京都大学防災研究所年報第31号A　昭63.4
Annuals, Disas. Prev. Res. Inst., Kyoto Univ., No. 31 A, 1988

VOLCANIC HAZARDS IN NEW ZEALAND

R.R. Dibble

Victoria University of Wellington, New Zealand

INTRODUCTION

New Zealand comprises three main islands which span 1410 km, and extend NNE along the boundary between the Pacific and Indian tectonic plates. From East Cape on the North Island to the Kaikoura Peninsula in the South Island, the boundary is a convergent one, but the rate of convergence decreases along the boundary to the SSW, as the plate motion changes progressively into transform fault motion on the Alpine fault and Hope/Kaikoura fault (**Fig. 1**).

Hence the present andesitic volcanic activity due to subduction processes is confined to a NNE trend, extending down the Tonga-Kermadec Island Arc into the North Island, and dying out before the South Island is reached. It differs from classic island arc structure only in the straightness of the arc, and in that the entire width of the subduction zone is under the land of the North Island, because the accretionary wedge of sediment has filled the ocean trench. The Cenozoic basaltic activity, on the other hand, is aligned along the old Mesozoic geosynclinal structure defined by the North Auckland peninsula and the Triassic-Jurassic sediments of both North and South Islands.

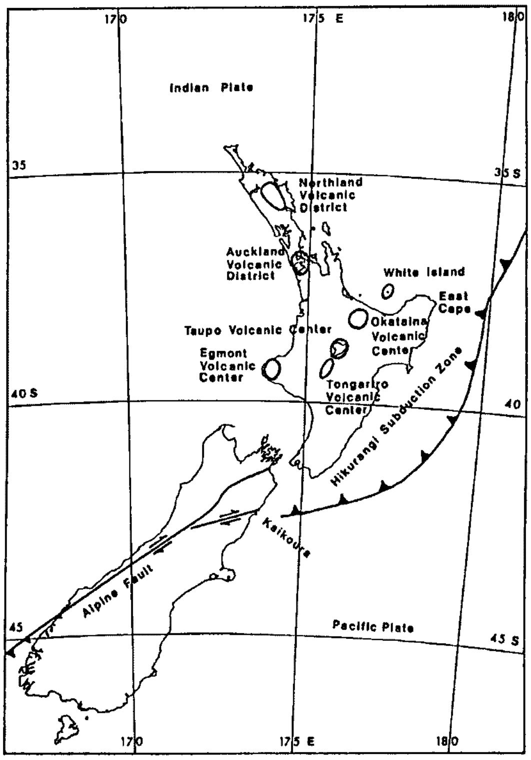

Fig. 1. Map of New Zealand, showing the active volcanic districts and centers, and the tectonic plate boundaries.

The recent basaltic activity however has been confined to the North Island.

Within the North Island, recent activity (<4 Ka BP) is mainly confined to the following areas:

Northland Volcanic District,	basaltic
Auckland Volcanic District,	basaltic
Mare Island	rhyolitic (alkaline)
White Island,	andesitic
Okataina Volcanic Center,	rhyolitic
Taupo Volcanic Center,	rhyolitic
Tongariro Volcanic Center,	andesitic
Egmont Volcanic Center,	andesitic

Many papers have been written on the activity in these regions, but in 1980, a National Civil Defence Planning Committee on Volcanic Hazards was formed, and solicited new reports on the hazards in each area. These were made available to Dibble and Neall (1984), and Dibble, Nairn, and Neall (1985) who published an overview. Extended accounts have also been published by Cole and Nairn (1975), Gregory and Watters (Eds. 1986), and Smith (Ed. 1986) and the present paper incorporates the presently available information.

In this paper, "hazards" refer to natural events having a probability of occurrence in a given period of time (100 years), calculated from the mean return time of similar events on the assumption of a random poisson distribution. "Risk" is only present when something of human value is at stake. This leads to the equation:

$$\mathrm{RISK} = \mathrm{HAZARD} \times \mathrm{VALUE} \times \mathrm{VULNERABILITY}$$

where vulnerability indicates the varying susceptibility of different things to destruction by the same hazard, and is strongly dependent on mitigation planning and operations. The "values" shown in the tables accompanying this paper were taken from the National Valuation Statistics for 1981, and the New Zealand Official Year Book for 1980/81. Average population, stock unit numbers, and value in Megadollar (M$) of improvements per square km were multiplied by area of hazard to get estimates of value at risk for each eruption type and location.

ASSESSMENT OF HAZARDS BY AREA

Northland

The region has a long history of basaltic and rhyolitic volcanicity extending back to the Cretaceous, but in the last c2.25Ma, activity has been of basaltic and hydrothermal type. Within the Bay of Islands—Kaikohe Volcanic Field of area 475 square km and the Whangarei Volcanic Field of c200 square km are about 30 small scoria cones, lava domes and flows, and one hydrothermal area (Ngawha Hot Spring). About 14 cubic km of deposit have been erupted in at least 33 eruptions (Latter 1986). The last eruption is dated (14C, Kohn, 1973) between 200 and 700 AD. The future risk at any one place is very low.

Auckland

The Auckland Volcanic District comprises over 50 eruptive centres within a 650 square km area which includes the Auckland Metropolitan area of population near 1 million. All past activity has been basaltic, and two eruptive styles have been dominant: effusive-magmatic, and phreato-magmatic. In the first type, an initially high rate of gas discharge may cause lava fountaining to create a steep-sided cone of welded bombs or scoria, often up to 200 m high. Examples are Mount Eden (**Photo. 1**) and One Tree Hill. Following this, fluid lava has often flowed from the cones along pre-existing streams and valleys, causing total destruction in a localised area close to source, and along the flows which have reached up to 7 km from source.

In phreato-magmatic activity, rising magma encounters water rich sediments at some depth, resulting in a series of explosive eruptions which ream out a maar crater up to 1 km in diameter (**Photo. 2**), and deposit a tuff ring of ejecta up to 10's of metres thick and several kilometre radius. No eruption of the type producing flat floored maars as in Auckland has ever been witnessed, but the multiple layers of current bedding and graded bedding in the tuff rings suggests repeated explosive

Photo. 1. The Scoria cone of Mount Eden. One of the many within the Auckland metropolitan area. Average eruption rate of the Auckland volcanic field is 0.1 cub. km deposit per ka, over the last 40ka. Photo by D.L. Homer.

Photo. 2. A maar near the northern plaza of Auckland Harbour Bridge in the metropolitan area.

ejections of comminuted debris to great heights, followed by lateral base surges as the dense eruption cloud falls back. Velocities of 100 m/s of hot steam and entrained rocks to distances of several kilometre could be expected. Few people would survive close to source.

Phreato-magmatic eruptions are more common than the present number of maars would suggest, because some have been covered by scoria cones and flows from continued eruption. In both effusive-magmatic and phreato-magmatic activity, tidal waves could be generated if the eruptive center was close to or below sea level.

There is no clear relationship between location and age of activity in the Auckland district, but there seem to have been six main periods of activity in the last 42 ka. The most recent eruption, of radiocarbon date 255+/−110 year B.P., was a lava flow at Rangitoto Island, and it is unclear whether this sequence has ended or not. Because most of Auckland's volcanoes are considered to have been monogenetic (one eruption each) there is presently no sound basis on which to predict the location of

Table 1

Auckland Volcanic Field.

Hazard	Phreatic Explosion	Scoria Cone	Lava Flow
Type example	Panmure Basin	Mt. Eden	Western Springs
Active area	< 640 km^2	640 km^2	640 km^2
Magnitude/Volume			
Area destroyed	3–28 km^2	0.4 km^2	1 km^2
Range of destruction	1–3 km	0.5 km	10 km
Velocity of destruction	100 m/s	$\leqslant$ 1 m/s	2 km/hr
Area damaged	9–170 km^2	c. 2 km^2	1.5 km^2
Range of damage	2–8 km	c. 1 km	10 km
Velocity of damage	ballistic	$\leqslant$ 1 m/s	2 km/hr
Deposit temperature	< 100°C	Incandescent	Incandescent
Incidence			
Volume since	← 4 km^3 →		
Origin time (BP)	← 40–100 kyr →		
Number of events	19	50	> 14
Return period	2000–4000 yr	1000–4000 yr	
Last event (BP)		Rangitoto 220 yr	
Probability in 100 yr	2.5–5%	2.5–9%	
Value at risk			
Population*	6000–100000	0–4000	0–3000
Property* M$	64–3600	9–43	21–32
Stock number*	low	low	low
Utilities			

Photo. 3. White Island volcano, 48 km offshore in the Bay of Plenty, New Zealand. This solfataric volcano is similar to Krakatoa prior to the 1883 eruption. A magmatic tephra eruption occurred in 1976–80. Photo by D.L. Homer.

future eruptions. With an average eruption rate of less than 0.1 cubic km per ka, the hazard is not great, but as the summary diagram (**Table 1**) shows, the values and risk are considerable.

Table 2

White Island

Hazard	Phreatic-tephra	Magmatic-Tephra	Lahar	Tsunami
Type example				Krakatoa
Active area	0.8 km^2	0.8 km^2	0.8 km^2	300 km^2
Magnitude/volume	10^{-3} km^3	12×10^{-3} km^3	c.3×10^{-3} km^3	5000 Mtonne HE
Area destroyed	0.1 km^2	0.3 km^2	c.0.5 km^2	White Island
Range of destruction	200 m	0.3 km	1.3 km	-
Velocity of destruction	Ballistic	low?	1–6 m/s	100 km/hr
Area damaged	0.1 km^2	c. 5 km^2	0.8 km^{2}100 km^2	
Range of damage	1 km	c. 1.5 km		200 km
Velocity of damage	low or ballistic	low or ballistic	high	100 km/hr
Deposit temperature	low	low or incandescent	$\leqslant$ 100°C	
Incidence				
Volume since		7×10^6 m^3		
Starting time		3 year		
Number of events	12 since 1914	1–2 in historic time	1 in historic time	None
Av. Return period	5 yr	-	-	-
Last event	1971 Crater	1976–80	1914	-
Probability in 100 yr	> 100%			Very low
Value at risk				
Population	← Occasional visitors →			6000
Property M$	← Visitors property →			25
Stock number	← None →			200,000
Utilities				Ports

White Island

This active volcano (**Photo. 3**) is situated 48 km offshore from Whakatane in the Bay of Plenty. Solfataric activity has been recorded since the first landing was made by europeans in 1826. In 1914, a major landslide fell from the western wall of the crater, and formed a lahar which flowed across the crater floor and into the sea, burying 11 workmen mining sulphur at the time.

Since 1967 the island has been under regular surveillance by parties from Victoria University of Wellington and DSIR. In December 1967, a renewed eruption phase began, and in March 1977 magmatic activity in the form of lava bombs occurred for the first time in written history. The largest observed eruption produced a column 5–6 km high, and partly destroyed the seismograph installation. By 1981, eruptions had enlarged the crater to a volume of 12 million cubic metre.

Photo. 4. The chasm of the Tarawera basaltic fissure eruption in 1886 split the rhyolite domes of Mt. Tarawera, which had formed only 650 years BP in the Okataina Volcanic Center. Average eruption rate in OVC has been 6 cub.km deposit per ka over the last 20ka. Photo by D.L. Homer.

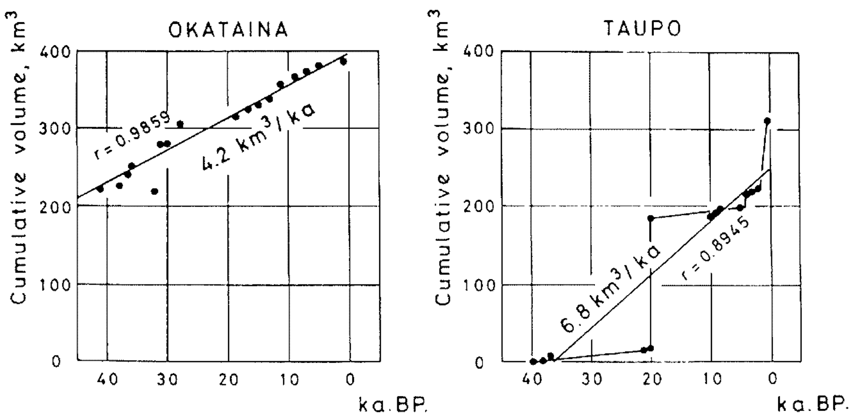

Fig. 2. Cumulative volume plotted against age for tephras from (a) Okataina, and (b) Taupo Volcanic Centers. The equations and correlation coefficients for regression lines use all the data. The near horizontal steps in (b) use relevant points only. After Froggatt (1982).

The early volcanic history is known in outline back to 15.5 ka BP from the study of marine cores in the Bay of Plenty. Seven significant ($>10^7$ cub.m) ash eruptions have been found in this period by Kohn and Glasby (1978), but the eruption rate is not well known.

White Island is uninhabited, and the volcanic hazard on the mainland is not likely to be great unless a Krakatoan type eruption occurred which could generate large tsunamis. The crater lip is only 23 m above sea level, and the sometimes incandescent vent reached to 300 m below sea level during the 1977–80 cruptive period. Whereas ash deposition on the low-lying mainland coast would be expensive rather than destructive to growers of high value horticultural products such as Kiwifruit, a tsunami could cause great damage along 100 km of coast line. A summary of hazards, values, and risks for White Island is given in **Table 2.**

Okataina

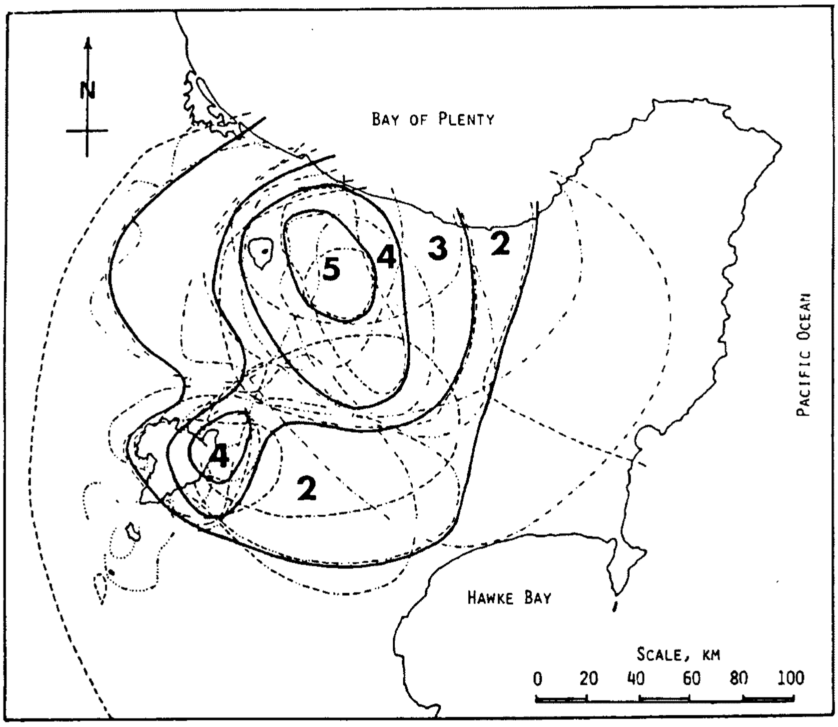

Fig. 3. Map of the central and eastern area of the North Island of New Zealand, showing (heavy lines) zones of percentage risk of tephra fall exceeding 0.3 m in any 100 year period. The fine lines are the 0.3 m isopachs for each tephra eruption from the Okataina and Taupo Volcanic Centers, recognized as occurring in the last 20ka.

The Okataina Volcanic Center extends from Rotorua in the west to Kawerau in the east, encompassing Mt. Tarawera (**Photo. 4**) and Lake Rotomahana, the vents of New Zealand's largest historic eruptions in 1886 AD. However the 1886 eruptions were small compared with those of earlier times. Between about 50 and 250 ka BP at least 4 large rhyolitic eruptions originated from the Okataina Center, depositing welded tuffs that individually exceeded 100 cubic km in magma volume. Between 20 and 50 ka BP, 8 major plinian eruptions occurred, showering thick pumice ash over the Bay of Plenty area. Within the last 20 ka, eleven eruptive episodes have been recognized, with a total erupted magma volume of 80 cubic km.

The vents for most of these post-20 ka BP eruptions were sited within the Haroharo Caldera—a large complex collapse structure produced by the earlier eruptions of welded tuff. All the post-20 ka BP eruptive episodes were of multiple vent type, with widely separated vents in simultaneous or sequential eruption, spread over up to 15 km of underlying fissures. The eruptions included rhyolitic pumice falls and pyroclastic flows which accompanied the extrusion of large lava flows and domes. In addition, events such as scoriaceous basaltic eruptions, hydrothermal eruptions, and creation of lahars and associated floods have all occurred. The complex stratigraphy of these deposits and the events they record are still being elucidated, but the overall pattern indicates that Okataina center is one of the major risk areas in the country. Froggatt (1982) has plotted cumulative eruption volumes against time, and shows (**Fig. 2**) that the 1886 eruption was 15 cubic km smaller than predicted by the trend, and that more eruptions are possible in the near future.

There have been 19 eruptive episodes in the past 50 ka; an average of one per 2.5 ka. These eruptions were of an intermediate size, and were of rhyolitic, dacitic/andesitic, or basaltic composition. In intermediate sized rhyolitic eruptions, complete devastation would be expected within a 10 km radius of the source, and many hundreds of square km may be buried in ash or pumice to at

Table 3

Okataina Volcanic Centre

Hazard	Basaltic Eruptions	Rhyolitic Pyroclastic Eruptions	Andesite-Rhyolite Lava Eruptions	Hydrothermal Phreatic Eruptions	Lahars/Floods
Type example	Tarawera 1886 yr AD	Rotoma 9.1 kyr BP	Tarawera lava domes	Rotomahana 1886 AD	Tarawera R 1904 AD
Active area		600 km^2	600 km^2		
Magnitude or volume	< 2 km^3	≤ 14 km^3	≤ 2 km^3	≤ 1 km^3	800 m^3/s, 0.1 km^3
Area destroyed	< 100 km^2	≤ 300 km^2	< 75 km^2	≤ 110 km^2	
Range of destruction	A few km	≤ 10 km	< 5 km	≤ 6 km	
Velocity of destruction	Ballistic or low	high		> 40 m/s	
Area damaged	4,500 km^2 (50 mm)	≤ 23,000 km^2 (100 mm)		≤ 4,500 km^2 (50 mm)	
Range of damage	50 km	180 km			
Velocity of damage	Low	Low	Low		
Deposit					
Temperature	Low to incandescent		c 800°C	< 100°C	
Incidence					
Volume since		72 km^3	48 km^3		
Starting time (BP)		20 kyr	20 kyr		
Number of events	3 in 20 kyr	9 in 20 kyr	≥ 24 in 9 epis. in 20 kyr	> 6 in 20 kyr	> 5 in 20 kyr
Return period	6,700	2,200 yr	2,200 yr	< 3,300 yr	4000 yr
Last event	1886 AD	650 yr BP	650 yr BP	1886 AD	1904 AD
Probability in 100 yr	1.5%	4.4%	4.4%	> 3%	2.5%
Value at Risk					
Population	1,300–60,000	4,000–300,000	1,000	1,400–60,000	
Property M$	13–610	40–3,100	10	15–610	
Stock number	67,000–3 × 10^6	200,000–15.5 × 10^6	50,000	14,000–3 × 10^6	
Utilities	Rotorua City, Tourist facilities, Power Station, Kaingaroa Forest Plantation, Kawerau Paper Mill				

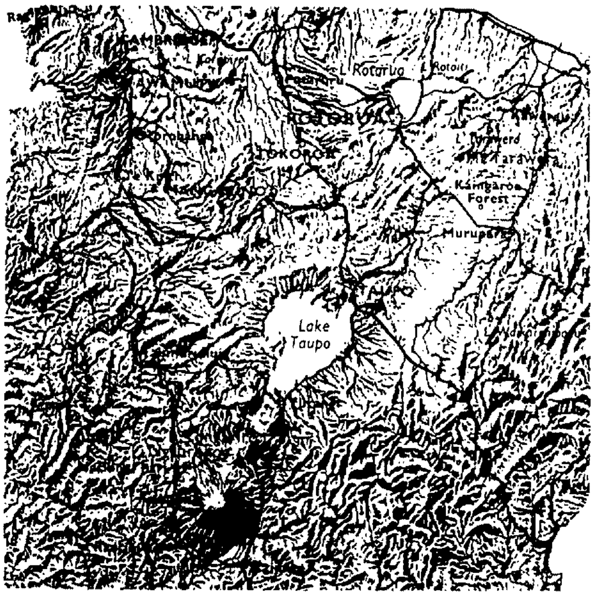

Fig. 4. Map of Lake Taupo, and the topography and drainage pattern around it resulting from the enormous eruptions which have originated beneath it. Average eruption rate has been 8 cub.km per ka over the last 20ka.

least 0.3 m depth. Much death and destruction of buildings would be expected. Hydrothermal eruptions and explosive basaltic eruptions may be locally as destructive, particularly if sited in lakes. Rain may be expected to mobilise unconsolidated tephras into lahars, and eruptive displacement of the many volcanic lakes could generate floods, particularly in the Tarawera River. Hot ejecta and lightning in ash clouds could start forest fires, particularly in the large exotic forests in the region.

The long time interval (>100 ka) between the large eruptions of welded tuffs means that the probability of occurrence in any century is very low (<1%), but such an eruption would be catastrophic beyond normal belief. The wide variety of past eruptive types, sizes, and locations in the Okataina Center makes delineation of more than two hazard zones very difficult, but statistical risk zones of tephra fall exceeding 0.3 m have been constructed from the isopach maps (**Fig. 3**) of 11 such events in the last 20 ka. In that period the volume of all erupted deposits has averaged 6 cubic km per ka. A summary diagram for Okataina is given in **Table 3.**

Taupo

Enormous rhyolitic eruptions have dominated the Taupo Volcanic Center over the past 50 ka, and largely hidden the pre-50 ka events. More than 400 cubic km of ejecta has come from 12 eruptions in the last 20 ka. Large plinian eruptions of pumiceous tephra have occurred on at least 11 occasions in the last 10 ka (an average interval of 910 years), compared to 16 in the last 40 ka. The ejecta are thought to have reached altitudes of up to 50 km, and vary from 1 to 70 cubic km in volume. They covered substantial areas of the North Island, and in one instance, over 20,000 square km was buried by more than 1 m of tephra. The effects of such an eruption today would be the destruction of towns, exotic forests, and farms in the region, and the hydroelectric power stations concentrated down the Waikato River, which is fed by Lake Taupo, would be either destroyed or unusable, depriving the Auckland Province of power.

On at least 3 occasions in the last 20 ka, enormous pyroclastic flows (up to 100 cubic km) have been violently erupted. Fluidised pumice blocks and ash have been expelled at tremendous speed (c200 km/h) and temperatures of 200–400 degree C. Charred trees within the flow deposits up to 50 km from source, and recognisable ash deposits up to 1000 km away, testify to the magnitude of these events. Now that the source area of these eruption is covered by Lake Taupo (**Fig. 4**), further eruptions could mobilise large volumes of water on to the surrounding landscape by phreatic explo-

Taupo Volcanic Centre

Hazard	Hydrothermal	Basalt scoria	Dome building	Plinian eruption	Phreatoplinian	Pyroclastic
Type Example	Rotokawa	K Trig	Karapiti 10,000 yr BP	Taupo lapillae 1,800 yr BP	Rotongaio 1,800 yr BP	Taupo 1,800 yr BP
Active area	4 km^2		7,000 km^2	6,000 km^2	600 km^2	7,000 km^2
Magnitude/ volume	Heat flow 800 MW	$\leqslant 10^{-3}$ km^3	10^{-3}–3 km^3	$<$ 1–70 km^3	$<$ 1–20 km^3	0,5–500 km^3
Area destroyed	$\leqslant$ 0.02 km^2	$\leqslant$ 0.03 km^2	0.03–20 km^2	80 km^2		20,000 km^2
Range of destruction	$\leqslant$ 100 m	$\leqslant$ 0.1 km	2.5 km	5 km		130 km
Velocity of destruction	ballistic	low	low	Ballistic to 5 km		30–200 km/hr
Area damaged	$\leqslant$ 2 km^2	$<$ 3–12 km^2	0.06–40 km^2	20,000 km^2	10,000 km^2	50,000 km^2
Range of damage	$\leqslant$ 1 km	$<$ 1–2 km		150 km	50 km	250 km
Velocity of damage	Ballistic	Ballistic	Low	Low	Low	High
Deposit temperature	100°C	1100°C	900°C	10–30°C	10–100°C	200–400°C
Incidence						
Volume since		$\leqslant$ 2 km^3		135 km^3		175 km^3
Origin time (B.P.)		0.5 Myr		40 kyr		50 kyr
Number of events		$\geqslant$ 3	9 in 10 kyr	16 in 40 kyr	5 in 40 kyr	3 in 40 kyr
Return period			1100	900–2500	5000–18000	5000–13000
Last event	Tauhara 1981 AD	Waimarino 10–20 kyr B.P.	1800 B.P.	Taupo 1800 B.P.	Taupo 1800 B.P.	Taupo 1800 B.P.
Probability in 100 yr	High			4–10.5%	0.5–2%	0.8–2%
Value at risk						
Population	0–200	0–150	0–50?	1000–15000	1000–250,000	250,000–650,000
Property M$	10^{-3}–22	10^{-3}–130	10^{-3}–270	3.4–1000		1000–2400
Stock number	0–363	50–21000		8×10^6		20×10^6
Utilities	Wairakei Power Station			8 Power Stations		10 Power Stations

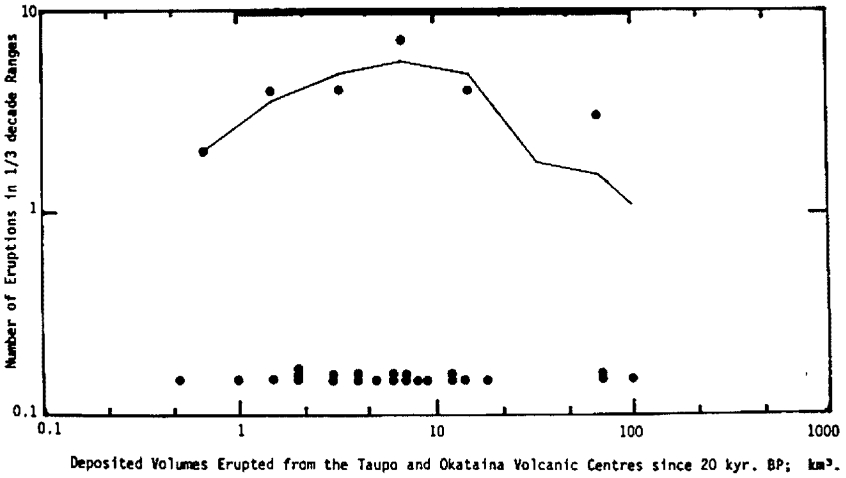

Fig. 5. Graph of the logarithm of number of eruptions of each volume range versus the logarithm of the deposit volumes, in factor-of-2.15 ranges. If volume is proportional to Magnitude, the graph is equivalent to a b-value graph, as for earthquakes, but it shows a preferred volume of 6 cub. km, instead of a continuously increasing number at progressively smaller volumes.

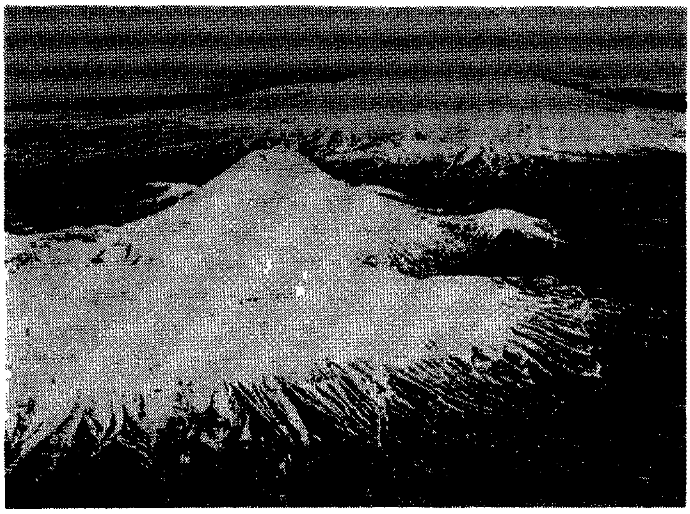

Photo. 5. Tongariro, Ngauruhoe and Ruapehu volcanoes in order of increasing distance, as seen from the northern margin of the Tongariro Volcanic Center. Average eruption rate is 0.7 cub.km deposit per ka over the last 10ka. Photo by D.L. Homer.

sion and tsunami, to cause wet ash falls and lahars. This probably happened as recently as 1.8 ka ago, when the Rotongaio Ash was deposited in the 4th phase of the Taupo eruption. This eruption began with a survivable phreato-magmatic eruption, followed by a 6 cub.km plinian eruption, a further 2.5 cub.km phreato-magmatic eruption, then 1.3 cub.km of Rotongaio ash, 23 cub.km of ultra-plinian pumice, and 30 cub.km of pyroclastics emplaced at high velocity as a thin layer out to 80 km radius. Dome building, scoriaceous basalt eruptions, and hydrothermal eruptions are also probable, but are likely to be only locally destructive and of very minor volume compared to the spectacular Plinian eruptions and pyroclastic flows.

The recognition of any earthquake swarms, increased heat flow, or tilting of the ground due to

Table 5

Tongariro Volcanic Centre

Hazard	Ruapehu lahars	Airfall Tephra	Pyroclastic Flows and base surges	Lava Flows
Type example	1975	Mangatawai		Ngauruhu 1954–55 AD
Activa area	Ruapehu Crater Lake	200 km^2	200 km^2	Summit Crater
Magnitude/Volume	6×10^5, 4×10^6, 2×10^8 m^3	1.2 km^3		
Area destroyed	1; 15; c. 300 km^2			
Range of destruction	10; 30; 100 km			
Velocity of destruction	1–12 m/s	Ballistic	30 m/s	
Area damaged	> above	2000 km^2		
Range of damage	> above	25 km		
Velocity of damage	> above	Low	High	
Deposit temperature	0–20°C	Low	200°C	
Incidence				
Volume since		$\geq$ 7 km^3		
Starting time (B.P.)		10 kyr	Upper Pliocene	
Number of events	4 since 1895; 2 since 130 AD; 2	8 in 2 episodes in 20 kyr		
Return period	17.5; 120; 5000 yr	2.5–10 kyr		
Last event	Ruapehu 1975 AD	Ngauruhoe 1975 AD		Ngauruhoe 1954–55 AD
Probability in 100 yr	20*, 3*, 0.1%	1–4%		
Value at risk				
Population	150; 1500; 15000	10,000		
Property M$				
Stock number	Low	Low		
Utilities	Tongariro Power Scheme, Transmission Lines, State Highways 1, 3 and 47, Waiouru Military Camp, Auckland-Wellington Railway			

an expanding magma body would require immediate monitoring to warn of an increased probability of eruption. Taupo ranks with the Okataina Center as areas where major disasterous eruptions might recur in New Zealand, and all attempts to understand the activity, and monitor it here must be considered to be a good investment. The average eruption rate of 8 cubic km per ka over the last 20 ka is higher than at Okataina, and includes larger eruptions, but Froggatt (1982) showed that the Taupo Pumice Eruption of 120 AD was much larger than expected from past trends (**Fig. 2**), and so the area may still be in a partly exhausted state. Zones of statistical chance of tephra falls exceeding 0.3 m (**Fig. 3**) are less reliably drawn than at Okataina, because Lake Taupo obscures much of the isopach maps, but it is clear that the greatest chances are on the east and north shores of the lake.

Photo. 6. Egmont volcano as seen from the east. The parasitic cone on the south side is Fanthams Peak. Average eruption rate has been 0.7 cub.km deposit per ka over the last 10ka. Photo by V.E. Neall.

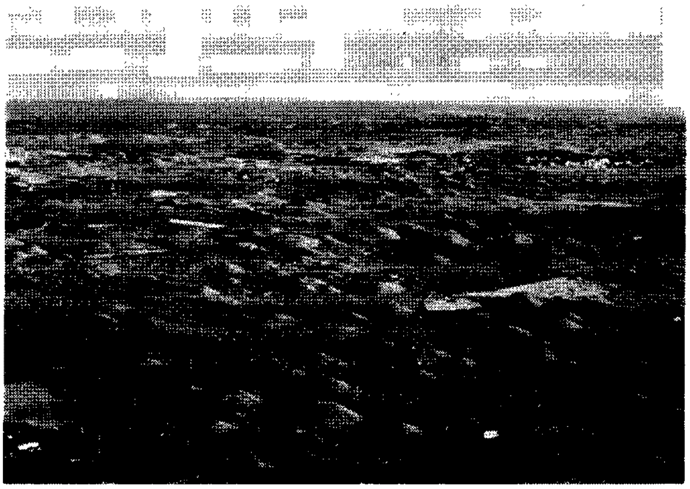

Photo. 7. Lahar mounds of the 7 cub. km Pungarehu Formation on the western flank of Mt. Egmont, dated at c. 23ka BP. This deposit resulted from a massive collapse of a former cone at the site of the present Mt. Egmont. Many smaller lahars (18) have occurred in ths last 13ka with volumes from 0.1–3 cub.km. Photo by V.E. Neall.

A summary diagram for Taupo is given in **Table 4**.

Data on the tephra eruptions from the Okataina and Taupo Volcanic Centers during the last 20 ka are unusually good, and all 23 eruptions exceeding 1 cubic km have been identified and measured. This gives a rare opportunity to plot a b-value graph for a homogeneous data set (**Fig. 5**). Although the range of magnitude (taken as a factor of 100 change in erupted volume) is not large, it is clear that the data do not lie on a straight line of negative slope. Rather that there is a peak in the distribution curve at a preferred size of 6 cubic km, and thus a very much lower risk of occurrence of 1 cubic km eruptions than would be inferred by extrapolating from the large eruptions using a constant negative b-value.

Tongariro

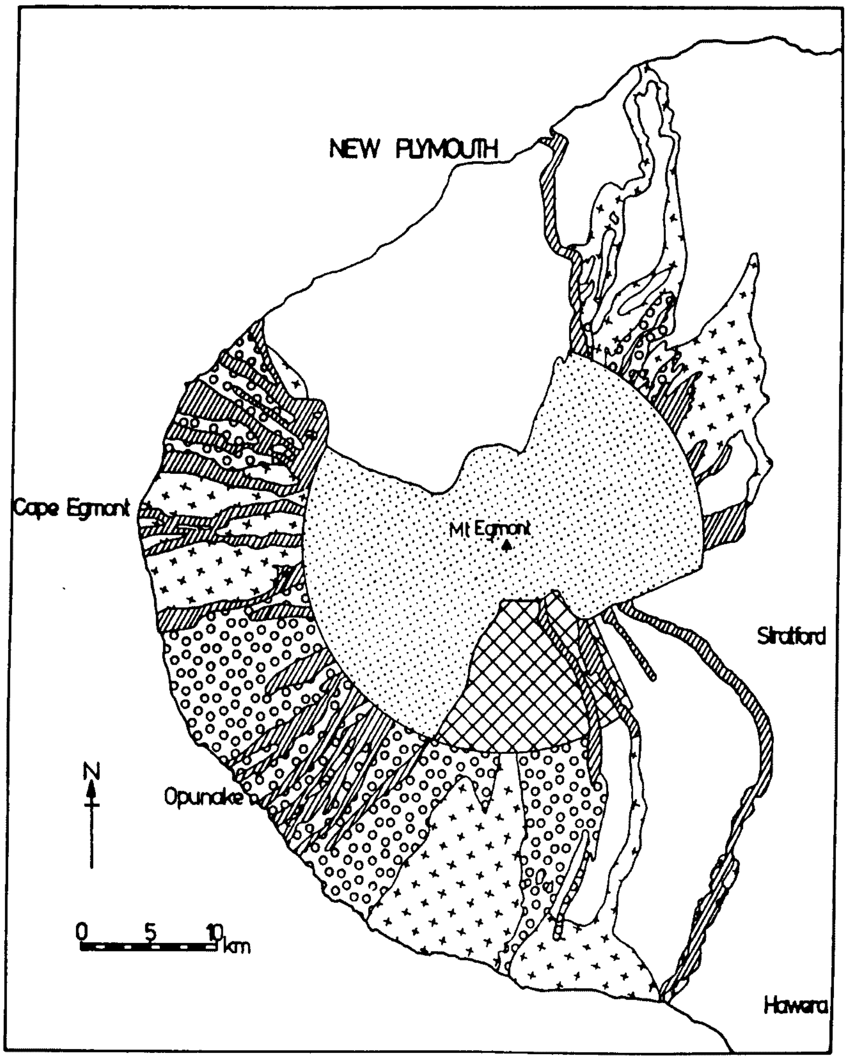

Fig. 6. Risk zones for future ground hugging volcanic hazards at Mt. Egmont. A: Stippled area is likely to be affected most severely and frequently by pyroclastic flows, lahars, lava flows and lateral blasts from Mt Egmong crater. B: The hatched area represents the same risk from Fanthams Peak crater. C: Diagonal stripes are areas likely to be affected most severely and frequently by lahars and associated floods. D: Open circles are areas likely to be affected severely by moderate lahars and floods of intermediate frequency. E: Crosses are areas that could be affected by unusually large, but infrequent lahars and floods. After Neall (1982).

The three principal sources of volcanic risk - Ruapehu, Ngauruhoe, and Tongariro volcanoes (**Photo. 5**) are located in Tongariro National Park. Ruapehu is a large stratovolcano of 2797 m elevation and volume 109 cubic km. It has a single active crater filled with about 10 million cubic m of water, having a normal temperature range of 20–40 deg.C, and a pH close to 1.2. The volcano is the source of many large rivers in the North Island, so that ground flowing products of past eruptions have tended to be guided along the Tongariro, Wanganui, Rangitikei and Whangaehu Rivers to the sea. The major hazard at Ruapehu is undoubtedly the occurrence of lahars. Their deposits are found at Taumaranui, 25 km to the NW, and near Mangaweka, 32 km to the south.

The ejection of crater lake waters has clearly been the cause of these lahars, and the size of erup-

Table 6

Egmont Volcano

Hazard	Lava flows, Domes	Pyroclastic Flow	Lahar-floods	Tephra deposition
Type example	Dawson Fall flow	Newall Lapilli	Opua Formation	Inglewood Tephra
Active area	Egmont, Fantham Peaks			
Magnitude/Volume	< 0.1 km^3	< 0.1 km^3	< 0.01; 0.01–0.1, 0.1–3 km^3	$\leqslant 0.1$ km^3
Area destroyed	1–2 km^2	10–50 km^2	< 10; 10–30; 30–250 km^2	$\leqslant 80$ km^2 ($\geqslant 1$ m ash)
Range of destruction	< 5 km	12.5 km	< 15; 15–40; > 40 km	$\leqslant 5$ km ($\geqslant 1$ m ash)
Velocity of destruction	0.2–2 m/s	200 km/hr	5–180 km/hr	Ballistic
Area damaged		20 km^2	> above	$\leqslant 2600$ km^2 ($\geqslant 1$ m ash)
Range of damage		20 km	> above	30 km
Velocity of damage		100–200 km/hr	5–40 km/hr	Wind velocity
Deposit temperature	1000°C	200–1000°C	< 100°C	low
Incidence				
Volume since	> 11 km^3	←	(220 km^3 5 km^3)	→
Starting time (B.P.)	120 kyr		(120 kyr 7 kyr)	
Number of events	Numerous	$\geqslant 16$ in 13 kyr	$\geqslant 18$ in 13 kyr	$\geqslant 39$ in 13 kyr
Return period		Highly variable (< 800 yr)	< 0.5; .5–5; 3–8 kyr	0.2; 1 kyr
Most recent event	Possibly 1655 AD	Puniho Lapilli 1655 AD	Maero Debris 1890 AD	Tahurangi Ash 1755 AD
Probability in 100 yr	Low	Uncertain ($> 11\%$)	> 18; 2–18; 1–3%	Low-Moderate
Value at risk				
Population	V.Low	Low	Low; Med; 1600	$\leqslant 31{,}000$
Property M$	Low	Low	Low; Med; > 50	16–520
Stock number	None	None	Low; Med; 4×10^5	5×10^6
Utilities	Mountain Lodges	Water supplies	Water supplies	Water supplies

tion and volume of water ejected has governed their size. The two largest since 1.8 ka BP swept the Whangaehu River valley about 790 and 440 years ago. In April 1975, about 3.3 million cubic m of water were expelled to create lahars which flowed into the Whangaehu, Whakapapa, and Mangaturuturu valleys. On the assumption that large magnitude B-type earthquakes do not occur without eruptions, Dibble et al. (1986) estimated from the earthquake b-value, and historical occurrences of lahars, that there was a 20% chance per century of a lahar sweeping the ski-fields during a weekend skiing day. Twice since 1969 a lahar has happened at night without causing casualties, but since 1986, a large B-type earthquake has occurred under Ruapehu without causing an eruption, so the 20% is known to be an over-estimate.

Eruption of airfall ash and lapilli, pyroclastic flows and lava flows are also likely from Ruapehu.

In 1945, fine ash from Ruapehu fell over 100 km away.

Ngauruhoe, of elevation 2290 m and volume 2 cubic km, is essentially a parasitic strato-cone of Tongariro, constructed in the last 2.5 ka. Lava flows, hot pyroclastic avalanches and ashfalls have been the most frequent product in historic time. The hot pyroclastic avalanches, travelling at speeds of 20-30 m/s probably are the greatest hazard from Ngauruhoe, which is fortunately in an uninhabited part of Tongariro National Park. However the ash eruptions have been the most common activity, often being observed up to 200 km from the vent. Since 1839, 73 eruptive periods have occurred, an average interval of 2 years.

Tongariro volcano of altitude 1978 m and volume about 43 cubic km, is an andesite complex with about 12 craters. It originated about 500 ka BP, and 11 minor eruptions were reported between 1855 and 1927. It has a hot spring high on its north side with a heat discharge rate of 65 MW. A summary diagram for the Tongariro Volcanic Center is given in **Table 5.**

Egmont

Mt. Egmont, 2518 m above sea level, and its parasitic cone of Fanthams Peak, 1692 m (**Photo. 6**), form a large 220 cubic km stratovolcano dominating Taranaki Province. In the last 100 ka, repeated tephra eruptions, cone building, collapses, and lahars have inundated the slopes of Egmont National Park, and have extended beyond 50 km from source. The 6 cub. km Pungarehu lahar of age 23 ka BP (**Photo. 7**), and the 0.5 cub.km Opua mud flow of age 7 ka BP, are examples. In the last 500 years, at least 9 eruptions spread hot pyroclastic flows for 15 km to the north-west, pumiceous lapilli and ash 15 km to the east, and lahars and associated floods more than 35 km from the summit along major river channels. A population of nearly 100,000 persons live within an 80 km radius of Mt. Egmont.

Three major processes constitute hazards to life and property in Taranaki in the event of a further eruption. Eruption of tephra is likely to contaminate water supplies to most communities in Taranaki. Tephra over 50 mm thickness is likely to destroy pasture, and under 50 mm would make forage unpalatable to dairy cows and sheep. Heavy ash accumulation would be likely to increase respiratory distress in humans and farm animals, disrupt communications, and transport in the region. Hazards from lahars and pyroclastic flows are likely to be more severe, because they remove or bury all structures in their paths. Such risks can only be avoided by refraining from construction in the highest risk areas. Latter (1984) has estimated that the greatest expected losses in an individual eruption, spread annually, reach their maximum of about NZ$2.2 million at Mt. Taranaki. A wall map of risk zones (**Fig. 6**) has been published by Neall (1982). Over the last 20 ka, the volume of all volcanic deposits (including lahars) has averaged 1-2 cubic km per ka. A summary diagram for Egmont is given in **Table 6.**

CONCLUSION

In some particularly useful work, Latter (1986) estimates the long term average annual property and livestock losses expected in unmitigated volcanic disasters in New Zealand, as about NZ$4.4 million per year. If adequate warning enabled chattels and livestock to be saved, he estimates that the losses for these alone could be reduced by about NZ$700,000 per year. In the long term, an investment of this amount per year in surveillance and warning systems costs nothing, and would pay a dividend in the saving of many lives. Thus it would provide the work force to restore damaged areas, and to exploit some of the often overlooked advantages of volcanic activity.

BIBLIOGRAPHY

Northland

Heming, R.F. 1980: Patterns of Quaternary basaltic volcanism in the northern North Island, New Zealand. New Zealand Journal of Geology and Geophysics 23: 335-344.

Kear, D. 1969: Relative ages, structure, and sequence of Kerikeri Basalts in Bay of Islands Volcanic Zone. Appendix I *in* Bauxite deposits in Northland. New Zealand Department of Scientific and Industrial Research Information Series 32: 12-39.

Kear, D., Thompson, B.N. 1964: Volcanic risk in Northland. New Zelaand Journal of Geology and Geophysics 7(1): 87–93.

Auckland

Brothers, R.N., Golson, J. 1959: Geological and archaeological interpretation of a section in Rangitoto Ash on Mototapu Island, Auckland. New Zealand Journal of Geology and Geophysics 2(3): 569–577.

Cassidy, J., Locke, C.A., Smith, I.E.M. 1986: Volcanic hazard in the Auckland region. *In* Gregory, J.G., Watters, W.A. (eds). Volcanic hazards assessment in New Zealand. New Zealand Geological Survey Record 10: 60–64.

Heming, R.F., Barnet, P.R. 1986: The petrology and petrochemistry of the Auckland volcanic field. *In* Smith, I.E.M. (ed), Late Cenozoic volcanism in New Zealand. Royal Society of New Zealand Bulletin 23.

Searle, E. 1964: Volcanic risk in the Auckland Metropolitan District. New Zealand Journal of Geology and Geophysocs 7(1): 94–100.

White Island

Clark, R.H. 1973: Surveillance of White Island Volcano, 1968–1972. Part 1. Volcanic events and deformation of the crater floor. New Zealand Journal of Geology and Geophysics 16(4): 949–957.

Clark, R.H., Cole, J.W. 1976: Prediction studies on White Island Volcano, Bay of Plenty, New Zealand. *In* Johnson. R.W. (ed), Volcanism in Australasia. Elsevier.

Clark, R.H., Cole, J.W., Nairn, I.A., Wood, C.P. 1979: Magmatic eruption of White Island volcano, New Zealand, December 1976-April 1977. New Zealand Journal of Geology and Geophysics 22(2): 175–190.

Clark, R.H. 1982: Surveillance of White Island Volcano 1972–77: volcanic events and deformation of the crater floor. New Zealand Journal of Geology and Geophysics 25: 317–324.

Healy, J. 1967: Geological history of the Whakatane District, Historical Review, Whakatane.

Luke, J. 1959: History. *In* Hamilton, W.M., Baumgart, I.L. (Compilers). White Island. Department of Scientific and Industrial Research Bulletin 127: 14–24.

Okataina

Cole, J.W. 1970: Structure and eruptive history of the Tarawera Volcanic Complex. New Zealand Journal of Geology and Geophysics 3(4): 879–903.

Cole, J.W. 1970: Description and correlation of Holocene volcanic formations in the Tarawera-Rerewhakaaitu region. Transactions of the Royal Society of New Zealand (Earth Sciences) 8 (7): 93–108.

Cole, J.W., Nairn, I.A. 1975: Catalogue of the active volcanoes of the world, including solfatara fields. Part XXII, New Zealand. International Association of Volcanology and Chemistry of the Earth's Interior. Rome 156p.

Howorth, R. 1975: New formations of Late Pleistocene tephra from the Okataina Volcanic Center, New Zealand. New Zealand Journal of Geology and Geophysics 18: 683–712.

Kohn, B.P., Glasby, G.P. 1978: Tephra distribution and sedimentation rates in the Bay of Plenty, New Zealand. New Zealand Journal of Geology and Geophysics 21: 49–70.

Nairn, I.A. 1979: Rotomahana-Waimungu eruption, 1886: base surge and basalt magma. New Zealand Journal of Geology and Geophysics 22: 363–378.

Nairn, I.A. 1980: Source, age, and eruptive mechanism of Rotorua Ash. New Zealand Journal of Geology and Geophysics 23: 193–207.

Nairn, I.A., Solia, W. 1980: Late Quaternary hydrothermal explosion brecica at Kawerau Geothermal Field, New Zealand. Bulletin Volcanologique 43(1): 1–13.

Pullar, W.A., Birrell, K.S. 1973: Age and distribution of Late Quaternary pyroclastic and associated cover deposits of the central North Island, New Zealand. N.Z. Soil Survey reports 1 and 2.

Pullar, W.A., Kohn, B.P., Cox, J.E. 1977: Airfall Kaharoa Ash and Taupo Pumice, and sea-rafted Loisels Pumice, Taupo Pumice and Leigh Pumice in the northern and eastern parts of the North Island, New Zealand. New Zealand Journal of Geology and Geophysics 20: 697–717.

Taupo

Froggatt, P.C. 1981: Stratigraphy and nature of Taupo Pumice Formation. New Zealand Journal of Geology and Geophysics 24: 231–248.

Froggatt, P.C. 1982: Review of methods of estimating rhyolitic tephra volumes; applications to the Taupo Volcanic Zone, New Zealand. Journal of Volcanology and Geothermal Research 14(3–4): 301–318.

Vucetich, C.G., Pullar, W.A. 1973: Holocene tephra formations erupted in the Taupo area, and interbedded tephras from other volcanic sources. New Zealand Journal of Geology and Geophysics 16(3): 745–780.

Walker, G.P.L. 1980: The Taupo Pumice: Product of the most powerful known (ultraplinian) eruption? Journal of Volcanology and Geothermal Research 8: 69–94.

Wilson, C.J.N., Rogan, A.M., Smith, I.E.M., Northey, D.J., Nairn, I.A., Houghton, B.F. 1984: Caldera volcanoes of the Taupo Volcanic Zone, New Zealand. Journal of Geophysical Research 89(B10): 8463–8484.

Tongariro

Giggenbach, W.F., Glover, R.B. 1975: The use of chemical indicators in the surveillance of volcanic activity affecting the Crater Lake of Mount Ruapehu, New Zealand. Bulletin Volcanologique 39(1): 70–81.

Gregg, D.R. 1960: The geology of the Tongariro subdivision. New Zealand Geological Survey Bulletin, new series 40, 152p.

Kohn, B.P., Topping, W.W. 1978: Time-space relationships between late Quaternary rhyolitic and andesitic volcanism in the southern Taupo volcanic zone, New Zealand. Geological Society of America Bulletin 89: 1265–1271.

Patterson, B.P. 1980: The hazard of lahars to the Tongariro Power Development, New Zealand. 3rd Australia-New Zealand Geomechanics Conference, Proceedings 2: 7–14.

Stillwell, W.F., Hopkins, H.J., Appleton, W. 1954: Tangiwai railway disaster. Report of the Board of Inquiry, Wellington. Government Printer.

Topping, W.W. 1973: Tephrostratigraphy and chronology of late Quaternary eruptives in the Tongariro Volcanic Center, New Zealand. New Zealand Journal of Geology and Geophysics 16(3): 397–423.

Egmont

Druce, A.P. 1966: Tree-ring dating of Recent volcanic ash and lapilli, Mt. Egmont. New Zealand Journal of Botany 4(1): 3–41.

Grant-Taylor, T.L. 1964: Volcanic history of western Taranaki. New Zealand Journal of Geology and Geophysics 7(1): 78–86.

Kohn, B.P., Neall, V.E. 1973: Identification of late Quaternary tephras for dating Taranaki lahar deposits. New Zealand Journal of Geology and Geophysics 16(3): 781–792.

Neall, V.E. 1971: Tephrochronology and tephrostratigraphy of western Taranaki (N108–109), New Zealand. New Zealand Journal of Geology and Geophysics 15(4): 507–557.

Neall, V.E. 1979: Sheets P19, P20, and P21; New Plymouth, Egmont, and Manaia. Geological Map of New Zealand 1:50,000. New Zealand Department of Scientific and Industrial Research, Wellington. 36p. and 3 maps.

Topping, W.W. 1972: The Birrell Lapilli eruptives, Mount Egmont. New Zealand Journal of Geology and Geophysics 15(3): 476–490.

New Zealand

Cole, J.W., Nairn, I.A. 1975: Catalogue of active volcanoes of the World, including solfatara fields.

Part XXII: New Zealand. International Association of Volcanology and Chemistry of the Earth's Interior. Rome 156p.

Dibble, R.R., Nairn, I.A., Neall, V.E. 1985: Volcanic hazards of the North Island, New Zealand-overview. Journal of Geodynamics 3: 369–396.

Latter, J.H. 1985: Frequency of eruptions at New Zealand volcanoes. Bulletin of the New Zealand National Society for Earthquake Engineering 18(1): 55–110.

Latter, J.H. 1986: Volcanic risk and surveillance in New Zealand. *In* Gregory, J.G., Watters, W.A. (eds). Volcanic hazard assessment in New Zealand. New Zealand Geological Survey Record 10: 5–22.

Smith, I.E.M. (ed) 1986: Late Cenozoic Volcanism in New Zealand. Royal Society of New Zealand Bulletin 23.

ニュージーランドにおける火山災害

Raymond R. Dibble

講演者の紹介及び滞在中の活動

略　歴

1946～1959	ニュージーランド科学技術省地震研究所員
1959～1965	同　上　地球物理調査所上級研究員
1965～1979	ウェリントン・ビクトリア大学上級講師
（1971	ハワイ大学客員準教授）
1979～	ウェリントン・ビクトリア大学助教授
（1984	国立極地研究所招聘研究員）

現在，IAVCEI (International Association of Volcanology and Chemistry of the Earth's Interior) の『火山災害の軽減に関する作業委員会』の委員長である。

研　究　業　績

ニュージーランド Ruapehu 火口湖の地震学的地球物理学的研究，ニュージーランドの火山活動，噴火予知および火山災害に関する研究など。現在は，火山災害の軽減および南極 Erebus 火山の噴火機構の研究に精力を注いでいる。

1987年

11月28日	東京国際空港（成田）到着。国立極地研究所において南極 Erebus 火山の共同研究を行う。12月15日まで滞在。期間中に以下の4ケ所を訪問。
12月 3日	東京大学浅間火山観測所を視察
12月 8日	気象庁を視察
12月 9日	気象庁気象研究所にて講演
12月14日	東京大学伊豆大島火山観測所を視察
12月17日	京都大学防災研究所附属桜島火山観測所に到着。南極 Erebus 火山と桜島火山の爆発地震の解析および両火山の噴火機構の比較研究を行った。1988年2月19日まで滞在。その間に以下の2ケ所を訪問。
2月 1日～2日	京都大学防災研究所を訪問。『ニュージーランドの火山災害』および『南極 Erebus 火山の爆発的噴火』に関する講演を行なう。
2月 3日～4日	愛知教育大学を訪問。インフラソニック波観測施設および記録解析システムを視察。火山爆発によって発生するインフラソニック波に関して田平誠教授と意見を交した。
2月21日	京都大学火山研究施設を視察。
2月22日	国立極地研究所に到着。南極 Erebus 火山の共同研究を行う。
2月28日	東京国際空港（成田）発。帰国。