The Rotomahana shower was a most unusual volcanic event, but nevertheless strikingly demonstrated the resilience of indigenous vegetation.

Ash *showers* may not always have been catastrophic for vegetation, and even where forest may have been obliterated by ash *flows* a return may not invariably have involved a long time and protracted plant successions. Long-lasting changes may be considered probable only where soils were radically changed.

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ASH BEDS AND SOILS IN THE ROTORUA DISTRICT

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INTRODUCTION

During the Late Quaternary, volcanic eruptions of the explosive or paroxysmal type (Taylor, 1953) occurred in the central North Island about centres, which for convenience, are designated Okataina, Waitahanui, Maroa, and Tokaanu (Fig. 1). The resulting ejectamenta formed thick layered beds largely of rhyolitic pumice. Most is known about the distribution of beds from the Okataina and Waitahanui eruptive centres where named beds have been mapped in the Rotorua, Bay of Plenty, and Gisborne districts (Vucetich and Pullar, *in press*). Little is known about the Maroa and Tokaanu centres except that they are considered to have been important contributors earlier in the Holocene and that they were also active contemporaneously with the Taupo Pumice eruptions.

STRATIGRAPHY

The following ash beds have been recognised; the age where known is given in years before 1950:

Named Beds

Tarawera scoria (and Rotomahana mud) erupted 1886	
Kaharoa Ash	810±70[1]
Taupo Pumice	1700±150[2]
Taupo Subgroup, members 9–13	
Waimihia Ash	3420±70[3]
Rotokawau Ash	
Whakatane Ash	
Mamaku Ash	
Rotoma Ash	
Taupo Subgroup, members 16–18	8850±1000[4]
Waiohau Ash	
Rotorua Ash	
Rerewhakaaitu Ash	

Unnamed Beds

"'X' Beds"; (Ash and lapilli) three in number in Rerewhakaaitu locality and believed of restricted distribution; not mapped because of few exposures.

*"Pinkish-brown Beds"; multiple, of ash grade, weakly weathered; mainly northern part of Kaingaroa Forest, Wairakei, Waiotapu and Rotorua.

*"Mauve Beds"; three in number mainly on Mamaku Plateau.

"Yellow-block Bed"; mainly along Bay of Plenty and in Gisborne District; not traced south and west of Rotorua.

* The "pinkish-brown" and "mauve" beds are not seen in stratigraphical order in one section and may be coeval. Mapping of these together with lower beds is proceeding.

"White-block Bed"; mainly along Bay of Plenty; not traced west and south of Rotorua. (Both of the above may be a correlative of Kawerau Breccia.)
"Grey-banded Bed"; wide distribution from west of Tauranga to Gisborne but southernmost limits not known. (Correlative of Rotoiti Breccia.)
"Red Beds" or "ginger tuffs" (Hamilton correlative); correlated with known Hamilton beds west of Tauranga and at Matamata; traced along Bay of Plenty to Gisborne; perhaps the most widespread of all ash-fall beds.

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ERUPTIVE EVENTS

The ash column records events separated by considerable time intervals. Each event caused complete or partial destruction of the vegetation within an inner zone and, during the ensuing period of quiescence, vegetation established itself and soils began to form. In the preceding cold period (Last Glaciation) the ash column shows erosion breaks and it would appear that a number of eruptions took place when the uplands were bare of vegetation and there was extensive erosion.

Detailed studies of the Taupo Pumice and soils derived from it are used as a basis for the pattern of forest destruction and for a suggested history of the forest during the Late Quaternary.

AREAS OF VULCANICITY AND VEGETATION DESTRUCTION

In the vicinity of the vents, *blast* and *glowing avalanches* were the principal agents of destruction and shower-bedded deposits beyond are considered to have fallen cold and to have killed vegetation by burial. This principle is well illustrated in the products of the Kaharoa eruption where charred logs are seen in localised *ash-flow* deposits dropped by glowing avalanches on the lower slopes of Mt. Tarawera, but the *ash-fall* deposits further away do not contain charcoal. Charcoal occurs sparingly in ash-fall deposits and is usually to be found in contact with or within the buried soil rather than in the overlying ash beds.

Products of ash-flow dropped by *glowing clouds* or *nuées ardentes* are often widespread and more difficult to plot because of violent eruption occurring simultaneously from a number of vents. The clouds travelled long distances, transporting vast quantities of pumice and ash at temperatures sufficiently high to char wood in their passage across the landscape. Deposits from one eruptive episode vary according to topography; in depressions and on valley floors, particularly towards the foot of hill slopes, they are characteristically thick pumice breccias frequently containing charcoal, and on slopes, they are ash breccias a good deal thinner but of irregular thickness.

Vegetation was also drowned or buried by water and alluvium impounded in temporary lakes.

From ash-fall plans prepared by Vucetich and Pullar (in press) the area covered by ash more than 24 in. thick is 5,000 square miles; more than 18 in., 7,000 square miles; and more than 12 in., 12,000 square miles in the combined districts of Rotorua, Taupo, Bay of Plenty, and Northern Hawke's Bay (Fig. 1).

The critical thickness of cold ash required to destroy vegetation cannot be given with precision. On Mt. Egmont A. P. Druce (pers. comm.) observes that the Burrell Ash deposited cold some 300 years ago had the following effect on cedar and Hall's totara:

15 in. thick	complete destruction
12–15 in.	almost complete destruction
9–12 in.	partial destruction

Thomas (1888) reports that the forest was not destroyed on Mt. Edgecumbe where Tarawera scoria and ash fell 14 in. thick. If a conservative estimate of ash thickness for complete destruction is 18 in., then destruction on at least one occasion occurred over an area of 7,000 square miles.

TAUPO PUMICE ERUPTIONS

A series of eruptions from centres at Waitahanui, Maroa, and Tokaanu and occurring at short intervals are known as the Taupo Pumice Eruptions. They terminated with particularly violent explosions from vents which appear to have extended beyond the centres named and with ash-flow material persisting for long distances.

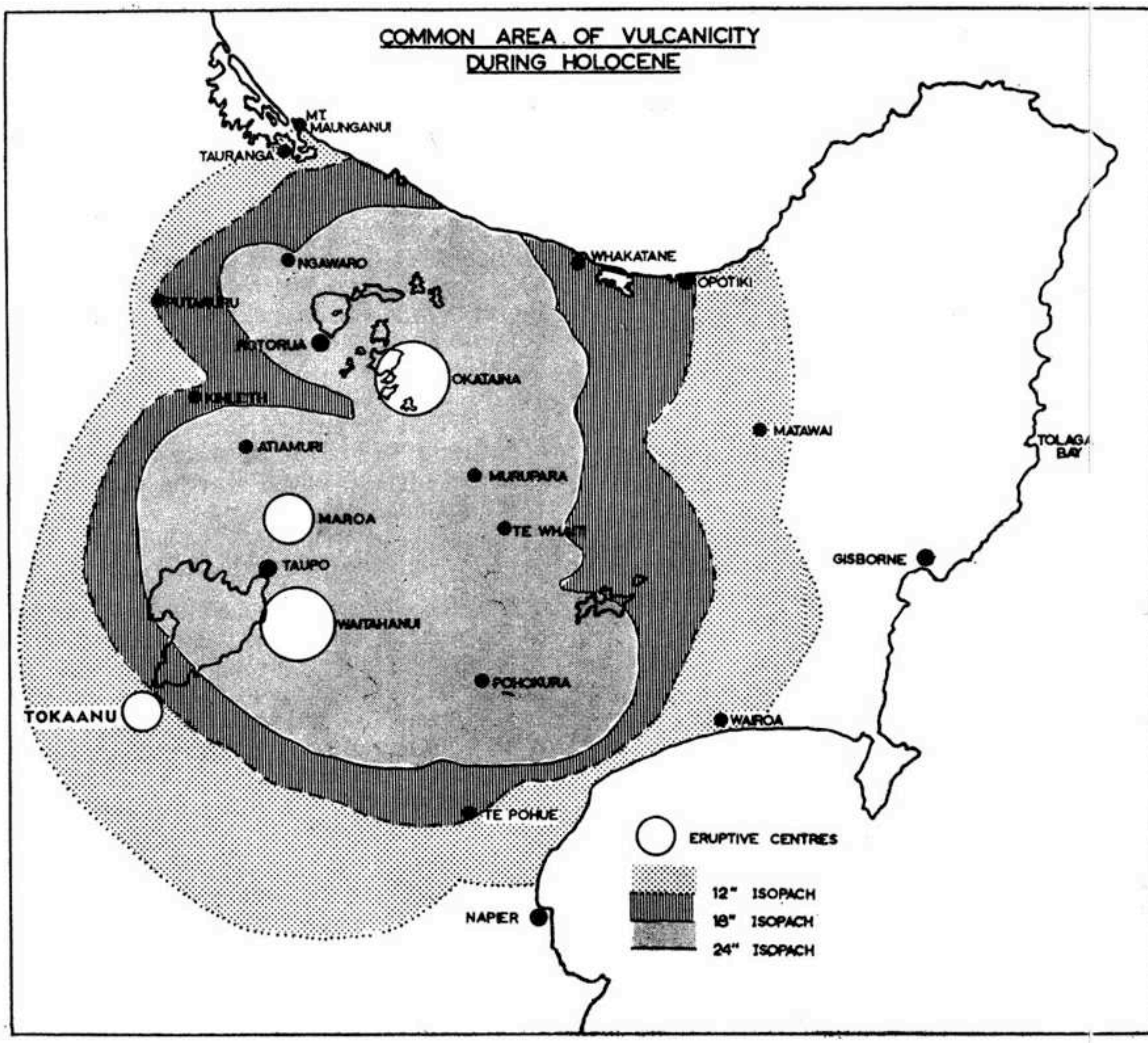

FIGURE 1. Area in which forest was destroyed by vulcanicity on at least one occasion during the Holocene. Destruction is postulated to be complete with deposits greater than 18 in. thick and partial with those 12–18 in. thick.

The timetable, form of eruption, and pattern of vegetation destruction is given below with particular reference to the Waiotapu-Oranui locality.

Phase 1

Initial ash-fall deposits from centres near Waitahanui; Hatepe Ash, "putty coloured layer", and Rotongaio Ash caused localised destruction mainly by burial.

Phase 2

Widespread deposits of Taupo Lapilli mainly from Waitahanui are shower bedded and caused localised complete destruction by burning and blast, and by burial in an outer zone. Large trees remained standing through 18 in. thick deposits.

Phase 3

After a short interval a violent eruption of the "rhyolitic block member" gave rise to a widespread thin bed of rhyolitic lapilli. This eruption appears to have its sequel in the Maroa centre where, on slopes near Orakei Korako, rhyolite ash and lapilli and pumice lapilli form thick, mainly loose, deposits of irregular thickness. In valley bottoms massive breccias up to 15 ft thick are characterised by discontinuous vertical fissures with inclusions of loose ash and chalazoidites (volcanic hailstones). This eruption caused localised forest destruction by blast and burning as well as by burial.

Phase 4

Upper Taupo members include multiple flow beds of indurated ash (and pumice lapilli) on the uplands thinning off as slope increases, and thick pumice breccias of the valley floors. Some hill slopes in the lee of the believed direction of blast have little or no ash deposit.

The pattern of breccias indicates that *nuées*, which were to some extent channelled by the Paeroa scarp into the Waikite and Whirinaki valleys, were partially obstructed by the orographic barriers of rhyolite domes and Horohoro Bluff and deflected to the west. The source of the *nuées* is not known but the occurrence of thick breccias containing pumice blocks near Orakei Korako suggests that there were eruptions from this place. The limit of breccia and ash-flow beds is also the limit of forest destruction. Forest would be destroyed by blast, by burning or charring where engulfed by *nuées*, and by the impounding of valleys for a short period when drainage was obstructed by pumice breccias; for example, Reporoa valley, which was a lake below the 1,070 ft contour. The area of destruction is roughly 4000 sq. miles, but it is believed that remnants of forest may have survived on thinly coated slopes within this area and so provided plant material for eventual colonisation.

Phase 5

A final phase with source vents in the Maroa-Mokai-Oranui area locally produced thick pumice breccias with restricted distribution but with more widespread ash-fall.

TEMPERATURE OF ASH-FLOW

Ash-flows must have had a substantial burning effect on the vegetation, but while the minimum temperature required to char wood is 250°C, there is no sign of baking of a buried soil and this would suggest lowest temperatures at the base of deposits and a temperature gradient within the overlying ash. If the buried soil was not appreciably heated seeds, rhizomes and fungal hyphae may be expected to survive and become important plant material to colonise those hill slopes which, although overrun by *nuées*, are thinly ash coated. These views may have substance from the observations of Miller *et al* (1955) who recorded temperatures as high as 600°C during scrub fires at Taita Experimental Station.

SOILS

Profiles of the buried soils are compared with present day soils and matched for development of pedologic horizons and degree of weathering as indicated by colour and content of amorphous clay minerals. With few exceptions the evidence suggests that forest reclothed each successive ash deposit but there is little indication as to the rate of recovery.

Soils derived from Kaharoa Ash

After 800 years, subsoil characters are very weakly expressed in the loose, coarse Kaharoa Ash. Under podocarp-dominant forest along Hongi's Track near Lake Rotoiti, subsoils are humus stained and lenses of fine ash are weakly cemented with humus and iron. In the Kaingaroa Forest and Galatea basin (Vucetich *et al*, 1960) profiles are more strongly developed on hill slopes under a manuka scrub community (*Leptospermum scoparium*) and least so on flattish sites in both basin and plateau under a manoao (*Dracophyllum subulatum*) and tussock (*Poa caespitosa*) cover. Differences may be explained by a relatively unfavourable microclimate.

Unfortunately, firing of the vegetation by the early Maori makes interpretation difficult. This point is well illustrated near Kaingaroa Forest Headquarters, where a Te Rere subsoil from Kaharoa Ash shows disrupted shower bedding about a site once occupied by a tree with a basal diameter of about 10 in. A thin weakly-stained lens of fine ash in the subsoil with further iron staining in the buried Taupo Pumice soil below indicates that a podzolising tree survived a 12 in. thick deposit of Kaharoa Ash and, furthermore, continued to podzolise the new material. But this forest was destroyed by a fire prior to European settlement.

Soils from Taupo Pumice

Present day podocarp-dominant forests have left a marked imprint in Taupo pumice soils particularly on the hills. Soil horizons are best exhibited in a saucer-shaped soil, podzolised under rimu (*Dacrydium cupressinum*) which has, under its mor-litter, a pale brown, bleached A2 and a dark brown, humus illuvial, B2 horizon. These features show up well in some 24 in. of indurated silty sand, representative of the ash-flow type of deposit, and the podzol B horizons are well preserved where the forest has been destroyed and where a black topsoil, enriched with bracken fern or scrub humus, has subsequently formed. By comparison, broadleaved trees produce mull litters and a humus-rich A horizon over a thin B except where grown on sites previously occupied by rimu or similar podzolising trees, *e.g.*, where rata supplants a host rimu, a mull litter and a humus-rich A overlie the podzol B horizon.

Soils derived from thick ash-flow beds on flattish basin sites are commonly shallow with a pumice pan restricting plant roots. A common profile under manoao or manuka scrub shows a black topsoil resting on a dark brown subsoil stained reddish-brown and weakly cemented, and passing abruptly to a massive silty sand at 10–12 in.

On the uplands, near Waimihia, scrub soils have similar characteristics also attributable to podzolisation. Taylor (1953) did not consider these shallow rooting soils to be normal "pumice podzols". But the weight of indirect evidence strongly suggests a previous shallow-rooting forest. Such a forest would be vulnerable to fire and may explain complete destruction before European settlement.

Profiles suggest a good recovery of the forest after the Taupo eruptions, being most rapid on the hills where pockets of plant material survived and then expanded slowly across lowlands and plateaux. It may be inferred that recovery would have been quicker after the ash-fall type of eruption, which destroyed smaller areas of forest, and which provided a more suitable loose parent material for forest growth.

Buried Soils and Past Vegetation

Information gained from profiles of present-day surface soils and from kinds of vegetation growing on them is used for a provisional interpretation of the vegetational and climatic history during the Late Quaternary.

Apart from the black scrub soils (Kaharoa Ash) buried beneath Tarawera or Rotomahana ashes, almost all buried soils are brown or yellowish brown in colour. Distinctive A horizons are not generally found and the buried soils comprise one main horizon over yellowish brown parent material. Most of the buried soils have irregular thickening of the old B horizons with tongues of similar material extending 10–12 in. below. The best example of 'tonguing' occurs in soils bearing fine-textured indurated lenses, and having a pale yellowish-brown colour penetrated by strongly coloured dark brown tongues. These features together with the infrequent occurrence of charcoal fragments in pockets are indicative of forest. The following is a brief inventory of characters for buried soils:

Rotokawau Ash; basic, but containing rhyolitic ash; one of the most weathered of Holocene ashes (sandy loam texture), and the most strongly and uniformly coloured; commonly reddish yellow; very limited area; stratigraphic relationship to Waimihia Ash not known.

Waimihia Ash; more uniformly humus and iron stained than overlying present day Taupo Pumice soils and considered to be more weathered but not yet confirmed by clay mineral analyses (note that comparison is made with soils derived from ash-fall deposits of Taupo Pumice east of the limit of ash-flow deposits). The climate may have been slightly warmer than after the Taupo Pumice eruptions.

Whakatane Ash; yellow brown silty sand and sandy loam; texture distinct from grey shower beds at base.

Mamaku Ash; strong brown or bright yellow-

brown coloured soil, more weathered than either Whakatane above or Rotoma below; soil colour distinctive for separating these beds.
Rotoma Ash; blackish brown soil contrasting sharply with marked shower bedding at base.
Taupo subgroup members 16–18; strong brown sandy loam for fine ash and yellowish brown silty sand for coarse ash; comprises several ash-fall accretions some probably from the Maroa eruptive centre; fine flecks of charcoal from soil on member 18 give an age of 8,850±1000 years, but the sample contained charcoal and organic matter existent in the soil before burial and so the result gives a maximum age and not necessarily the time of eruption.
Waiohau Ash; silty sand or sandy loam and the colour is similar to Taupo subgroup 16–18; bears forest imprint.
Rotorua Ash; soil is the most weathered of the Holocene ash beds; sandy loam throughout with strong-brown or yellowish brown colours and characterised by having fine pumice lapilli in the surface horizon; colour and texture remarkably constant over a range of sites and rainfall conditions and indicate soil formation under an appreciably warmer climate than today; little clear forest imprint but occasional pockets of charcoal discovered; no features suggesting podzolisation attributable to kauri trees (*Agathis australis*).

The fine ash beds which overlie and seal the Rotorua Ash provide a strong contrast in weathering which supports the premise that weathering is relatively ineffectual after burial. Nor is there evidence that the Rotorua Ash is more basic in composition or weathers more readily than other pumiceous materials. Rotorua Ash is thus an important marked bed in Holocene ash-fall deposits but no time span can be allotted until 14C dates have been determined on samples already collected.*

Rerewhakaaitu Ash; the basal named bed of the Holocene ash; brown in colour but less weathered than Rotorua; bears forest imprint.
"X Beds"; three in number and each of limited extent; silty sand texture; weak forest imprint.
"Pinkish-brown beds"; multiple beds, sand or silty sand texture; no distinct pedologic horizons; no evidence of forest.
"Mauve beds"; multiple beds with weak pedological features; fine ash weathered to sandy silts, silty loams, and silty clays; firm, compact, massive; no evidence of forest.
"White block bed"; fossil soil not conspicuous.
"Grey banded bed"; pedological features weak and no definite forest imprint; at Te Puke, fossil soil a sandy loam while at Opotiki more a "slippery" loam and silt loam.
"Red beds" (correlative of Hamilton beds); pedologic features strong including colour of yellowish red and dark red, clayey textures, and strongly developed blocky structures with clay skins on faces of aggregates; slippery and non-sticky; much amorphous clay mineral — allophane; most distinctive soils of all pyroclastic deposits in the Rotorua, Taupo, Bay of Plenty and Gisborne districts. No obvious forest imprint noted but charcoal occurs sparingly in the lower "grey banded beds" and this implies forest destruction.

The evidence from all named beds is that forest was the main vegetation on pyroclastics erupted during the Holocene.

NATURAL HISTORY AND THE PATTERN OF VULCANICITY

On uplands, Holocene ash deposits down to and including the Waiohau Ash are wholly mantling beds and without unconformities; but the older beds are not always present and their absence is an indication of the incidence, degree and time of erosion. All older beds are present on the western margin of the Mamaku Plateau towards Tirau but they are absent on the crest of the Mamaku Plateau, where Rotorua Ash rests directly on ignimbrite, and largely so on Kaingaroa Plateau where Rerewhakaaitu ash mantles a thin weakly-weathered pinkish brown soil containing fragments of ignimbrite; on Taupuke Saddle (Huiarau Range) the same ash rests on "pinkish-brown beds" which in turn rest on fragmented greywacke. In the Gisborne district all older beds are present on a high level terrace along the coast at Uawa, on Hamurian shale at Whangara, and on a terrace remnant amidst spectacular accelerated erosion, in the headwaters of the Waipaoa River.

From this rather fragmentary evidence, a major erosion break is established some 30,000 years ago when the older Hamilton beds were stripped from the uplands and eroded from greywacke ranges to the east. The "grey banded beds", probably erupted about this time, were also stripped from these surfaces as were later deposits during the last glaciation — "pinkish brown beds" from some uplands and "mauve-beds" from the crest of the Mamaku Plateau.

In Figure 2 trends in climate are expressed relative to weatheredness of Late Quaternary ash beds. A weathering index has been determined using 14C dates of

* Age of the Rotorua Ash is considered to be less than 15,000 years for the following reason: at Piarere, and along the Waihou River from Te Poi to near Te Aroha, the high level terraces of Hinuera Formation (pumice alluvium) are capped by two ash-fall beds, the upper one of which is thought to include Rotorua Ash. Two samples of wood have been dated from the Hinuera alluvium and the younger age is 15,000 years.

eruptive events, and a date previously discussed establishes a tentative chronology for the older beds. A zero rating (0) for "pinkish-brown", "mauve", "yellow-block" and "white block" beds implies slight weathering but not sufficient to rate as (1).

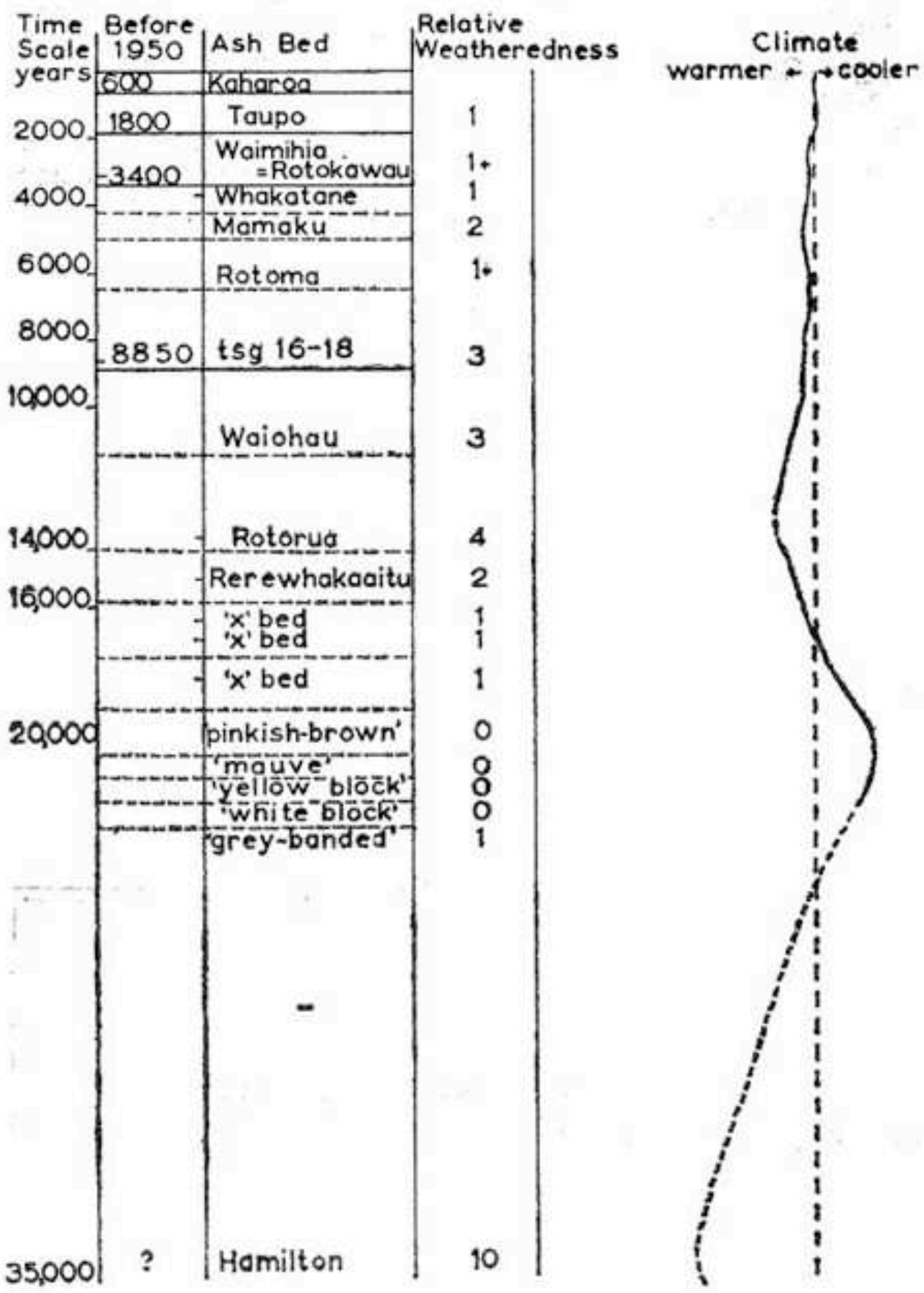

FIGURE 2. Trends in climate expressed relative to weatheredness of Late Quartenary ash beds. A weathering index is based on 14 C dating of four volcanic eruptions.

Warmer temperatures are marked by distinct soil formation on the unnamed "X" beds and a further increase in temperature by stronger weathering of the Rerewhakaaitu soil. An interval for a "thermal maximum" is acknowledged during the Rotorua episode extending with perhaps decreasing temperature to the time of eruption of Taupo Subgroup members 16-18. From the Rotoma episode to the present day the record shows relatively little change although a comparison of Taupo and Waimihia soils each with the same time of soil formation would indicate a slight decrease in the intensity of soil weathering after the Waimihia eruption.

CONCLUSIONS

The impact of Holocene and Late Quaternary vulcanicity on the vegetation in the central region is summed up as follows:

1. Has speeded the establishment of vegetative cover on the eroded uplands after the Last Glaciation by providing a rooting medium over fretted ignimbrite, and likewise, speeded colonisation of the greywacke axial ranges.
2. Caused subsequent short-lived destruction of forests around eruptive centres. An area of 5000 square miles has been affected at one or more times during the Holocene.
3. Each eruptive event has mantled a large zone beyond the central zone of destruction with an accretion of fresh minerals and so offset the progressive degrading of soils by weathering, leaching, and podzolisation. Benefit is optimum where the accretion is 12 in. or less of fine ash and where the vegetation is not greatly disturbed.
4. Each accretion increased the thickness of ash mantle on the steep slopes of the greywacke ranges and has assured protection from erosion and so provided watershed control.
5. Taupo Pumice eruptions were the most devastating to vegetation.
6. Thick deposits of Taupo Pumice on the Kaiweka Range, for example, are highly susceptible to actual or potential erosion (A. P. Druce pers. comm.).
7. Indirectly, the effect of vulcanicity is also demonstrated in the widespread destruction of forest following the introduction of fire by man. Yellow-brown pumice soils, unlike the more weathered and more moisture-retentive yellow-brown loams and yellow-brown earths, dry out periodically to a depth of about 12 in. (Will, 1962) and at these times their vegetation is susceptible to fire. The scrub vegetation at the time of European settlement was largely induced by fire

and not by vulcanicity. Succession from fire-induced scrub to forest has has been prevented or slowed down by soil degradation including both strong leaching and unfavourable physical properties.

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