and is rarely seen south of Taupo. Its occurrence in Northland is documented in Lowe (1987).

Kawakawa Tephra is the most widely distributed late Quaternary tephra in New Zealand, being found throughout most of the country and in many offshore cores. It is well preserved on the West Coast (Mew et al. 1986), Marlborough (Campbell 1979, 1986), Canterbury (Kohn 1979), and Chatham Island where it was locally named Rekohu Ash (Hay et al. 1970; Mildenhall 1976). Glass shards attributed to Kawakawa Tephra have been isolated from loess near Timaru (Eden & Froggatt 1988) and Southland (McIntosh et al. 1988).

ERUPTED VOLUMES OF LATE QUATERNARY TEPHRA

Methods of calculating erupted volumes vary considerably, but all are approximations based on extrapolations of assumed relationships of thickness or volume distribution. All methods require a reliable isopach map from which variations of thickness and volume with distance or area can be calculated. Approximate volumes of many of the late Quaternary tephra deposits (Pullar & Birrell 1973a; Vucetich & Pullar 1973; Howorth 1975; Vucetich & Howorth 1976b) were first calculated from the circular isopach formula of Cole & Stephenson (1972) and are certainly underestimates. A review of methods and a consistent set of calculations were presented by Froggatt (1982b). Other recent calculations, based on a

Table 5 The volume of airfall tephra, ignimbrite, and lava (extrusives) produced during each eruptive episode. Asterisks indicate volumes are estimates only and are not based on calculations from isopach maps or other reliable thickness data. Blank values show that extrusive bodies or ignimbrite have not yet been positively identified for that eruptive episode, or an estimate is currently difficult to determine. Erupted volumes have been converted to magma volumes using densities for silicic airfall tephra, unwelded ignimbrite, basaltic tephra, silicic lava, and silicic magma of 1.0, 1.25, 2.0, 2.3, and 2.3 Mg/m³, respectively.

	Volume (km³)			
Formation & members	Airfall	Ignimbrite	Lava	Magma
Okataina Volcanic Centre				
Tarawera Tephra				
Rotomahana Mud	<1			
Tarawera Scoria	2			1.5
Kaharoa	5		2.5	4.0
Rotokawau	0.7		0.5	
Whakatane	10		9	13.5
Mamaku	6		15	17.5
Rotoma	12		2	7.0
Waiohau	18		4	12
Rotorua	7		1	4.0
Rerewhakaaitu	7		2	5.0
Okareka	8		5	8.5
Te Rere	6*		8	11.5
Omataroa	16	5		10
Awakeri	2			1.0
Mangaone	16	6		10
Hauparu	10			4.5
Te Mahoe	0.3			0.1
Maketu	15			6.5
Tahuna	2*			1
Ngamotu	2			1
Earthquake Flat Tephra				
Rifle Range Ash	2*			1
Earthquake Flat Ig.		5*		2.7
Rotoiti Tephra	91	150		120.5
Rotoehu Ash	90			40
Rotoiti Ignimbrite		150		80
Matahi Scoria	1*			0.5
Total for Okataina	**238**	**166**	**49**	**242.8**
Taupo Volcanic Centre				
Taupo Tephra	17.5	70	0.2	45.5
Taupo Ignimbrite		70		38
Taupo Lapilli	12			5
Rotongaio Ash	1			0.5
Hatepe Ash	2.5			1.0
Hatepe Lapilli	2			1
Mapara	2			1
Whakaipo	2			1
Waimihia Tephra	14	5		9.0
Waimihia Ignimbrite		5		3
Waimihia Lapilli	14			6.0
Hinemaiaia	3		0.1	1.5
Motutere	1		0.1	0.6
Opepe	4			2.0
Poronui	3		0.5	2.0
Karapiti	2		0.5	1.5
Kawakawa Tephra	70	150		112
Oruanui Ignimbrite		150		82
Aokautere Ash	70			30
Poihipi	1			0.5
Okaia	7			3
Tihoi	5			3.0
Waihora	1			0.5
Otake	2			1
Total for Taupo:	**134.5**	**225**	**1.4**	**184.1**
Maroa Volcanic Centre				
Puketarata	1*		0.1	1
Tuhua Volcanic Centre				
Tuhua	1*			1
Total for Taupo Volcanic Zone (in the last c. 50 000 years):	**374.5**	**391**	**50.5**	**428.9**

variety of methods, are given in Froggatt (1981a, c), Froggatt & Solloway (1986), Houghton & Wilson (1986), Nairn (1981, 1986), Walker (1979, 1980, 1981a), Walker et al. (1984), and Wilson et al. (1986).

The current best estimates of volume of airfall tephra, ignimbrite, and lava for each formation, from the references listed above, are given in Table 5 and have also been converted to equivalent magma volumes. The list indicates that the two largest late Quaternary eruptions, volumetrically, were the Kawakawa and Rotoiti eruptive episodes. The total volume of rhyolitic material erupted from TVZ within the last c. 50 000 years is estimated at about 370 km³ of airfall tephra, 390 km³ of ignimbrite, and 50 km³ of extrusive lava, together equivalent to about 430 km³ of magma.

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APPENDIX 1

Radiocarbon ages relevent to New Zealand tephra layers

All the radiocarbon ages (in conventional years B.P.) known to us for each tephra formation are listed here. They are given in alphabetical order by tephra formation, then by laboratory and age number. NZ and NZA = gas counter and accelerator mass spectrometry, respectively, at New Zealand Radiocarbon Dating Laboratory, DSIR, Lower Hutt; WK = University of Waikato Radiocarbon Dating Laboratory, Hamilton; Q = Godwin Laboratory, University of Cambridge, Cambridge; GAK = Gakushuin University Radiocarbon Dating Laboratory, Tokyo. All ages are quoted as conventional ages based on the old half life (5568 ± 30 years). The material dated is listed as C = charcoal, CW = charred wood, E = extract from chemical treatment, H = humus, G = gyttya (lake sediment), M = organic mud, P = peat, Po = pollen, Pf = fine peat, Pr = roots in peat, R = residue from chemical treatment, S = soil, SE = seeds, SH = shell, W = wood. The reference where first quoted in full or discussed in relation to the tephra is numbered; the key is below. Our assessment of the value of the age is based on the type of material dated, proximity to the tephra, whether one of a paired set, and whether any doubt about the sample or tephra identity exists. The ratings are 1 = optimal; 2 = useful; 3 = little current value. Ages with ratings of 1 or 2 have been used to calculate error-weighted means which are listed in Table 1. For ages currently unpublished, the sources (pers. comm. 1988 and 1989) are lettered and listed below. In the Comments column, min = sample overlies tephra; max = sample underlies tephra.

1 Buck et al. (1981)
2 Campbell (1986)
3 Cole (1970a)
4 Froggatt (1981c)
5 Froggatt (1981b)
6 Froggatt & Solloway (1986)
7 Goh & Pullar (1977)
8 Grant-Taylor & Rafter (1963)
9 Grant-Taylor & Rafter (1971)
10 Green (1987)
12 Green & Lowe (1985)
13 Hay et al. (1970)
14 Healy (1964b)
15 Hogg & McCraw (1983)
16 Hogg et al. (1987)
17 Howorth & Vucetich (1976)
18 Howorth & Ross (1981)
19 Howorth et al. (1980)
20 Hull (1986)
21 Kennedy et al. (1978)
22 Kohn et al. (1981)
23 Lowe (1986)
25 Lowe (1988a)
26 Lowe & Green (1987)
27 Lowe & Hogg (1986)
28 Lowe et al. (1980)
29 McGlone (1983a)
30 McGlone (1981)
31 McGlone (1983b)
32 McGlone et al. (1984)
33 Mildenhall (1976)
34 Nairn (1986)
35 Nairn (1980)
36 Nairn (1981)
37 Pullar (1970)
38 Pullar et al. (1973)
39 Pullar & Heine (1971)
40 Topping & Kohn (1973)
42 Vucetich & Howorth (1976a)
43 Vucetich & Pullar (1964)
44 Vucetich & Pullar (1969)
45 Vucetich & Pullar (1973)
46 Mew et al. (1986)
47 Froggatt & Rogers (1990)
48 Wilson et al. (1988)
49 Green (1963)
50 Wellman (1962)
51 Leahy (1974)
52 McFadgen (1982, 1985)
53 Houghton et al. (1985)
54 Berryman & Hull (1984)
55 Pullar et al. (1977)
56 Pullar (1973)
57 Harris (1963)
58 Houghton & Wilson (1986)
59 Ota et al. (1988)
60 Atkinson (1973)
61 Hammond et al. (1988a,b)
62 Dahm (1987)
63 Abrahamson (1987)
64 de Lange (1989)

Sources of unpublished dates:

a P. C. Froggatt
b B. V. Alloway & D. J. Lowe
c P. L. Singleton
d D. J. Lowe & R. M. Newnham
e N. M. Kennedy
f D. J. Lowe & A. G. Hogg
g B. Clarkson
h B. V. Alloway
i N. Osborne
j J. Dahm & A. G. Hogg
k I. A. Nairn
l G. N. A. Wigley & D. J. Lowe
z Radiocarbon files, Institute of Nuclear Sciences, DSIR

Tephra formation	Lab	C14 Number	Age (yr B.P.)	Std deviation	Sample type	Assessed value	References	Collector	Comments
Hauparu	NZ	3404	39,000	5600	M	2	32	Howorth	min (=R5031/1)
Hauparu	NZ	3405	35,700	1300	M	2	32	Howorth	max (=R5031/2)
Hinemaiaia	NZ	3160	4,220	60	P	1	23	Neall	min
Hinemaiaia	NZ	3161	4,800	50	P	1	23	Neall	max (min for Wk)
Hinemaiaia	NZ	4574	4,650	80	C	1	4,23	Froggatt	
Hinemaiaia	WK	496	4,490	60	P	1	23,27,16	Rogers, Lowe, Hogg	max (also min for Wk)
Hinemaiaia	WK	497	4,530	60	P	1	23,27,16	Rogers, Lowe, Hogg	max (also min for Wk)
Hinemaiaia	WK	541	4,490	70	G	1	23,16,25	Lowe, Green, Hendy	min
Hinemaiaia	WK	542	4,470	70	G	1	23,16,25	Lowe, Green, Hendy	max
Hinemaiaia	WK	662	4,260	140	G	1	23,16,25	Lowe, Hendy, Ouellet	max (also min for Wk)
Hinemaiaia	WK	663	3,510	150	G	1	16,25	Lowe, Hendy, Ouellet	min (?contaminated)
Hinemaiaia	WK	1336	4,580	120	P	3	64	de Lange, Crowcroft, Gilmour	min
Hinemaiaia	WK	1337	4,640	110	P	1	64	de Lange, Crowcroft, Gilmour	max
Hinemaiaia	WK	1437	4,550	100	P	1	l	Wigley, Edwards, et al.	min
Hinemaiaia	WK	1438	4,490	90	P	1	l	Wigley, Edwards, et al.	max
Kaharoa	GAK	10446	920	100	S	2	59	Ota, Beanland, Berryman	soil overlying Ka
Kaharoa	NZ	10	930	70	W	1	8,43	Baumgart, Vucetich	max
Kaharoa	NZ	872	850	60	P	2	55,36	Cox	peat at Whangarei
Kaharoa	NZ	1765	610	60	C	2	55,36	Cox	charcoal in humus
Kaharoa	NZ	4304	950	60	C	1	36	Nairn	
Kaharoa	NZ	4803	680	85	P	1	30,36	Lawlor & McGlone	min
Kaharoa	NZ	4804	650	60	P	1	30,31,36	Lawlor & McGlone	max
Kaharoa	NZ	4991	670	60	C	1	29,36,34	Nairn	
Kaharoa	NZ	4992	1,145	65	W	3	36	Nairn	max (from large tree)
Kaharoa	NZ	4993	780	58	C	1	36	Nairn	
Kaharoa	NZ	5087	940	90	C	1	36,34	Nairn & Bishop	
Kaharoa	NZ	5993	630	60	C	1	36	Nairn	
Kaharoa	NZ	7472	980	60	P	1	59	Ota, Beanland, Berryman	max
Kaharoa	WK	1013	710	110	P	1	d	Lowe, Newnham, Lowe	min
Kaharoa	WK	1014	680	130	P	1	d	Lowe, Newnham, Lowe	max
Kaharoa	WK	1346	660	45	CW	1	f	Lowe	sample in block and ash flow

(*Continued on next page*)

(Continued from previous page)

Tephra formation	Lab	C14 Number	Age (yr B.P.)	Std deviation	Sample type	Assessed value	References	Collector	Comments
Karapiti	NZ	1372	9,780	170	W	1	40,6	Topping	min
Karapiti	NZ	1373	9,700	210	P	1	40,6	Topping	min
Karapiti	NZ	1374	9,790	160	W	1	40,6	Topping	max
Karapiti	NZ	4847	9,910	130	C	1	5,6	Froggatt	
Kawakawa	NZ	12	20,670	300	W	1	39,8,44,42	Berry	
Kawakawa	NZ	330	20,000	500	P	2	8,44,42		in Hinuera Fm alluvium
Kawakawa	NZ	373	39,600	2000	P	3	8,13	Mutch	peat 0.3 m beneath Rekohu Ash
Kawakawa	NZ	520	20,500	430	P	1	9,44,42,60	Pohlen, Harris	max
Kawakawa	NZ	521	21,900	510	P	1	9,44,42,60	Grant-Taylor	min
Kawakawa	NZ	522	35,000	1700	P	3	9,44,42		peat 1.5 m beneath tephra
Kawakawa	NZ	1056	19,850	310	W	1	39,36,42	Nairn	
Kawakawa	NZ	3103	20,100	400	W	1	33		Rekohu Ash
Kawakawa	NZ	3128	>45,000	0	P	3	z	Self	lignite?
Kawakawa	NZ	3211	32,320	1750	P	3	z	Self	repeat of NZ3128
Kawakawa	NZ	4575	42,100	5190	C	3	a	Froggatt	lignite?
Kawakawa	NZ	4576	>45,600	0	C	3	a	Froggatt	lignite?
Kawakawa	NZ	6557	15,600	250	P	3	46	Moar	contaminated
Kawakawa	NZ	7144	21,300	450	P	2	2	Campbell	max
Kawakawa	NZ	7373	21,300	460	P	2	48	Campbell	min
Kawakawa	NZA	239	15,204	239	E	3	61	Hammond	lipids from NZA262
Kawakawa	NZA	0	13,146	1428	E	3	61	Hammond	humic acids from NZA262 (=4b in ref 61)
Kawakawa	NZA	240	14,458	364	E	3	61	Hammond	lipids from NZA262
Kawakawa	NZA	256	8,710	300	E	3	61	Hammond	hydrolysate from NZA262
Kawakawa	NZA	258	7,772	267	E	3	61	Hammond	fulvic acid from NZA262
Kawakawa	NZA	262	12,563	366	P	3	61	Hammond	untreated peat
Kawakawa	NZA	263	17,898	336	R	3	61	Hammond	residue from NZA262
Kawakawa	NZA	264	5,975	248	E	3	61	Hammond	HCl:HF pretreatment
Kawakawa	NZA	269	13,869	246	E	3	61	Hammond	humic acid from NZA262
Kawakawa	NZA	270	17,517	462	R	3	61	Hammond	residue from NZA262
Kawakawa	NZA	271	12,523	170	R	3	61	Hammond	residue from NZA262
Kawakawa	NZA	287	12,079	344	E	3	61	Hammond	hydrolysate from NZA262
Kawakawa	NZA	293	18,807	377	R	2	61	Hammond	HNO3 hydrolysis of NZA262
Kawakawa	NZA	328	11,870	122	P	3	61	Hammond	untreated (min)
Kawakawa	NZA	329	19,635	331	R	2	61	Hammond	HNO3 hydrolysis of NZA328
Kawakawa	NZA	335	15,240	510	Po	3	61	Hammond	pollen from NZA262
Kawakawa	NZA	371	15,540	240	R	3	61	Hammond	HNO3 hydrolysis
Kawakawa	NZA	372	20,670	470	R	2	61	Hammond	HNO3 hydrolysis
Kawakawa	NZA	373	19,170	480	R	2	61	Hammond	HNO3 hydrolysis
Kawakawa	Q	2665	22,630	450/430	C	1	48	Wilson	charcoal in ig.
Kawakawa	Q	2666	22,470	410/380	C	1	48	Wilson	charcoal in ig.
Kawakawa	Q	2667	22,630	470/440	C	1	48	Wilson	charcoal in ig.
Kawakawa	Q	2668	22,720	580/540	C	1	48	Wilson	charcoal in ig.
Loisels	NZ	354	640	50	C	2	49,52	Golson	below Ls
Loisels	NZ	396	799	40	C	2	50,52	Wellman	below Ls
Loisels	NZ	631	520	40	C	3	50,52	Wellman	above Ls, but long-lived tree
Loisels	NZ	632	700	60	SH	2	50,52	Wellman	above Ls
Loisels	NZ	651	930	50	W	3	50,52	Wellman	well below Ls
Loisels	NZ	1296	450	40	SH	2	51,52	Leahy	above Ls
Loisels	NZ	1297	520	40	SH	2	51,52	Leahy	above Ls
Loisels	NZ	4726	973	40	SH	3	i	Enright, Osborne	shell above Ls
Loisels	NZ	4727	1,233	28	SH	3	i	Enright, Osborne	shell below Ls
Loisels	NZ	7291	1,030	60	SH	3	i	Enright, Osborne	shell bank seaward of Ls
Loisels	NZ	7560	1,360	45	SH	3	i	Enright, Osborne	shell below Ls
Loisels	NZ	7568	726	74	SH	3	i	Enright, Osborne	shell with Ls
Loisels	NZ	7613	1,441	34	SH	3	i	Enright, Osborne	shell above Ls
Loisels	NZ	7648	2,383	54	SH	3	i	Enright, Osborne	shell with mixed Ls and Taupo Pumice
Loisels	NZ	7649	1,449	52	SH	3	i	Enright, Osborne	shell with Ls
Loisels	WK	874	780	165	C	2	63	Abrahamson	in paleosol below Ls
Mamaku	NZ	719	8,050	105	C	2	39,9	Pullar	max (paleosol on Rm)
Mamaku	NZ	1152	7,050	77	C	1	39,45,7	Pullar, Birrell	
Mamaku	NZ	1399	7,760	135	E	2	7	Goh	extract of NZ1452
Mamaku	NZ	1400	7,730	135	R	2	7	Goh	residue of NZ1452
Mamaku	NZ	1401	6,430	135	E	2	7	Goh	extract of NZ1453
Mamaku	NZ	1402	7,410	135	R	2	7	Goh	residue of NZ1453
Mamaku	NZ	1452	8,030	150	C	1	7	Goh	
Mamaku	NZ	1453	7,440	150	C	1	7	Goh	
Mamaku	NZ	4310	7,390	110	C	1	36	Nairn	
Mamaku	NZ	4311	7,620	110	C	1	36	Nairn	
Mamaku	NZ	4542	6,340	100	P	3	a	Froggatt	Poukawa: ?contaminated
Mamaku	NZ	4939	7,440	70	C	1	36	Nairn	
Mamaku	NZ	5033	7,340	140	C	1	36	Nairn	
Mamaku	NZ	6741	6,880	60	P	1	c	Singleton	underlies ash
Mamaku	NZ	7029	4,740	75	P	3	c	Singleton	overlies ash; root contam.
Mamaku	NZ	7030	6,360	90	P	2	c	Singleton	underlies ash; ?contam.
Mamaku	NZ	7039	4,640	70	P	3	c	Singleton	overlies ash; root contam.
Mamaku	NZ	7043	4,440	70	P	3	c	Singleton	overlies ash; root contam?
Mamaku	NZ	7058	6,980	90	P	1	c	Singleton	underlies ash
Mamaku	NZ	7557	7,660	80	C	1	k	Nairn	dates dome collapse ?
Mamaku	WK	227	6,830	90	G	1	12,16,25	Lowe, Green	min
Mamaku	WK	228	8,170	90	G	3	16,25	Lowe, Green	contaminated
Mamaku	WK	524	7,920	80	G	2	16,25	Lowe, Green	max
Mamaku	WK	525	5,800	70	G	3	16,25	Lowe, Green	min (max for Tu; thick sample)
Mamaku	WK	547	7,980	150	G	3	16,25	Lowe, Green, Hendy	max (not adjacent to tephra)
Mamaku	WK	562	5,850	70	P	3	16	Lowe, Hogg, Lane	min (not adjacent to tephra)
Mamaku	WK	570	7,200	120	G	1	16,25	Lowe, Green, Hendy	max
Mamaku	WK	571	7,140	110	G	1	16,25	Lowe, Green, Hendy	min
Mamaku	WK	604	5,410	150	G	3	16	Lowe, Green, Boubee, Bergin	min (thick sample)
Mamaku	WK	612	8,560	80	P	3	16	Lowe, McLeod	min (tentatively ident.) reworked sed

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Tephra formation	Lab	C14 Number	Age (yr B.P.)	Std deviation	Sample type	Assessed value	References	Collector	Comments
Mamaku	WK	626	8,030	330	G	3	16	Lowe, Green, Boubee, Bergin	max (diluted; thick sample)
Mamaku	WK	1269	7,060	120	P	1	64	de Lange, Champion	straddles tephra
Mamaku	WK	1271	7,030	100	P	1	64	de Lange, Crowcroft, Gilmour	straddles tephra
Mangaone	NZ	866	21,900	400	C	3	39,9	Pullar, King	contaminated with roots
Mangaone	NZ	867	26,300	700	C	3	39,44	Pullar	contaminated with roots
Mangaone	NZ	868	30,100	1300	C	1	39,32	Pullar	
Mangaone	NZ	1132	29,400	800	S	1	39,32	Pullar, Juene	
Mangaone	NZ	1556	26,100	800	C	1	32		
Mangaone	NZ	1610	26,800	1400	E	2	32		extract of NZ1556
Mangaone	NZ	1611	25,000	700	R	2	32		residue of NZ1556
Mangaone	NZ	1812	35,300	2200	C	1	32		
Mangaone	NZ	1859	31,400	1500	C	2	32		(=R4803)
Mangaone	NZ	1944	33,300	2000	C	1	36,34	Nairn	
Mangaone	NZ	3406	27,000	1000	P	1	32	Howorth	(=R5031/3)
Mangaone	NZ	3407	31,000	2100	P	1	32	Howorth	(=R5031/4)
Mapara	NZ	157	2,270	55	C	1	39,8,14	Healy	
Mapara	NZ	178	2,100	100	C	1	8,14	Healy	
Mapara	NZ	1068	2,010	60	P	1	9,45,39	Pullar	min
Mapara	NZ	1069	2,150	50	P	1	9,45,39	Pullar	max
Mapara	WK	1289	2,130	60	P	2	64	de Lange, Rosenberg	straddles tephra; ident uncertain
Mapara	WK	1503	2,230	50	P	1	l	Wigley	max
Motutere	NZ	3950	5,680	130	P	1	4,19,23	Howorth	min
Motutere	NZ	3951	5,370	90	P	1	4,19,23	Howorth	max
Motutere	NZ	4846	5,370	90	C	1	4,23	Froggatt	
Ohakune	WK	1260	31,500	300	C	1	a,f	Froggatt	charcoal in distal tephra
Oira	NZ	370	8,390	135	W	1	8,53	Brothers	underlies Ruru Pass Tephra (ref 58)
Oira	WK	105	8,000	70	CW	1	1	Buck	underlies Ruru Pass Tephra (ref 58)
Omataroa	NZ	876	27,900	850	C	1	9,39,32,44	Cox	see ref 32
Omataroa	NZ	1136	29,700	1500	M	1	39,32	Pullar, Kohn	min
Omataroa	NZ	1147	27,900	1200	M	1	39,32	Pullar, Holmes	max
Opepe	NZ	185	8,850	1000	C	2	45,39,8,43,14	Vucetich	
Opepe	WK	229	7,650	160	G	3	16,25	Lowe, Green	compressed contam. sample
Opepe	WK	230	9,370	210	G	1	12,16,25	Lowe, Green	max
Opepe	WK	492	8,710	80	P	1	27,16	Rogers, Lowe, Hogg	min
Opepe	WK	520	8,930	100	G	1	16,25	Lowe, Green	max
Opepe	WK	521	8,670	110	G	1	16,25	Lowe, Green	min
Opepe	WK	707	8,700	130	G	1	16,25	Lowe, Hendy, Ouellet	max
Opepe	WK	713	8,990	220	G	2	16,25	Lowe, Hendy, Ouellet	straddles tephra
Opepe	WK	1000	7,910	70	P	3	47	Rogers	? too young
Opepe	WK	1291	9,060	110	P	1	64	de Lange, Rosenberg	max
Opepe	WK	1292	9,050	120	P	1	64	de Lange, Rosenberg	min
Opepe	WK	1320	8,390	280	P	3	64	de Lange, Champion	straddles tephra (too young)
Opepe	WK	1335	9,600	70	C	1	a,f	Froggatt	sample in ignimbrite
Poronui	WK	351	10,160	130	Pr	1	27,16	Rogers, Lowe, Hogg	max (coarse roots from WK352)
Poronui	WK	352	9,960	90	Pf	1	27,16	Rogers, Lowe, Hogg	max (fine peat residue from WK351)
Poronui	WK	491	9,560	80	P	1	27,16	Rogers, Lowe, Hogg	min
Puketarata	NZ	5391	9,180	170	S	3	a	Froggatt	contaminated
Rangitoto	NZ	220	750	50	SH	2	8	Brothers	in sand beneath ash
Rangitoto	NZ	222	770	50	C	1	8	Brothers	
Rerewhakaaitu	NZ	716	14,700	200	C	1	9,44,39,45	Pullar	sample in Ok Tephra
Rerewhakaaitu	NZ	1554	12,460	160	C	3	z		
Rerewhakaaitu	NZ	1607	12,510	160	C	3	z		
Rerewhakaaitu	WK	237	14,700	220	G	1	25,16,28	Lowe, Green	min
Rerewhakaaitu	WK	238	14,700	180	G	1	16,25,28,12	Lowe, Green	max
Rotoiti	NZ	0	>43,900	0	MW	1	39,17	Pullar, Kohn	N78/542
Rotoiti	NZ	0	27,900	1500	R	3	17	Pullar	residue of N77/553
Rotoiti	NZ	0	23,200	850	E	3	17	Pullar	extract of N77/553
Rotoiti	NZ	0	33,700	2300	C	3	17	Pullar	N77/553
Rotoiti	NZ	643	>41,000	0	W	2	9,39,32,44	Thompson	in underlying paleosol
Rotoiti	NZ	877	44,000	5300	P	1	9,39,32	Cox	95% prob. >43,700
Rotoiti	NZ	1126	41,700	3500	W	1	39,32	Nairn	
Rotoiti	NZ	4303	>40,400	0	C	2	36	Nairn	Nairn
Rotoiti	WK	590	>35,000	0	G	2	16	Lowe, Green, Boubee, Bergin	max (heavily diluted)
Rotokawau	NZ	7356	3,440	70	P	1	e	Kennedy	
Rotokawau	WK	939	2,260	70	P	3	10	Green, Lowe, Hogg	min (contam.)
Rotokawau	WK	940	2,820	60	P	3	10	Green, Lowe, Hogg	max (contam.)
Rotokawau	WK	941	2,360	60	P	3	10	Green, Lowe, Hogg	max (contam.)
Rotokawau	WK	942	2,700	60	P	3	10	Green, Lowe, Hogg	min (contam.)
Rotokawau	WK	943	2,380	130	Pr	3	10	Green, Lowe, Hogg	rootlets from WK939-942
Rotoma	NZ	719	8,050	105	C	2	9,39	Pullar	min (in paleo on Rm - max for Ma)
Rotoma	NZ	1199	7,330	235	C	1	39,38,45		
Rotoma	NZ	1943	8,830	90	C	1	36	Nairn	
Rotoma	NZ	1945	8,860	120	C	1	36,35,12	Nairn	
Rotoma	NZ	3089	7,040	250	C	2	7		
Rotoma	NZ	6020	8,745	41	C	1	z	Nairn	
Rotoma	NZ	6021	8,671	52	C	1	z		
Rotoma	NZ	6022	8,652	52	C	1	z		
Rotoma	NZ	6023	8,765	53	C	1	z		
Rotoma	NZ	6024	8,733	41	C	1	z		boiled in water
Rotoma	NZ	6025	8,772	53	C	1	z		boiled in water
Rotoma	NZ	6026	8,744	36	C	1	z		
Rotoma	NZ	6027	8,795	53	C	1	z		
Rotoma	NZ	6028	8,623	42	C	1	z		
Rotoma	NZ	6029	8,504	139	E	1	z		extract of NZ6028
Rotoma	NZ	6030	6,749	53	C	1	z		washed hot NaOH
Rotoma	NZ	6031	8,145	199	C	1	z		hot NaOH
Rotoma	NZ	6032	8,660	53	C	1	z		
Rotoma	NZ	6033	8,624	127	E	1	z		extract from hot NaOH

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Tephra formation	Lab	C14 Number	Age (yr B.P.)	Std deviation	Sample type	Assessed value	References	Collector	Comments
Rotoma	NZ	6034	8,754	53	C	1	z		hot NaOH
Rotoma	NZ	6035	8,510	111	E	1	z		extract hot NaOH
Rotoma	NZ	6036	8,595	52	C	1	z		Na4PO7
Rotoma	NZ	6037	9,509	281	E	3	z		extract Na4PO7
Rotoma	NZ	6310	8,904	41	C	1	z		
Rotoma	NZ	6362	8,610	52	R	1	z		residue Na4PO7
Rotoma	NZ	6371	7,406	135	E	3	z		extract Na4PO7
Rotoma	NZ	6385	8,759	52	R	1	z		residue Na4PO7
Rotoma	NZ	6399	8,696	102	E	1	z		extract Na4PO7
Rotoma	NZ	6410	8,233	51	R	1	z		residue Na4PO7
Rotoma	NZ	6753	8,662	52	R	1	z		residue Na4PO7
Rotoma	NZ	6761	8,373	113	E	1	z		extract Na4PO7
Rotoma	WK	229	7,650	160	G	3	16,25	Lowe, Green	min (reworked sed. not adjacent to tephra)
Rotoma	WK	493	5,440	170	Pr	3	27,16	Rogers, Lowe, Hogg	min (coarse roots from WK494: contam.)
Rotoma	WK	494	7,380	80	Pf	3	16,27	Rogers, Lowe, Hogg	min (fine peat residue of WK493: contam.)
Rotoma	WK	495	7,560	100	P	2	16,27	Rogers, Lowe, Hogg	min (?contam.)
Rotoma	WK	522	8,370	90	G	1	16,25,12	Lowe, Green	max
Rotoma	WK	523	8,350	100	G	1	16,25,12	Lowe, Green	min
Rotoma	WK	548	8,030	200	G	3	16,25	Lowe, Green, Hendy	min (reworked sed not adjacent to tephra)
Rotoma	WK	611	5,510	70	P	3	16	Shaw	min (sample not adjacent to tephra)
Rotoma	WK	705	7,520	130	G	2	16,25	Lowe, Hendy, Ouellet	min (sed. rate low)
Rotoma	WK	706	7,920	130	G	2	16,25	Lowe, Hendy, Ouellet	max (sed. rate low)
Rotoma	WK	711	8,000	170	G	2	16,25	Lowe, Hendy, Ouellet	straddles tephra
Rotoma	WK	932	7,720	70	P	2	10	Green, Lowe, Hogg	min
Rotoma	WK	933	9,820	210	G	2	10	Green, Lowe, Hogg	max
Rotoma	WK	934	9,890	180	G	2	10	Green, Lowe, Hogg	max
Rotoma	WK	935	7,560	70	P	2	10	Green, Lowe, Hogg	min
Rotoma	WK	936	8,520	80	W	1	10	Green, Lowe, Hogg	underlies tephra
Rotoma	WK	937	8,560	80	W	1	10	Green, Lowe, Hogg	within tephra
Rotoma	WK	938	8,530	80	W	1	10	Green, Lowe, Hogg	overlies tephra
Rotoma	WK	1270	8,510	100	P	1	64	de Lange, Champion	straddles tephra
Rotoma	WK	1293	8,310	110	P	1	64	de Lange, Rosenberg	max
Rotoma	WK	1319	8,240	70	P	1	64	de Lange, Rosenberg	min
Rotorua	NZ	1186	13,150	300	C	2	40	Topping	beneath ?Rr
Rotorua	NZ	1187	12,350	220	C	2	40	Topping	in tephra overlying ?Rr
Rotorua	NZ	1615	13,450	250	C	1	21,35,36	Nairn	
Rotorua	NZ	4183	6,650	0	C	3	z	Goh	
Rotorua	NZ	4185	12,810	580	C	1	z	Goh	
Rotorua	WK	235	12,900	310	G	1	16,25	Lowe, Green	min
Rotorua	WK	236	12,600	230	G	2	16,25	Lowe, Green	max (too young?)
Rotorua	WK	511	13,450	120	G	1	16,12,25	Lowe, Green	max
Rotorua	WK	512	12,800	150	G	1	16,25	Lowe, Green	min (thick sample)
Rotorua	WK	529	13,300	110	MP	2	16	Lowe, Hogg, Lane	max (tephra ident. uncertain)
Rotorua	WK	530	12,950	110	P	2	16	Lowe, Hogg, Lane	min (tephra ident. uncertain)
Rotorua	WK	572	12,650	230	G	3	16,25	Lowe, Green, Hendy	max (sed reworked)
Rotorua	WK	573	12,350	210	G	3	16,25	Lowe, Green, Hendy	min (sed reworked)
Taupo	WK	1502	1,890	50	P	1	l	Wigley	max
Taupo	NZ	1	1,820	150	C	1	14,8	Baumgart	
Taupo	NZ	3	1,970	150	C	1	14,8	Taylor	
Taupo	NZ	4	1,920	150	C	2	14	Taylor	water sorted
Taupo	NZ	37	1,780	60	C	1	14,8	Schofield	
Taupo	NZ	38	1,800	70	C	1	14,8	Schofield	
Taupo	NZ	82	2,040	50	CW	2	14,8	Banwell	log in cave
Taupo	NZ	158	1,760	80	C	1	14,8	Grant-Taylor	
Taupo	NZ	159	1,750	80	W	1	14,8	Grant-Taylor	
Taupo	NZ	160	1,300	80	W	3	8	Cameron	not adjacent to tephra
Taupo	NZ	161	1,780	80	C	1	14,8	Healy	
Taupo	NZ	162	1,830	70	C	1	14,8	Healy	
Taupo	NZ	163	1,840	50	C	1	14,8	Healy	
Taupo	NZ	164	1,890	70	W	1	14,8	Healy	
Taupo	NZ	165	1,900	70	W	1	14,8	Healy	
Taupo	NZ	168	1,980	40	W	1	14,8,43	Vucetich	
Taupo	NZ	170	1,800	50	C	1	14,8	Gregg	
Taupo	NZ	172	1,800	100	C	1	14,8	Vucetich, Cross	doubtful strat.
Taupo	NZ	173	1,750	50	C	1	14,8	Healy, Thompson	
Taupo	NZ	174	1,800	100	C	1	14,8	Healy, Thompson	
Taupo	NZ	175	1,850	100	C	1	14,8	Healy	
Taupo	NZ	176	1,960	70	C	1	14,8	Healy	
Taupo	NZ	183	1,840	70	C	1	14,8	Gibbs	
Taupo	NZ	502	1,770	70	P	1	9,39	Pullar	min
Taupo	NZ	503	1,900	60	P	1	9,39	Pullar	max
Taupo	NZ	524	1,775	75	W	1	9,39	Pullar	
Taupo	NZ	525	2,101	75	W	2	9,39	Pullar	stump below Tp
Taupo	NZ	869	1,995	60	W	2	39	Pullar	
Taupo	NZ	1059	1,870	60	P	1	37,39,9	Pullar, Kohn	min
Taupo	NZ	1060	2,090	60	P	1	37,39,9	Pullar, Kohn	max
Taupo	NZ	1548	1,840	50	C	1	56,7,21		
Taupo	NZ	3121	1,680	70	P	3	55	Pullar	min (?too young)
Taupo	NZ	5531	1,890	70	C	1	z	Wilson	
Taupo	NZ	5610	1,790	65	PW	2	20	Hull	sample surrounds NZ6511
Taupo	NZ	5611	1,735	65	W	2	20	Hull	tree in situ
Taupo	NZ	7013	1,600	55	P	2	c	Singleton	3 cm slice straddles tephra
Taupo	NZ	7442	1,795	55	SE	1	g	Clarkson	seeds from peat
Taupo	NZ	7482	1,850	60	P	1	59	Ota, Beanland, Berryman	min
Taupo	WK	215	1,730	60	G	2	16,25,28,12	Lowe, Green	
Taupo	WK	424	2,040	50	W	3	16,26	McCabe, Lowe, Hendy	wood in mud buried by Tp
Taupo	WK	928	1,870	60	C	1	f	Lowe	
Taupo	WK	1015	1,690	80	P	1	d	Lowe, Newnham, Lowe	min

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Tephra formation	Lab	C14 Number	Age (yr B.P.)	Std deviation	Sample type	Assessed value	References	Collector	Comments
Taupo	WK	1016	1,790	80	P	1	d	Lowe, Newnham, Lowe	max
Taupo	WK	1094	1,800	50	W	1	j,62	Murray	in situ tree trunk in Taupo Pumice alluvium
Te Rere	NZ	523	20,700	450	C	2	44	Vucetich, Pullar	misident. as Ok (ref. 36)
Te Rere	NZ	5171	21,500	450	C	1	36	Nairn	underlain by Kk
Tuhua	NZ	333	5,370	54	P	3	8,57	Harris	max (tephra ident. uncertain)
Tuhua	WK	77	6,340	190	CW	1	1	Buck	
Tuhua	WK	106	6,280	70	P	1	16,15	Hogg, Lowe, Gaylor	max
Tuhua	WK	214	6,210	70	G	1	16,25,28	Lowe, Green	max
Tuhua	WK	241	6,070	80	P	1	16,15	Hogg, Lowe	min
Tuhua	WK	242	6,440	80	P	1	16,15	Hogg, Lowe	max
Tuhua	WK	243	6,710	80	P	3	16,15	Hogg, Lowe	max: thick sample
Tuhua	WK	244	6,060	80	P	1	16,15	Hogg, Lowe	min
Tuhua	WK	505	5,800	90	G	1	16,25	Lowe, Green, Hendy	min
Tuhua	WK	525	5,800	70	G	2	16,25	Lowe, Green	max: also min for Ma (thick sample)
Tuhua	WK	1019	5,280	130	P	3	d	Lowe, Newnham, Lowe	min (sample not adjacent to tephra)
Tuhua	WK	1317	6,130	100	P	1	64	de Lange, Rosenberg	min
Tuhua	WK	1318	6,440	120	P	1	64	de Lange, Rosenberg	max
Waimihia	GAK	10461	2,920	220	SH	2	54		shells under tephra
Waimihia	NZ	2	3,440	70	C	1	8,14,45	Baumgart	
Waimihia	NZ	179	3,420	70	C	1	8,14,39	Healy	
Waimihia	NZ	180	3,150	90	C	1	8,14,45	Healy	
Waimihia	NZ	289	3,400	100	W	1	8	Elder	
Waimihia	NZ	504	3,170	80	P	1	9,39,45		min
Waimihia	NZ	505	3,440	80	P	1	39,45,9		max
Waimihia	NZ	1061	3,270	65	W	1	9,37,39	Pullar, Kohn	max
Waimihia	NZ	1062	3,130	65	W	1	9,37,39	Pullar, Kohn	min
Waimihia	NZ	3947	3,280	110	P	1	19	Howorth	min
Waimihia	NZ	6702	3,590	70	P	2	h	Alloway	max: thick sample
Waimihia	NZ	7237	3,580	70	P	1	47	Rogers	max
Waimihia	WK	498	3,250	70	P	2	23,27,16	Rogers, Lowe, Hogg	max
Waimihia	WK	499	2,910	60	Pr	2	27,16	Rogers, Lowe, Hogg	min (coarse roots from WK500)
Waimihia	WK	500	3,040	50	Pf	2	27,16	Rogers, Lowe, Hogg	min (fine peat residue from WK 499)
Waimihia	WK	610	3,660	70	P	3	16	Shaw	max (sample not adjacent to tephra; also min for Wk)
Waimihia	WK	1032	3,870	110	P	2	b	Alloway	max: 1 cm slice (? too old)
Waimihia	WK	1259	3,940	70	P	2	b	Alloway	max: 1 cm slice (? too old)
Waiohau	NZ	568	11,250	200	C	1	39,9,3,45	Cole	
Waiohau	NZ	878	11,100	210	W	1	39,9,45	Pullar	
Waiohau	NZ	1135	11,800	150	C	2	39	Pullar, Birrell	sample in Rk
Waiohau	WK	233	12,200	230	G	1	12,16,25	Lowe, Green	min
Waiohau	WK	234	12,500	190	G	1	12,16,25	Lowe, Green	max
Waiohau	WK	515	12,450	200	G	1	12,16,25	Lowe, Green	max
Waiohau	WK	516	12,300	190	G	1	12,16,25	Lowe, Green	min
Waiohau	WK	531	12,800	110	P	3	16	Lowe, Hogg, Lane	straddles tephra (ident. uncertain)
Waiohau	WK	574	11,700	270	G	1	16,25	Lowe, Green, Hendy	max
Waiohau	WK	575	11,800	230	G	1	16,25	Lowe, Green, Hendy	min
Waiohau	WK	708	10,220	160	G	3	16,25	Lowe, Hendy, Ouellet	min (too young – ?low sed. rate)
Waiohau	WK	709	11,570	130	G	2	16,25	Lowe, Hendy, Ouellet	max
Waiohau	WK	714	11,840	340	G	1	16,25	Lowe, Hendy, Ouellet	min
Waiohau	WK	716	11,990	230	G	1	16,25	Lowe, Hendy, Ouellet	max
Whakaipo	NZ	171	2,650	150	W	2	8,14	Cross	strat. position uncertain
Whakaipo	NZ	177	2,530	70	C	2	39,8,14	Healy	may be Mp or Wo
Whakaipo	NZ	182	2,800	100	C	1	39,8,14	Healy	
Whakaipo	NZ	184	2,400	80	C	2	8,14	Gibbs	identity uncertain
Whakaipo	NZ	1070	2,670	50	P	1	9,45	Pullar	min
Whakaipo	NZ	1071	2,730	60	P	1	36	Pullar	max
Whakaipo	NZ	2740	2,520	65	C	1	z	Nairn	
Whakaipo	WK	506	3,010	70	G	1	16,25	Lowe, Green, Hendy	max
Whakaipo	WK	507	2,010	80	G	3	16,25	Lowe, Green, Hendy	min, too young?
Whakaipo	WK	537	2,560	60	G	1	16,25	Lowe, Green, Hendy	min
Whakaipo	WK	538	2,860	60	G	1	16,25	Lowe, Green, Hendy	max
Whakaipo	WK	1017	2,900	110	P	2	d	Lowe, Newnham, Lowe	straddles tephra; ident. uncertain
Whakaipo	WK	1441	2,670	70	P	1	l	Wigley, Edwards	min
Whakaipo	WK	1442	2,710	80	P	1	l	Wigley, Edwards	max
Whakatane	NZ	426	5,085	100	C	2	9,23	Healy	uncertain strat.
Whakatane	NZ	1066	5,180	80	C	1	39,23,9,38	Pullar, Pain	max
Whakatane	NZ	1072	3,200	65	P	3	39,9	Pullar	min only
Whakatane	NZ	1137	6,390	120	M	3	39,45,23	Pullar, Kohn	min: unreliable as section reworked (ref. 18, 22)
Whakatane	NZ	1198	5,050	100	C	2	z		tephra ident. uncertain
Whakatane	NZ	1247	6,190	70	M	3	39,45,23	Pullar, Kohn	max: unreliable as section reworked (refs. 18, 22)
Whakatane	NZ	1358	4,690	120	C	1	23,7,56	Healy, Nairn	in flow
Whakatane	NZ	1946	4,910	70	C	1	36,34	Nairn	
Whakatane	NZ	3161	4,800	50	P	1	23	Neall	min (also max for Hm)
Whakatane	NZ	3162	5,210	80	P	1	23	Neall	max
Whakatane	NZ	3948	4,600	90	P	1	19,23	Howorth	min
Whakatane	NZ	3949	4,640	90	P	1	19,23	Howorth	max
Whakatane	NZ	4305	4,830	90	C	1	36,34	Nairn	
Whakatane	NZ	4306	4,880	90	C	1	36,34	Nairn	
Whakatane	NZ	4307	4,940	80	C	1	36,34	Nairn	
Whakatane	NZ	4308	5,000	80	C	1	36	Nairn	
Whakatane	NZ	4930	5,090	100	W	2	36	Jackson, Nairn	wood submerged by lake
Whakatane	WK	496	4,490	60	P	1	23,27,16	Rogers, Lowe, Hogg	min (also max for Hm)
Whakatane	WK	497	4,530	60	P	1	23,27,16	Rogers, Lowe, Hogg	min (also max for Hm)
Whakatane	WK	501	4,860	70	P	1	23,27,16	Rogers, Lowe, Hogg	max
Whakatane	WK	610	3,660	70	P	3	16	Shaw	min (sample not adjacent to tephra)
Whakatane	WK	611	5,510	70	P	3	16	Shaw	max (sample not adjacent to tephra)
Whakatane	WK	660	4,850	80	G	1	23,16,25	Lowe, Hendy, Ouellet	max
Whakatane	WK	662	4,260	140	G	1	23,16,25	Lowe, Hendy, Ouellet	min (also max for Hm)
Whakatane	WK	1333	4,990	110	P	1	64	de Lange, Crowcroft, Gilmour	min
Whakatane	WK	1334	4,770	110	P	1	64	de Lange, Crowcroft, Gilmour	max