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TREE-RING DATING OF RECENT VOLCANIC ASH AND LAPILLI, MT EGMONT

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SUMMARY

Previous literature on the recent volcanic history of Mt Egmont is reviewed. In the present account nine beds, constituting the volcanic ash and lapilli deposited on the mountain within the last 500 years, are described, mapped, and approximately dated. In stratigraphic sequence these are: Newall Ash, Newall Lapilli, Waiweranui Lapilli, Waiweranui Ash, constituting the *Newall Formation* dated about A.D. 1604; Burrell Ash, Burrell Lapilli, Puniho Lapilli 1, Puniho Lapilli 2, constituting the *Burrell Formation* dated about A.D. 1655; and Tahurangi Ash, the sole member of the *Tahurangi Formation* dated about A.D. 1755. The dating is based on tree-ring counts for the most part, but relative depths of interbedded peat have also been used. Sources of error in tree-ring dating and the problems involved in applying the method to the particular ash beds are discussed in detail. The recent volcanic history of the mountain is outlined. Further study needs to be made of the beds on the west side to elucidate the history of the numerous showers directed there.

HISTORICAL INTRODUCTION

The first person to realise that Mt Egmont (Fig. 1) had erupted recently appears to have been A. W. Burrell; Oliver (1931) records that "as early as 1883 Mr Burrell found volcanic material in the forks of a matai

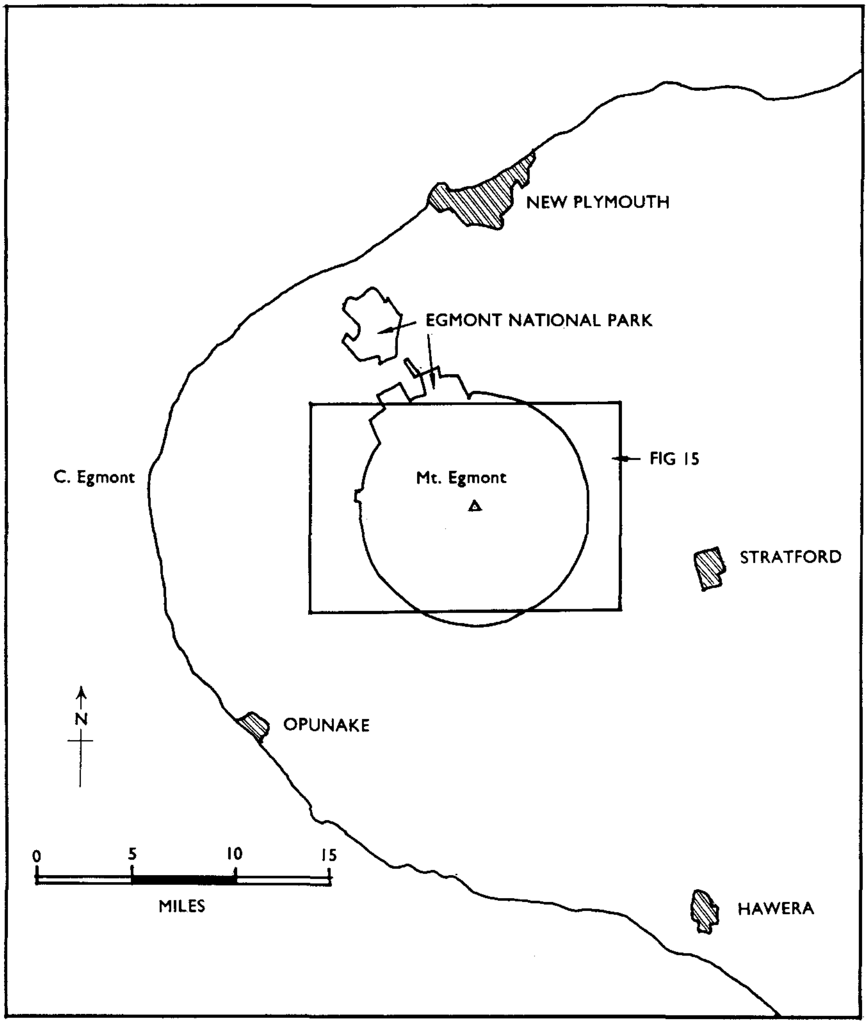


FIG. 1—Locality map.

(*Podocarpus spicatus*) which had just been felled", and that Burrell had a "theory, based on the finding of scoria in the forks of trees, that the last eruption of Mt Egmont occurred only a few hundred years ago". The earliest published suggestion of recent activity so far traced is the following observation by Skeet (1901): "Judging from the different layers of pumice and earth, I think there have been three comparatively recent eruptions". No details are given. Both Burrell's discovery and Skeet's report were apparently unknown to Morgan and Gibson (1927), who make no mention of the possibility of any recent eruption.

Oliver (1931) discusses the significance of the discovery of a Maori oven buried under 15 in. of pumice and ash near Stratford Mountain House on the eastern slopes of Mt Egmont and records Burrell's previously unpublished observations on volcanic material found in trees. For a date for the eruption he says the most definite line of evidence is that of the matai. From a count of the annual rings Burrell estimated the age of this tree to be about 600 years in 1883. By assuming the tree to be 150 years old when the pumice was deposited in its fork he arrived at a date of about 450 years before 1883. Oliver himself thought that "the standing, partly buried trunks of totara,* some only a foot in diameter, would indicate a more recent date for the eruption".

A report of the N.Z. Department of Scientific and Industrial Research (1933) states that the Burrell shower was erupted "probably less than 500 years ago"; a map shows the distribution of the soils derived from the shower deposits on the lower slopes of Egmont. Taylor (1953) refers to the "Burrell ash, a later eruption of Mt Egmont which occurred about A.D. 1500". In a general survey of the soils of North Island, New Zealand (N.Z. Soil Bur., 1954), the Burrell shower is said to have erupted from Mt Egmont "some four hundred years ago". The area covered by the shower is shown on a map of the soil-forming ash showers of part of North Island. In the same publication a second shower from Mt Egmont is recorded as Newall ash, the parent material of a soil set mapped as occurring on the western and north-eastern slopes of the mountain. Newall ash was first recognised by L. I. Grange and N. H. Taylor in the early 1930s (H. S. Gibbs, pers. comm.).

Fergusson and Rafter (1957) report on ^{14}C measurements of "charcoal from a Maori oven buried below 15 in. of volcanic ash, which is classified as a deposit of the Burrell shower": figures of 400 ± 60 years B.P. (before 1950) for a "large piece of wood in centre of oven" and 360 ± 60 for "small pieces of charred wood from various parts of oven" were obtained. The authors point out that the "age of the samples shows the age of the material used for firewood and would be older than either the oven or the volcanic ash deposit".

Wellman (1962, p. 78) reports on an ash, tentatively correlated with the Burrell ash, that occurs in a section on the coast north-east of Egmont. From its stratigraphic position he estimates the date to be about A.D. 1500. He states that the ash is in thin layers interbedded with magnetic sand, and that it indicates at least three eruptions within a period of a few tens or

*Identified by Oliver as *Podocarpus totara*, but actually *P. hallii*.

hundreds of years. In a summary Wellman (loc. cit., p. 96) estimates the date of Burrell ash as about A.D. 1650.

Grant-Taylor (1964a) records and maps a third shower, resulting from an explosive eruption breaching the crater wall on the west side. The deposit, which overlies the Burrell ash, is named the Puniho Lapilli, though in a later publication (Grant-Taylor, 1964b) the name Puniho Grit is substituted. It is stated that no other ash or lapilli deposit overlies Puniho Lapilli.

The estimates of the date of the Burrell ash are listed in Table 1. Puniho Lapilli is presumed by Grant-Taylor (1964a) to have been deposited a short time after the Burrell ash during an eruptive phase lasting a few days or weeks, but the Newall ash is stated by Gibbs (*in* Wellman, 1962) to be older from its stratigraphic position Wellman (loc. cit., p. 78) estimates the date of an ash, tentatively correlated with the Newall ash, as about A.D. 1000. In a summary (Wellman, loc. cit., p. 96) the estimated date of the Newall ash is given as about A.D. 1350.

TABLE 1—Estimates of the date of the Burrell ash

Observer/Author	Date (A.D.)
Burrell in 1883 (Oliver, 1931)	*c.* 1430
Oliver (1931)	post 1430
N.Z. Dep. Sci. Industr. Res. (1933)	post 1430
Taylor (1953)	*c.* 1500
N.Z. Soil Bur. (1954)	*c.* 1500
Fergusson and Rafter (1957)	post 1600
Wellman (1962)	*c.* 1650

The present work was done during a general vegetation survey of Egmont National Park begun in 1959 and continued at intervals until May 1964. Soon after the commencement of the survey, on the east side of Egmont, it became apparent that the Burrell ash could be divided into three separate beds: the characteristic Burrell pumice bed was both overlain and underlain by ash. At a later date, when the survey was extended to the western side, it was found that Newall ash could likewise be divided into a number of distinct beds—in this case four. Lastly, a lapilli deposit, tentatively correlated with the Puniho Lapilli and overlying Newall ash and the lowest two beds of the Burrell ash, was divided into an upper and a lower bed.

When it was discovered early in the survey that vegetation and soil varied considerably from one side of the mountain to another it seemed probable that the differences could be related in large part to the nature and distribution of the ash showers and the time since they had fallen. An ash shower changes the course of community development both by destroying part or all of the previous vegetation and by adding new parent rock to the soil. During the last 350 years approximately one-fifth of the vegetation on the slopes of Egmont at present within the boundary of Egmont National Park has been destroyed by ash showers through impact, burial, or fire.

Probably another fifth has been damaged to some extent, and the whole area has received ash and lapilli varying in depth from a few inches to 5 ft or more.

The aim of the present work has been to provide a basis on which correlations can later be made between vegetation and soil on the one hand, and volcanic disturbance, parent rock, and time for community development on the other. Each of the beds discussed has been deposited within the life span of the older trees living today on Egmont, and it is to these trees that I have turned in seeking evidence for dating the beds.

THE ASH AND LAPILLI BEDS AND THEIR DISTRIBUTION

COLLECTION OF PROFILE DATA

Profiles were examined in about 260 soil pits; in addition about 40 sections were described from roadsides, track sides, and river cliffs. Particular attention was paid to the depth and nature of the ash and lapilli layers, and to the presence or absence of buried soil and carbonised wood. Some of the profiles were described in detail so that they could be used as standard profiles. Sites were chosen wherever possible on gently undulating or easy rolling land away from water channels. Even so, whenever several pits were dug close together the depths of the beds were found to vary considerably. Deflection by trunks and branches of trees and shrubs probably accounts for much of the variation in the depth of lapilli, and redistribution following torrential rain for much of the variation in the depth of ash. Sites near gorges cut in agglomerate were found to be unsatisfactory, for the accretions of blown sand derived from the cliff faces made it impossible to measure the true depth of ash. It was difficult to find suitable sites above 4,000 ft, where increasing steepness and decreasing vegetation cover limit stability (Figs. 2 and 3); 4,750 ft was the highest altitude at which satisfactory measurements could be made. On the west side of Egmont suitable sites are restricted to relatively small areas, such as hilltops and remnants of old fans; young alluvial fans cover most of the intervening country.

THE ASH AND LAPILLI BEDS

The recent ash and lapilli beds discussed here are those overlying the uppermost well developed buried soil on the slopes of Egmont. A typical sequence of beds as seen on the eastern slopes is shown in Fig. 4, in which the buried soils have been indicated. Buried soil 9 is not well developed; the first well developed soil is No. 8, the surface of which is indicated by the upper limit of vertical cracking. All the beds below this surface down to the underlying agglomerate are tentatively correlated with the "Stratford ash" of Taylor (1953). As is shown below, the sequence of beds discussed here includes three soil-forming breaks; in addition to buried soil 9 there is a buried soil that is seen in bogs (incorporated in the present soil elsewhere), and a buried soil (below buried soil 9) that is sometimes seen on the upper slopes as a horizon distinct from the underlying old soil.

The uppermost part of the sequence on the eastern slopes, the so-called "Burrell ash" or "Burrell shower", is here divided into three beds: Burrell

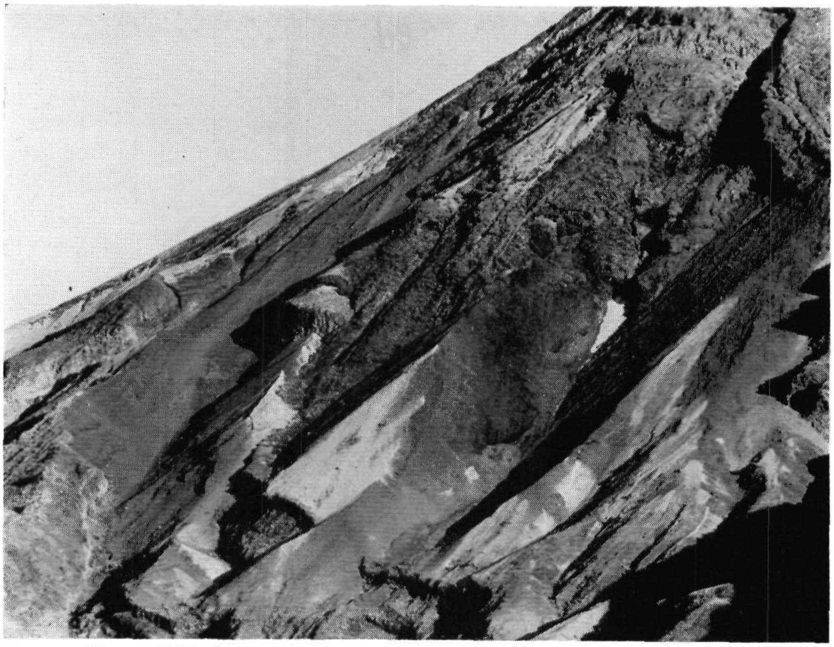


FIG. 2—Upper ESE slopes of Mt Egmont, showing residual accumulations of white pumice (Burrell Lapilli).

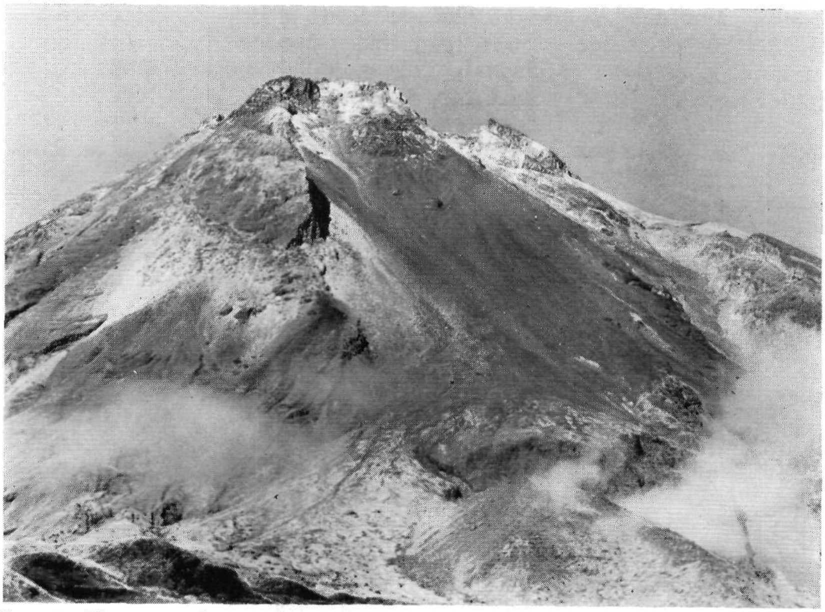
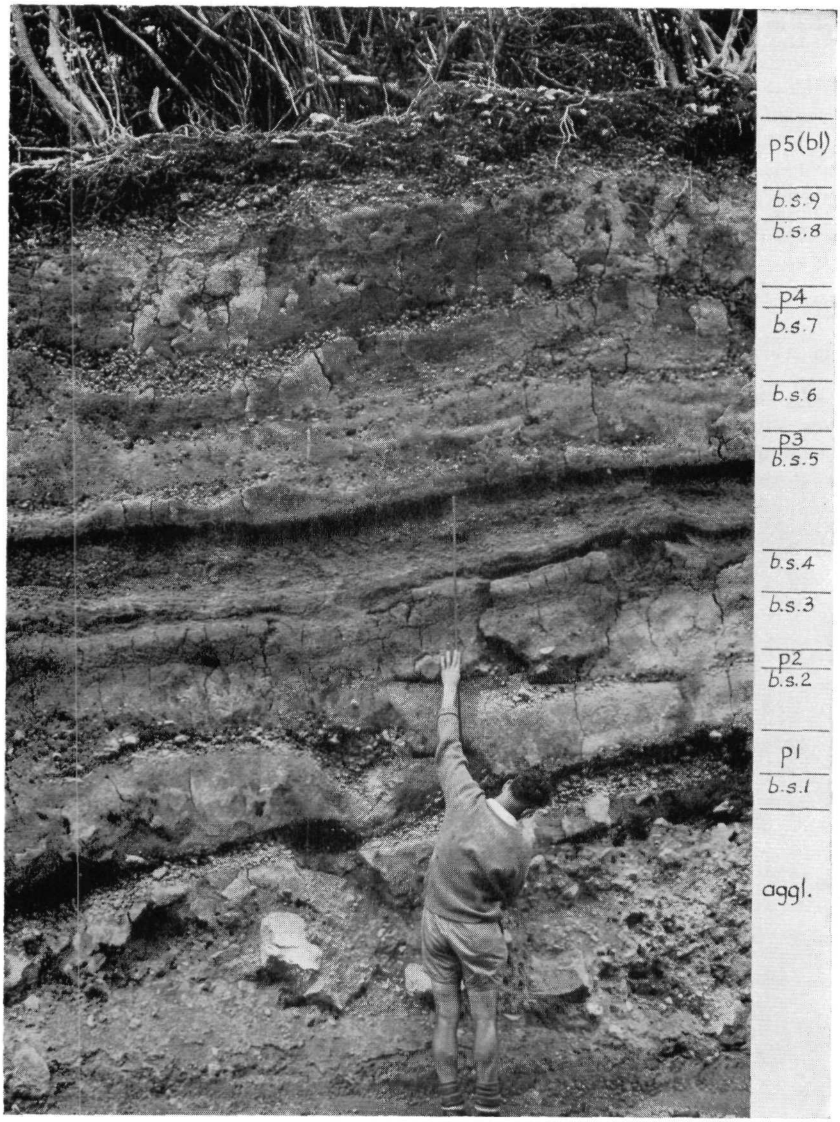


FIG. 3—Upper north-west face of Mt Egmont, showing scree slopes below the exposed tholoid. Moss-covered debris fan lower left centre.



Photo—G. C. Kelly

FIG. 4—Cutting, Stratford Mountain Road, 3,400 ft, showing 13 ft of ash beds over agglomerate. Prominent pumice lapilli beds, p1 to p5 (Burrell Lapilli—bl), and prominent buried soils, b.s.1 to b.s.9, are indicated. Profile 37 from the top 21 in. of the left-hand (north) end of this cutting (out of photo) is shown diagrammatically in Fig. 6 and described in Appendix 1. Part of the profile is shown in detail in Fig. 12.

Ash, Burrell Lapilli, and Tahurangi Ash. Oliver's (1931) description of a profile adjacent to the Maori oven, Stratford Mountain House, is compared in Table 2 with the present interpretation of a profile, No. 33, from there.

TABLE 2—Comparison of profile interpretations

Oliver (1931)	Present Author
2 in. surface soil, volcanic loam*	$2\frac{1}{2}$ in. Tahurangi Ash
10 in. pumice	12 in. Burrell Lapilli
3 in. volcanic ash (Maori oven)	2 in. Burrell Ash (Maori oven)
12 in. volcanic ash	$2\frac{1}{2}$ in. Waiweranui Ash (buried soil, containing charcoal from oven)
	$\frac{1}{2}$ in. Waiweranui and/or Newall Lapilli
	$1\frac{1}{2}$ in. Newall Ash
	on unnamed ash (buried soil)

*Oliver (loc. cit.) thought this had been formed by weathering of the pumice below.

As the type locality for the three beds, I have chosen a cutting at the new site for Manganui Hut; the type profile (No. 41) is shown in Figs. 5 and 6, and described in Appendix 1.

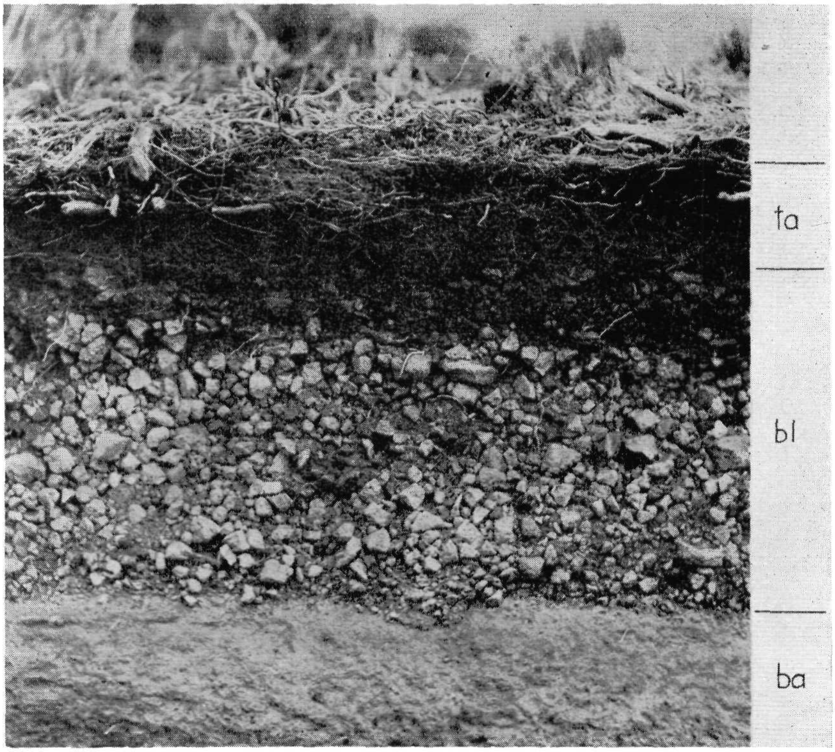


FIG. 5—Cutting at new site for Manganui Hut, 4,150 ft, eastern slopes of Mt Egmont. This is the type locality for Tahurangi Ash (ta), Burrell Lapilli (bl), and Burrell Ash (ba). Profile 41 from here is shown diagrammatically in Fig. 6 and described in Appendix 1.

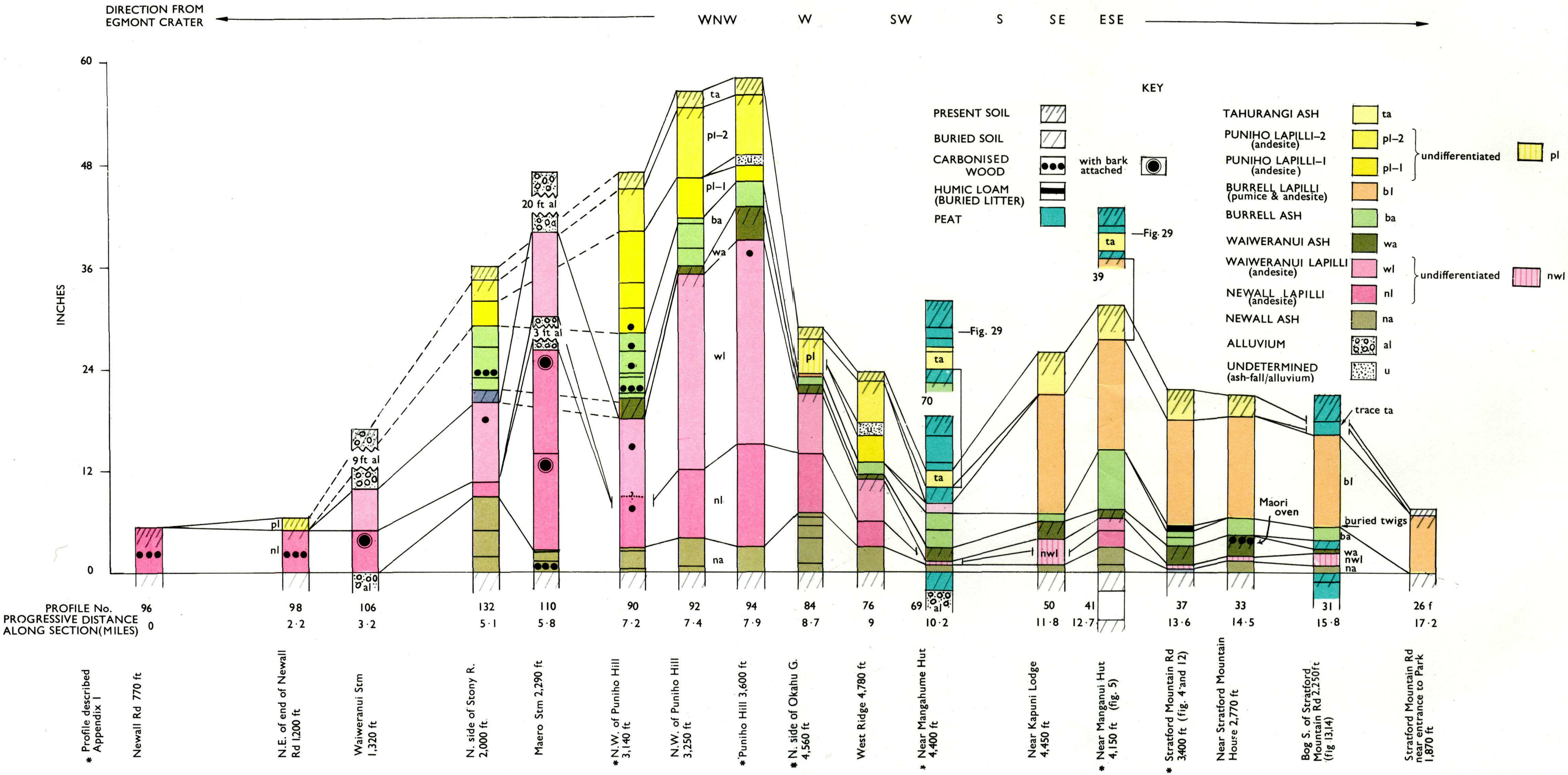


Fig. 6—Correlation section across Mt Egmont from WNW to ESE via southern slopes (a–b Fig. 15). Base level is bottom of Newall Ash.

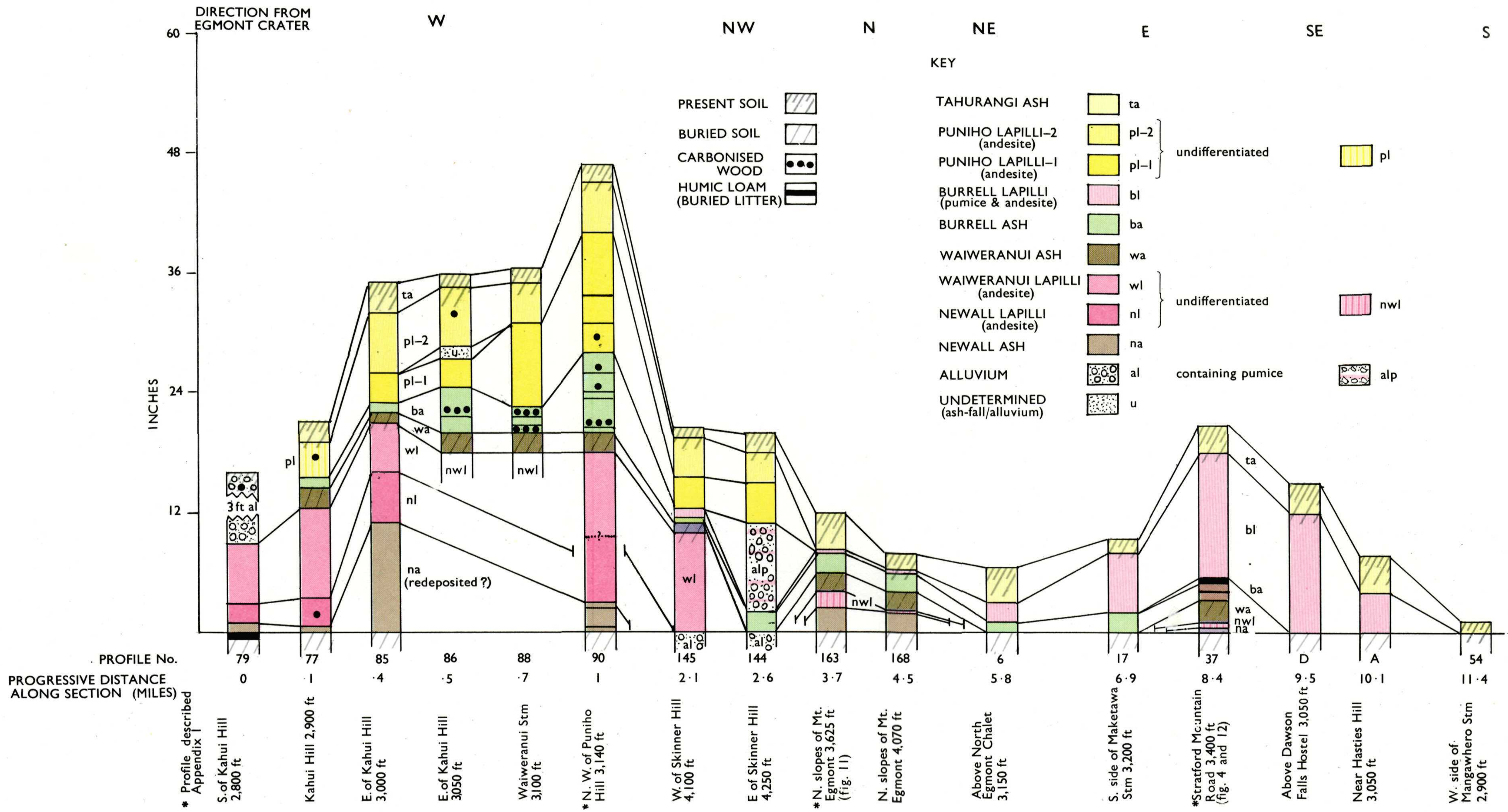


FIG. 7—Correlation section round Mt Egmont at 3,000 to 4,000 ft (c–d Fig. 15). Base level is bottom of Newall Ash.

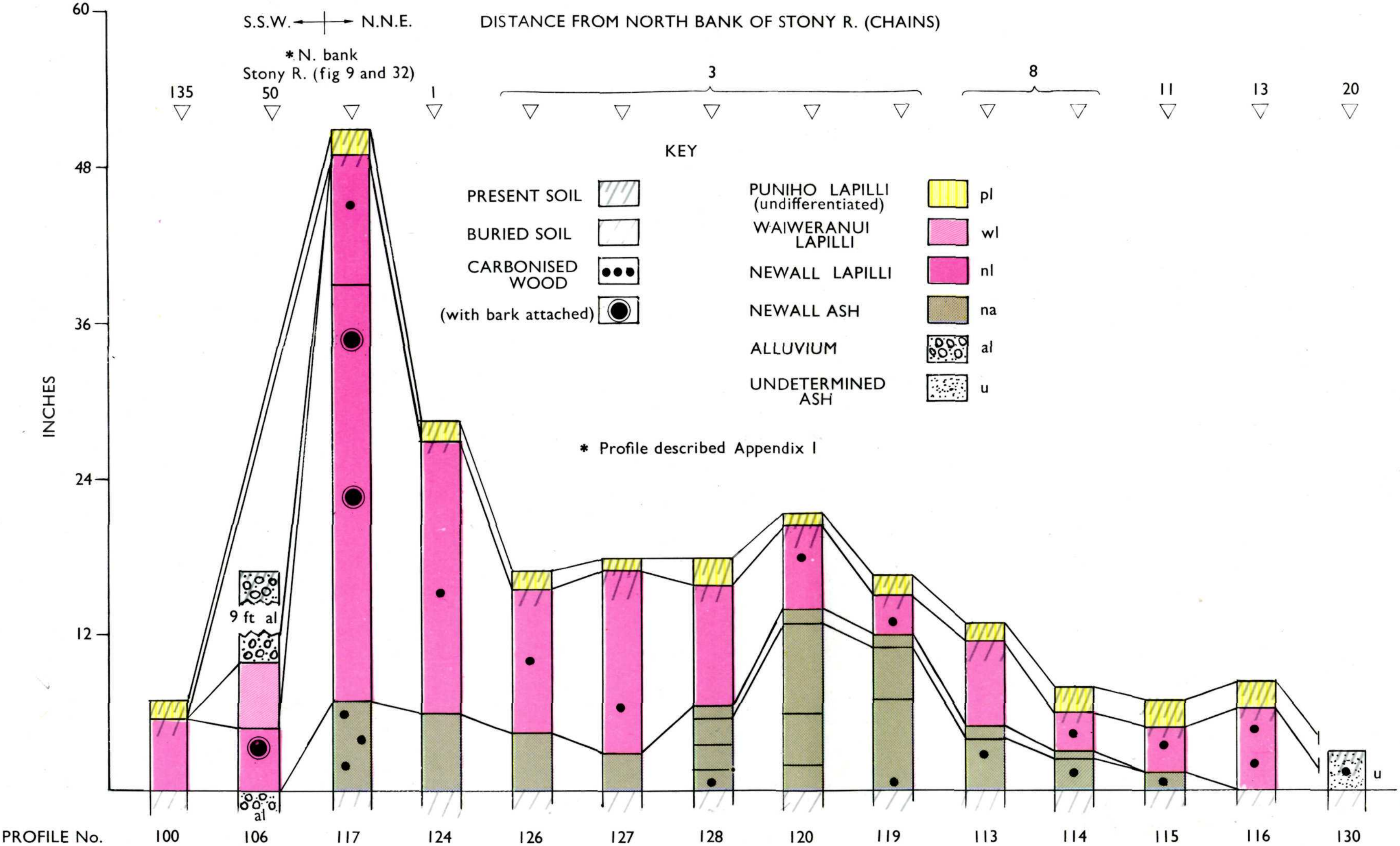


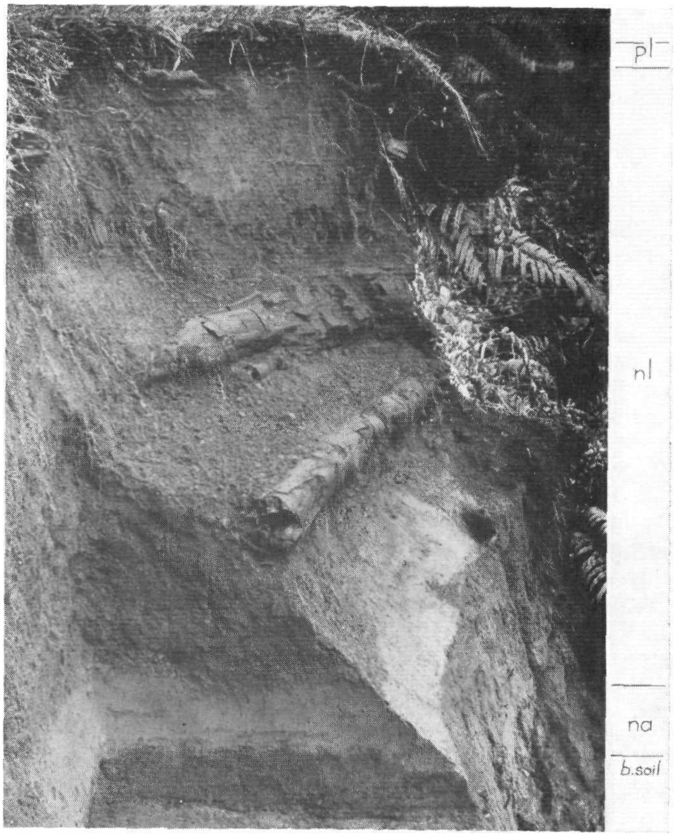
FIG. 8—Correlation section near Stony River, 6 miles from Mt. Egmont (e-f Fig. 15) showing (a) variation in depth of Newall Ash and Newall Lapilli, and (b) concentration of both on or near the course of the river (here flowing in a radial direction from Mt. Egmont). Base level is bottom of Newall Ash.

On the western slopes Burrell Lapilli is thin or absent, but Burrell Ash thickens, coarsens, and shows shower banding and numerous fragments of carbonised wood. Two further beds make their appearance lying between Burrell Lapilli and Tahurangi Ash; these I have tentatively correlated with Puniho Lapilli (Puniho Grit) (Grant-Taylor, 1964 a and b) and called Puniho Lapilli 1 and Puniho Lapilli 2. The type locality is north-west of Puniho Hill at a point 17 yd south-west of the signpost at the junction of Puniho Track with the track round the mountain; the type profile (No. 90) is shown diagrammatically in Fig. 7 and described in Appendix 1. Grant-Taylor (1964a) states that "on the western side of the mountain the Burrell Lapilli is overlain by fragments of scoriaceous lava and dense porphyritic andesite up to $\frac{1}{4}$ in. diameter at 3,500 ft, coarsening uphill", and that "no other ash or lapilli deposit overlies the Puniho Lapilli". No type locality is indicated nor are any depths given, though it would seem that a thin bed is implied by the use of the word "fragments". The above correlation is tentative, firstly because Tahurangi Ash overlies Punihi Lapilli 2, secondly because the depth of Puniho Lapilli 1 and 2 may be 12 in. or more at 3,000 ft, and thirdly because the lapilli in Puniho 1 and 2 are up to at least $\frac{3}{4}$ in. diam. Tahurangi Ash cannot be the same bed as Puniho Lapilli (Puniho Grit), for no lapilli are present in Tahurangi Ash and the ash is distributed all round Egmont and not just on the western side.

The "Newall ash" is divided into four beds—Newall Ash, Newall Lapilli, Waiweranui Lapilli, and Waiweranui Ash. As the type locality for Newall Ash and Newall Lapilli I have chosen the north bank of Stony River, 5 chains east of the top end of Saunders Road. The type profile (No. 117) is shown in Figs. 8 and 9 and described in Appendix 1. Newall Ash is similar in many respects to Burrell Ash: each shows shower banding, each contains many small fragments of carbonised wood (mainly on the west side of the mountain), and each is predominantly greyish brown in colour. Newall Lapilli may be compared to Burrell Lapilli in that it shows no shower banding and is the result of a single explosive eruption; in all other respects, however, it is not comparable. The type locality for Waiweranui Lapilli and Waiweranui Ash is the same as that chosen for Puniho Lapilli 1 and Puniho Lapilli 2 (north-west of Puniho Hill). Waiweranui Lapilli is very similar to Newall Lapilli, differing only in the coarser texture; at 3,000 ft blocks up to 5 in. diam. may be found. Waiwarenui Ash is similar to Tahurangi Ash.

In a number of profiles on the east, west, and south sides of the mountain (e.g., profiles 41 and 69, Fig. 6) a further ash bed has been noted between Newall Ash and the underlying well developed buried soil, but as not enough measurements have been made of its depth for it to be mapped, it is not being named at present. The ash is similar to Newall Ash and is only separated from it by the fact that the upper portion has undergone soil development.

The criteria for the recognition of the above-mentioned beds are shown in Fig. 10. In addition to any special property a bed may possess, the presence of a break above or below the bed—particularly a soil forming one—will often lead to a quick identification. For instance, the twin greyish brown beds of Newall Ash and Burrell Ash, separated by a buried soil formed from Waiweranui Ash, are usually very easily recognised on the north, east, and south sides of the mountain (Figs. 11–13). The main problems



Photo—G. C. Kelly

FIG. 9—Profile 117, north bank of Stony River, 1,250 ft, showing carbonised logs lying in Newall Lapilli (nl) *in situ*. The log (right centre) projecting from Newall Ash (na) is carbonised on the upper surface only. This is the type locality for Newall Ash and Newall Lapilli. The profile is shown diagrammatically in Fig. 8 and described in Appendix 1. (Puniho Lapilli—pl.)

in identification arise through the similarity of Puniho Lapilli 1 and Puniho Lapilli 2, and of Newall Lapilli and Waiweranui Lapilli. The possibility of accretions and removals by wind and water has at all times to be kept in mind. As indicated by the shower banding, Newall Ash and Burrell Ash are composite beds; however, subdivision has not been attempted at present owing to lack of adequate data.

Correlation sections round the mountain at 3,000–4,000 ft and across the mountain from WNW to ESE via the southern slopes are shown in Figs. 5 and 6. Fig. 8 shows a series of profiles near Stony River arranged to show the features of Newall Ash and Lapilli in that area. Nine of the 44 profiles shown in the above figures are described in Appendix 1; they are regarded as standard profiles and include the three type profiles.

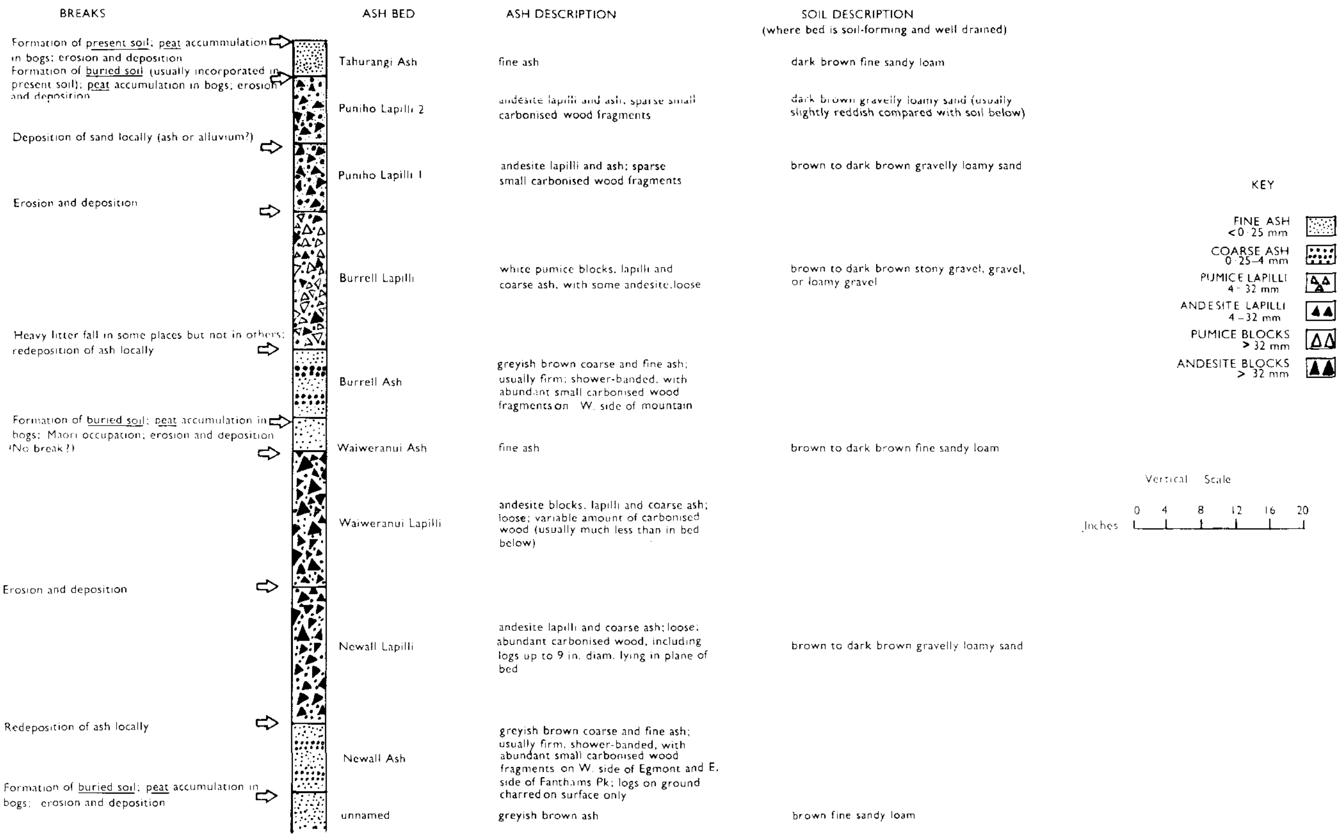


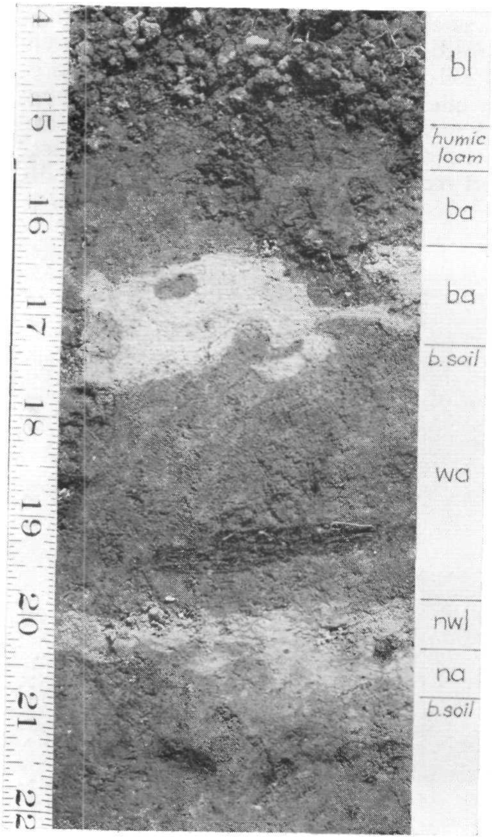
FIG. 10—Criteria for recognition of the ash beds. The column shows approx. maximum depth of each bed at 3,000 to 4,000 ft.

FIG. 11—Cutting beside track, 3,625 ft, northern slopes of Mt Egmont, showing characteristic greyish brown horizons of Burrell Ash (ba) and Newall Ash (na) above buried soils. Profile 163 from here is shown diagrammatically in Fig. 7 and described in Appendix 1. (Tahurangi Ash—ta; Waiweranui Ash—wa; undifferentiated Newall Lapilli and Waiweranui Lapilli—nwl.)

THE FORMATIONS

The three soil-forming breaks in the sequence (Fig. 10) enable the 10 beds discussed above to be grouped into four formations, each separated by appreciable time intervals from the beds above and below. Three of these formations are named here as follows:

Formation	Members
Tahurangi Formation	Tahurangi Ash
Burrell Formation	Puniho Lapilli 2 Puniho Lapilli 1 Burrell Lapilli Burrell Ash
Newall Formation	Waiweranui Ash Waiweranui Lapilli Newall Lapilli Newall Ash



Photo—R. R. Julian

FIG. 12—Portion of profile 37, Stratford Mountain Road, 3,400 ft, showing humic horizon under Burrell Lapilli (bl), and buried soils under Burrell Ash (ba), and Newall Ash (na). The profile is shown diagrammatically in Fig. 6 and described in Appendix 1. (Waiweranui Ash—wa; undifferentiated Newall Lapilli and Waiweranui Lapilli—nwl.)

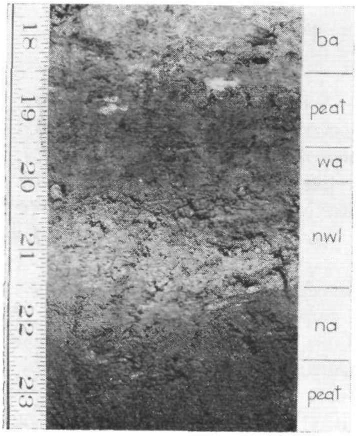
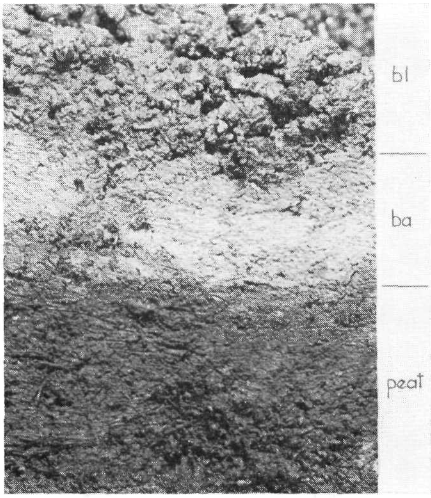


FIG. 13—Portion of profile 31, bog south of Stratford Mountain Road, 2,250 ft, showing peat below Newall Ash (na) and between Waiweranui Ash (wa) and Burrell Ash (ba). The profile is shown diagrammatically in Fig. 6 and described in Appendix 1. (Undifferentiated Newall Lapilli and Waiweranui Lapilli— nwl.)

At one time I thought there was a soil-forming break between Burrell Ash and Burrell Lapilli. In the roadside section shown in Fig. 4 Burrell Lapilli appears to overlie a buried soil; part of a profile from this section is seen in Fig. 12. Further work in other areas, however, showed that most profiles were without this "soil". A profile in a bog near Stratford Mountain Road provided strong evidence that there had not been a soil-forming interval, for no peat was present between Burrell Ash and Burrell Lapilli (Fig. 14). A likely explanation of the origin of these buried "soils" is that



Photo—R. R. Julian

FIG. 14—Portion of profile 31, bog south of Stratford Mountain Road, 2,250 ft, showing peat below Burrell Ash (ba), but none between Burrell Ash and Burrell Lapilli (bl). The profile is shown diagrammatically in Fig. 6 and described in Appendix 1.

one of the showers that deposited Burrell Ash induced a sudden leaf fall by scorching the plants. The litter was then buried under Burrell Lapilli; in time humus formed and became partly incorporated with the underlying ash (Fig 12). It has been suggested that the leaves may have fallen as a result of soil oxygen deficiency. However, it seems unlikely that Burrell Ash would have been both continuously saturated with water and unbroken by cracks and pores—conditions necessary for the formation of an effective air seal (M. W. Gradwell, pers. comm.). A hypothesis that the litter was formed as a result of stripping by the falling lapilli appears to be untenable; with equal depths of lapilli the humic horizon may be present in one area but not in another. Further, it seems unlikely that stripping would lead to such a distinct layer *under* the lapilli.

DISTRIBUTION OF THE ASH AND LAPILLI BEDS

The positions of the profile sites are shown in Fig. 15 and the depths of the beds at each site are shown in Figs. 16–23. Isopachs have been drawn, but with the possible exceptions of Burrell Lapilli and Tahurangi Ash, the beds have not been measured in enough places for these isopachs to be considered the only possible interpretation of ash and lapilli distribution. With the maps of Newall Ash and Newall Lapilli (Figs. 22 and 23) it has not been possible to draw isopachs in the Stony River area, where the depths apparently change very sharply each side of a radial line from Egmont coincident with the course of the river (Fig. 8).

There appear to be three distinct types of distribution, each focussed on Mt Egmont rather than on Fantham Peak: Burrell Lapilli (Fig. 18) is distributed almost entirely to the east of the mountain; Waiweranui Ash and Tahurangi Ash (Figs. 16 and 20) are arranged more or less concentrically on Mt Egmont; Newall Lapilli, Waiweranui Lapilli, and Puniho Lapilli 1 and 2 (Figs. 17, 21, and 22) are distributed to the west of the mountain. The distribution pattern displayed by the composite beds of Newall Ash and Burrell Ash (Figs. 19 and 23) may be interpreted as a combination of the last two types.

TREE-RING DATING OF THE ASH AND LAPILLI BEDS

SOURCES OF ERROR IN TREE-RING DATING

In using counts of tree rings (growth layers) for dating there are two possible sources of error apart from the obvious one of miscounting very closely spaced rings (184 rings in $1\frac{3}{4}$ in. in an extreme case during the present work). The first is the formation of partial (incomplete) rings which can lead to an underestimate of the age. Little is known about partial growth layers in New Zealand plants; their presence has been recorded in senile gorse (*Ulex europaeus*) (Druce, 1957) and is suspected in other species. The possibility of error can be reduced by selecting trees with well developed, fully exposed crowns.

The second is the formation of false (intra-annual) rings which can lead to an overestimate of the age. These rings can undoubtedly be a serious source of error under certain conditions. Larson (1962) states that "false rings occur in nature under a variety of conditions, but all can be associated with a temporary cessation of terminal growth followed by growth resumption". Storm and frost damage, drought, insect defoliation, and second flushes can induce false ring formation (Larson, loc. cit.; Glock and Agerter, 1963). In the drier parts of New Zealand, drought is probably the most frequent cause. Cameron (1960) states that false rings are common in totara (*Podocarpus totara*), and Druce (1957) records their presence in manuka (*Leptospermum scoparium*) and in kamahi (*Weinmannia racemosa*). Lloyd (1963) believes that false rings occur quite commonly in indigenous conifers. In wet subalpine areas, as on Egmont, false rings due to drought are probably rare or absent. Wardle (1963) concludes from a study of New Zealand subalpine shrubs and trees that growth rings are annual in formation, and Glock and Agerter (1963) state that if soil moisture is plentiful, cambial activity tends to be continuous and to produce one growth layer for the year. Frost damage and insect defoliation have not been observed on Egmont over a four-year period in the five species used for ring counting, namely kaikawaka (*Libocedrus bidwillii*), northern rata (*Metrosideros robusta*), rimu (*Dacrydium cupressinum*), kanuka (*Leptospermum ericoides*), and mountain fivefinger (*Neopanax colensoi*), though of course such damage may well have occurred in the past.

During the present work a few rings were classed as intra-annual on account of their unusually small width compared with those on either side. One was seen near the outer end of core 63/B taken from a kaikawaka. Backdating indicated a temporary cessation of growth shortly before the end of the 1958–59 growing season. I recalled a particularly severe southerly storm early in 1959 and had noted in March of that year that plants had been "burnt" by salt up to 5,000 ft on the slopes of Egmont. The New Zealand Meteorological Service (pers. comm.) confirmed that there had been a strong southerly on 22–23 February. Since nearly all emergent kaikawaka trees on Egmont show the effect of severe periodic salt "burn" (Druce, 1964), this is the most likely source of error in dating from growth rings in this species. In many places northern rata shows similar damage, so false rings may occur in this species too.

PREPARATION OF CORES AND SECTIONS

Cores for ring counting were extracted from rimu and kaikawaka with a 16 in. Swedish increment borer. Immediately after extraction each core was placed in a glass tube to prevent drying out. To prepare a core for counting, two faces—one transverse, one longitudinal—were planed with a sharp blade. The surface was allowed to dry for a few minutes, then the core was held close to a shaded light source so that by a slight rotation the densewood could be seen by either scattered or reflected light. The layers of densewood and lightwood—to use the terms of Glock and Agerter (1963)—are very clearly seen in freshly cut cores of kaikawaka. Drying for more than a few minutes or using a blunt blade impairs their clarity, especially when the rings are closely spaced. Viewed by scattered light the layers of densewood appear as dark bands against a lighter background; viewed by reflected light they appear as pale bands against a darker background. Rings were marked off in small groups under a hand lens for counting; the best view was usually obtained by light reflected off the densewood on a transverse face.

Tree sections, with few exceptions, were examined *in situ* in the field immediately after cutting. Rings were marked off in groups, often along two or more radial lines as a check in counting.

The width of a group of rings was measured with a steel tape, but the width of an individual ring in a core was measured by means of an eye-piece scale in a dissecting microscope.

DATE OF BURRELL ASH AND BURRELL LAPILLI

Discussion

At the beginning of the survey in 1959 two features of the forest at 3,000 ft near Dawson Falls Hostel, on the south-east side of the mountain,

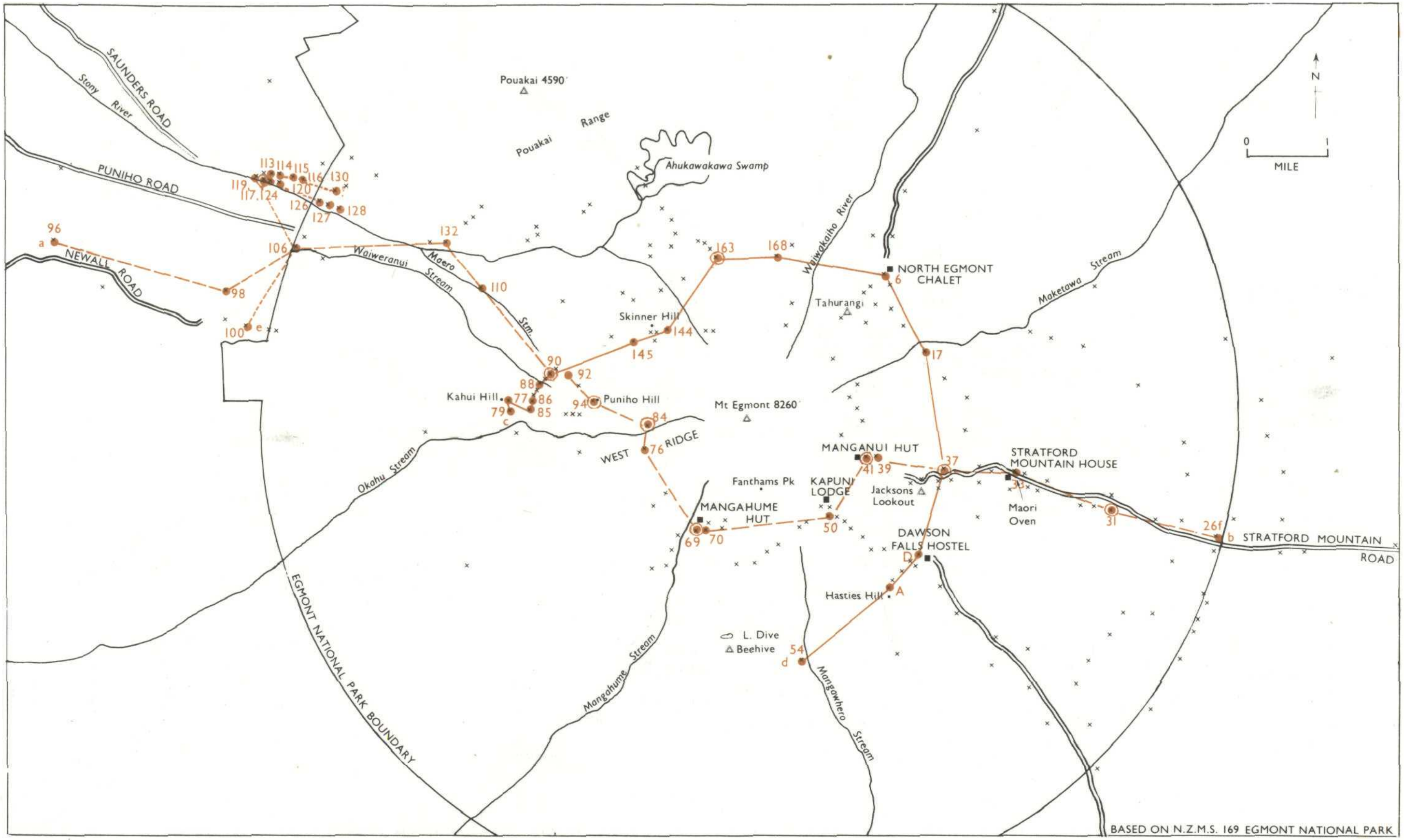


FIG. 15—Map showing localities mentioned in the text, section lines a–b, c–d, e–f, (see Figs. 6–8) and positions of numbered profiles. A ring indicates that the profile is a standard one, described in Appendix 1. Crosses mark the positions of other profiles used in the compilation of the isopach maps (Figs. 16–23).

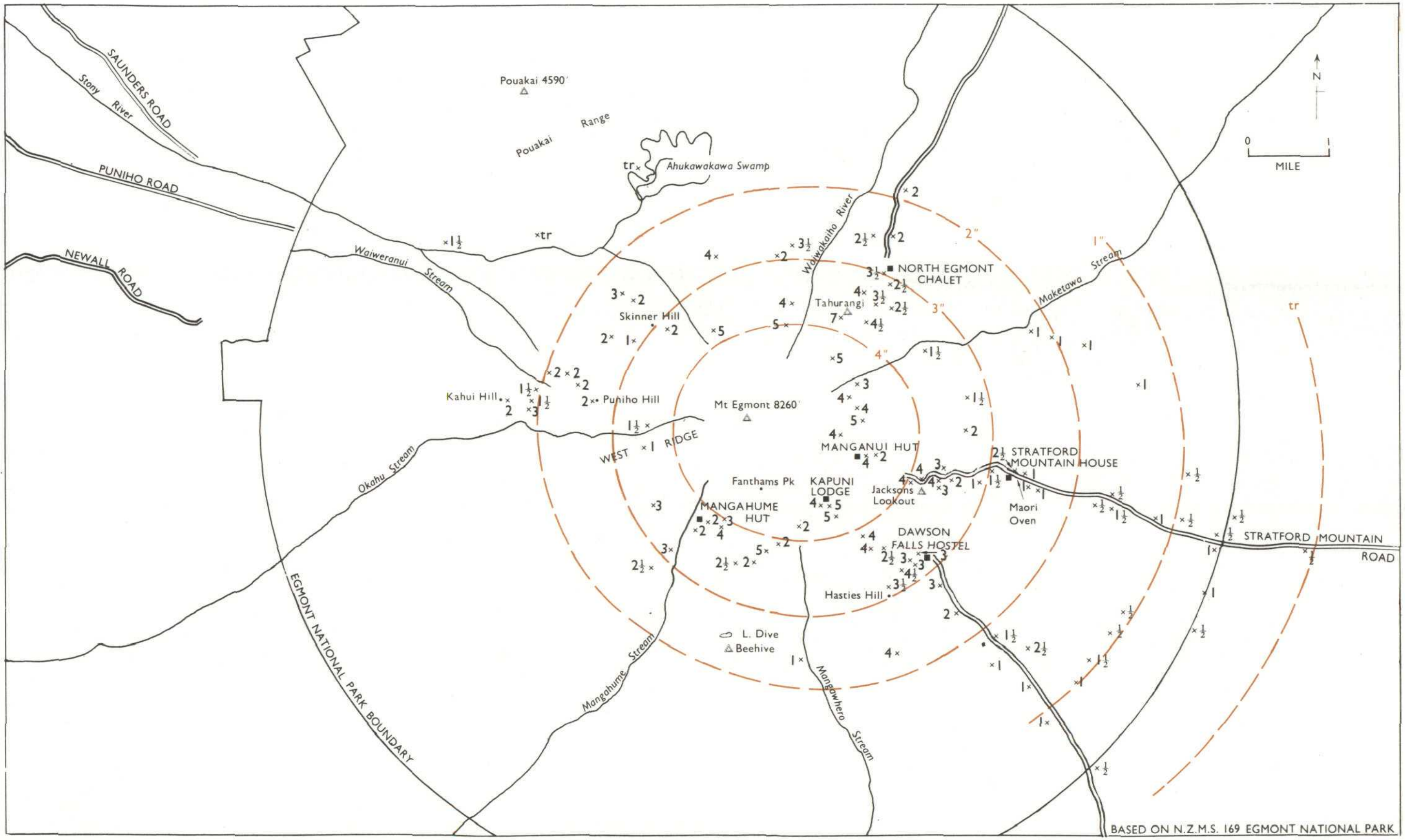


FIG. 16—Isopach map showing distribution of Tahurangi Ash.

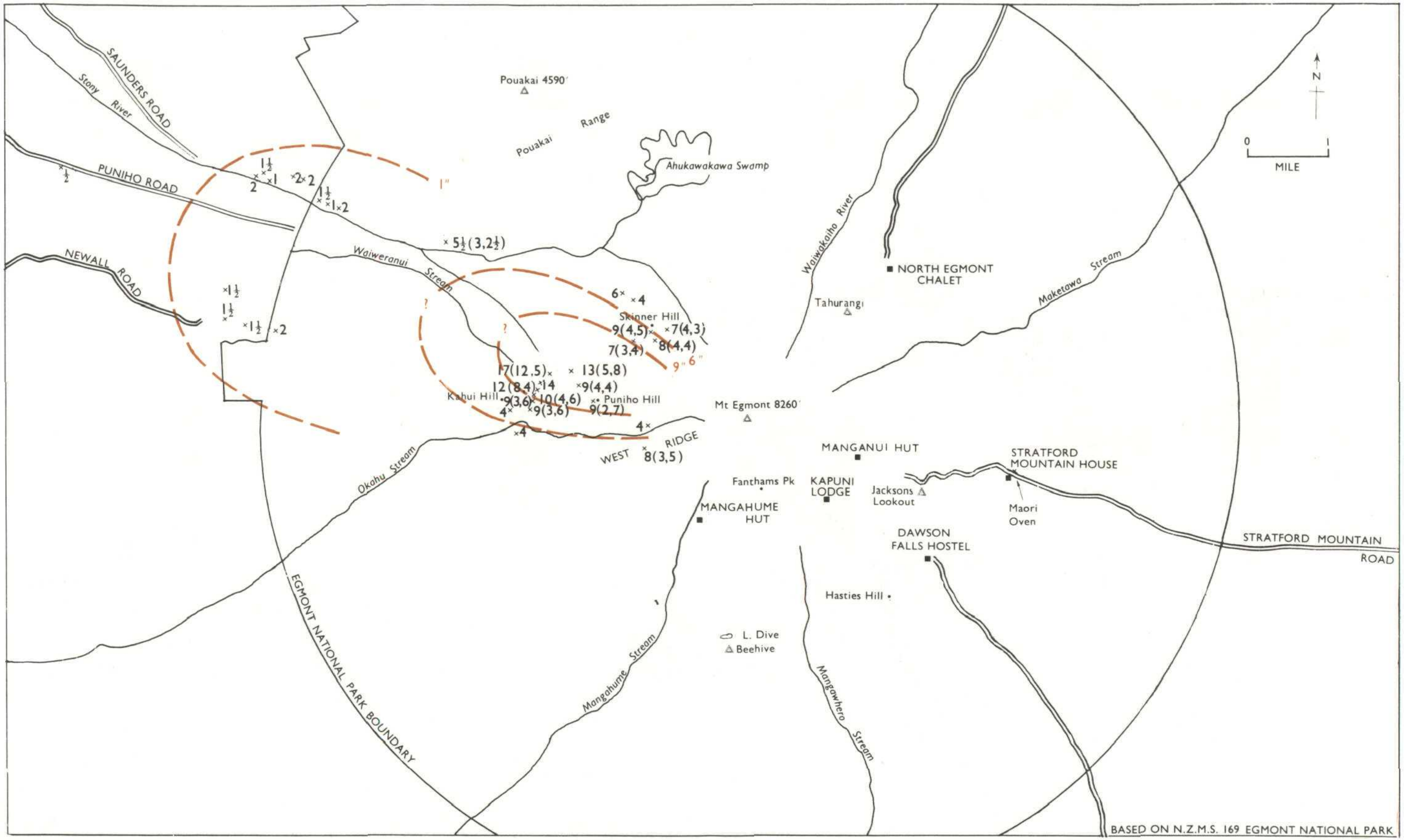


FIG. 17—Isopach map showing distribution of Puniho Lapilli. The figures in brackets are the separate depths of Puniho Lapilli 1 and Puniho Lapilli 2, in that order.

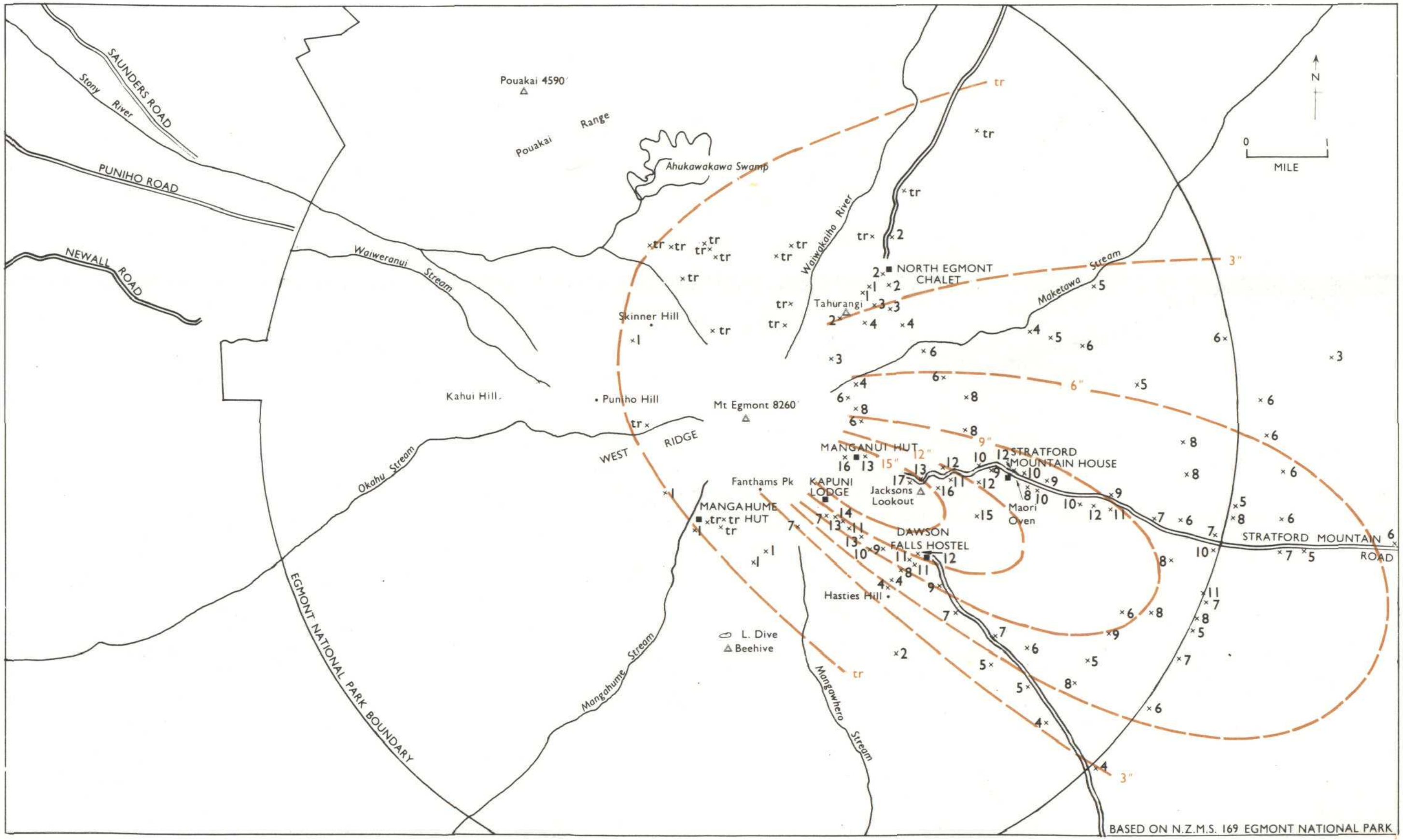


FIG. 18—Isopach map showing distribution of Burrell Lapilli.

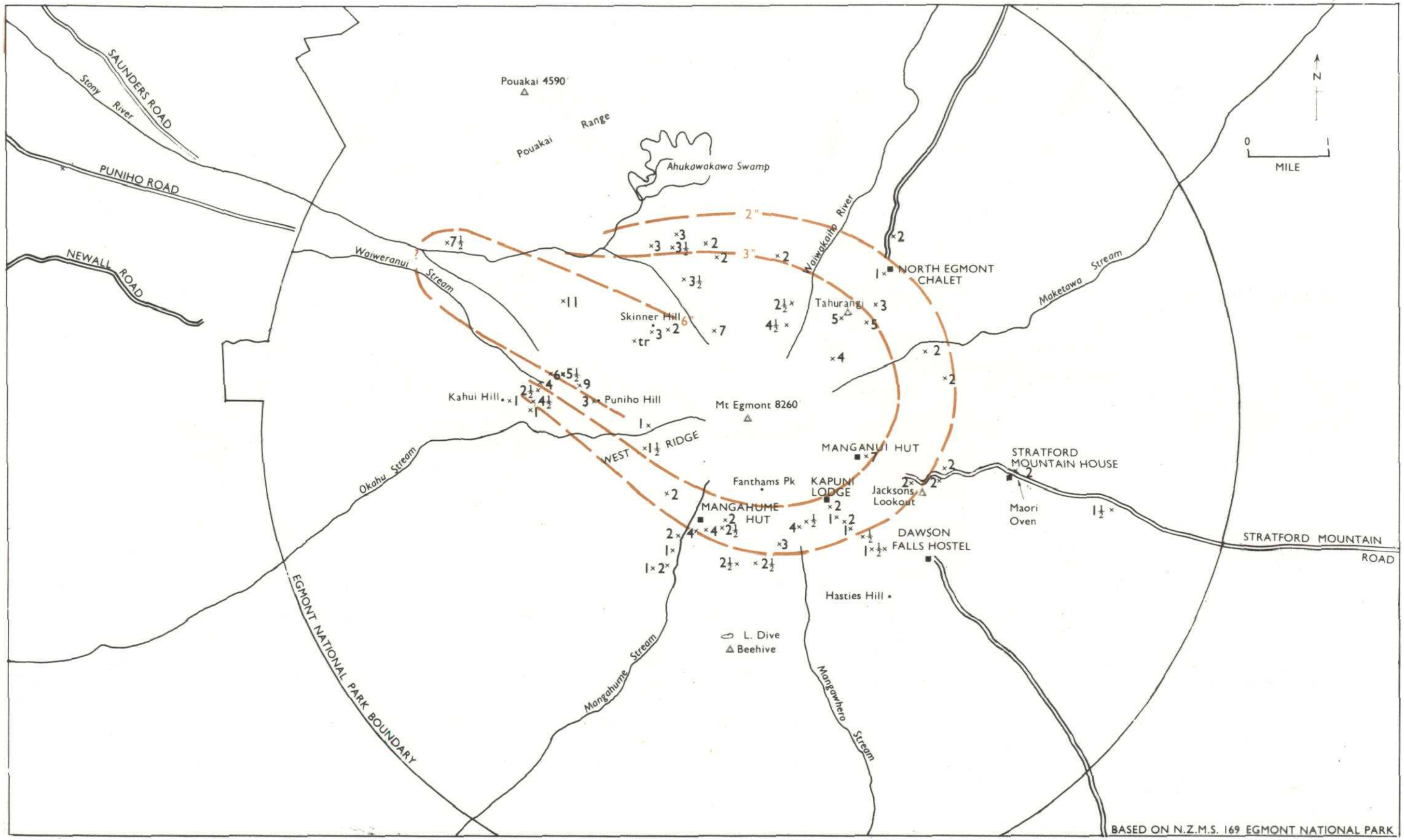


FIG. 19—Isopach map showing distribution of Burrell Ash.

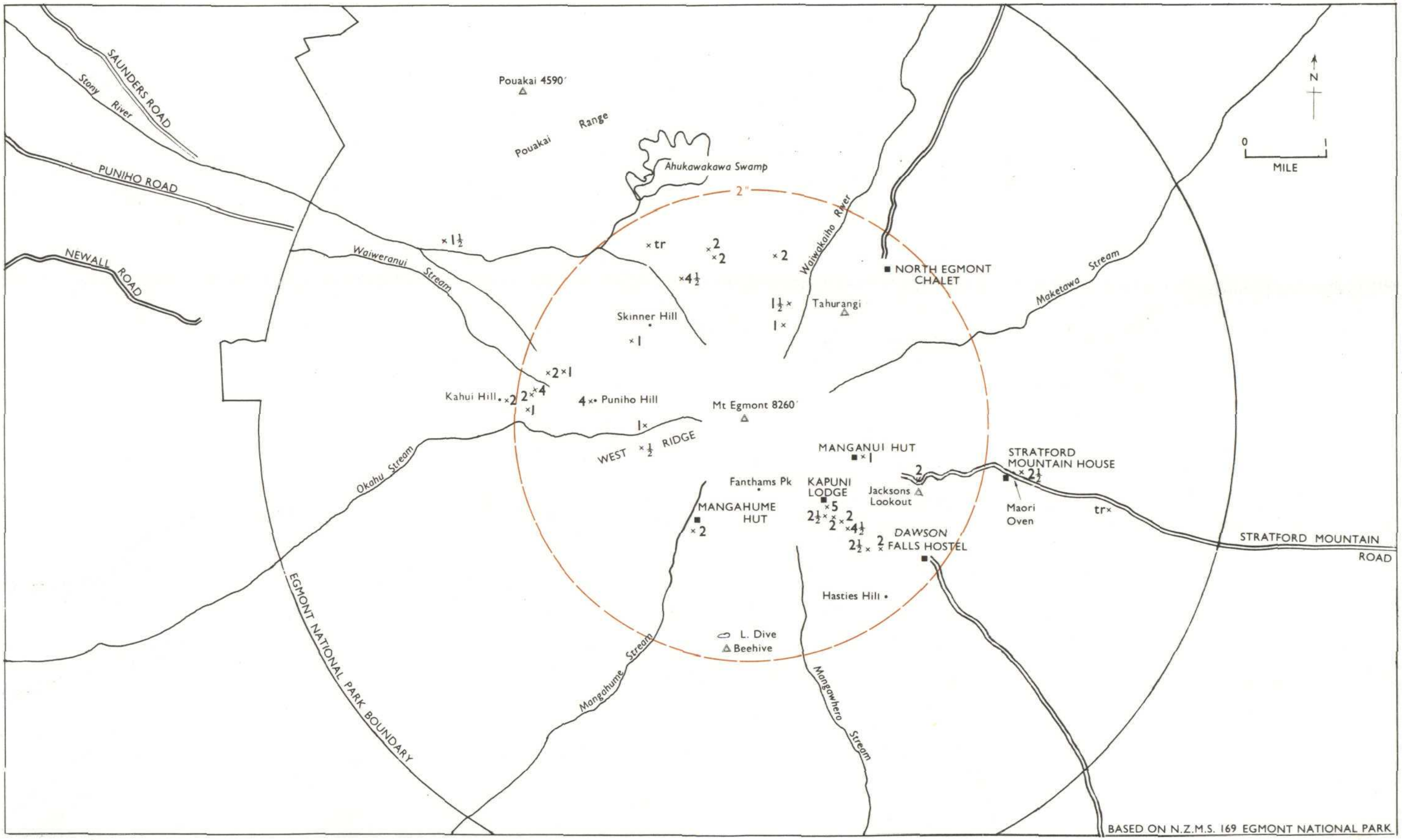


FIG. 20—Isopach map showing distribution of Waiweranui Ash.

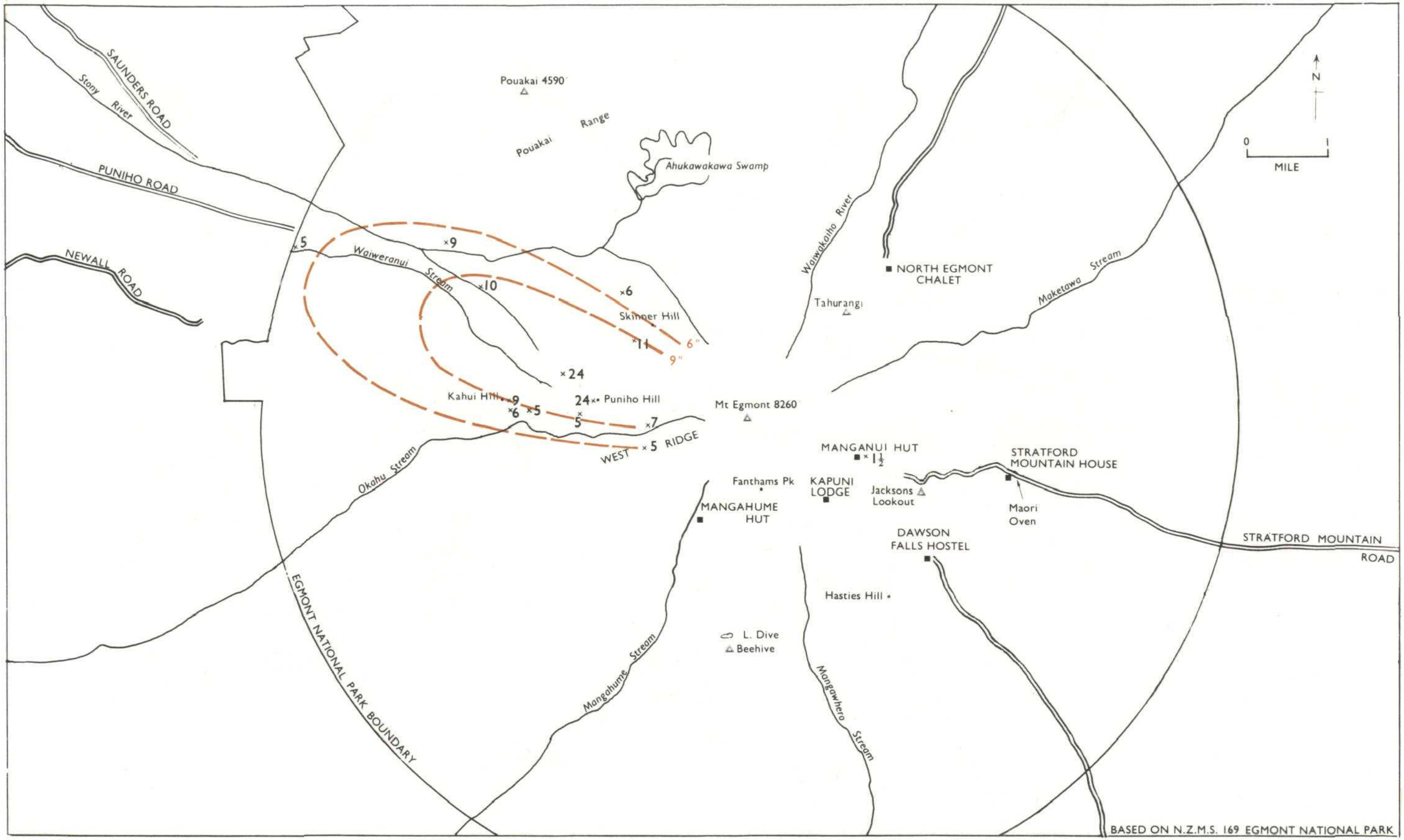


FIG. 21—Isopach map showing distribution of Waiweranui Lapilli.

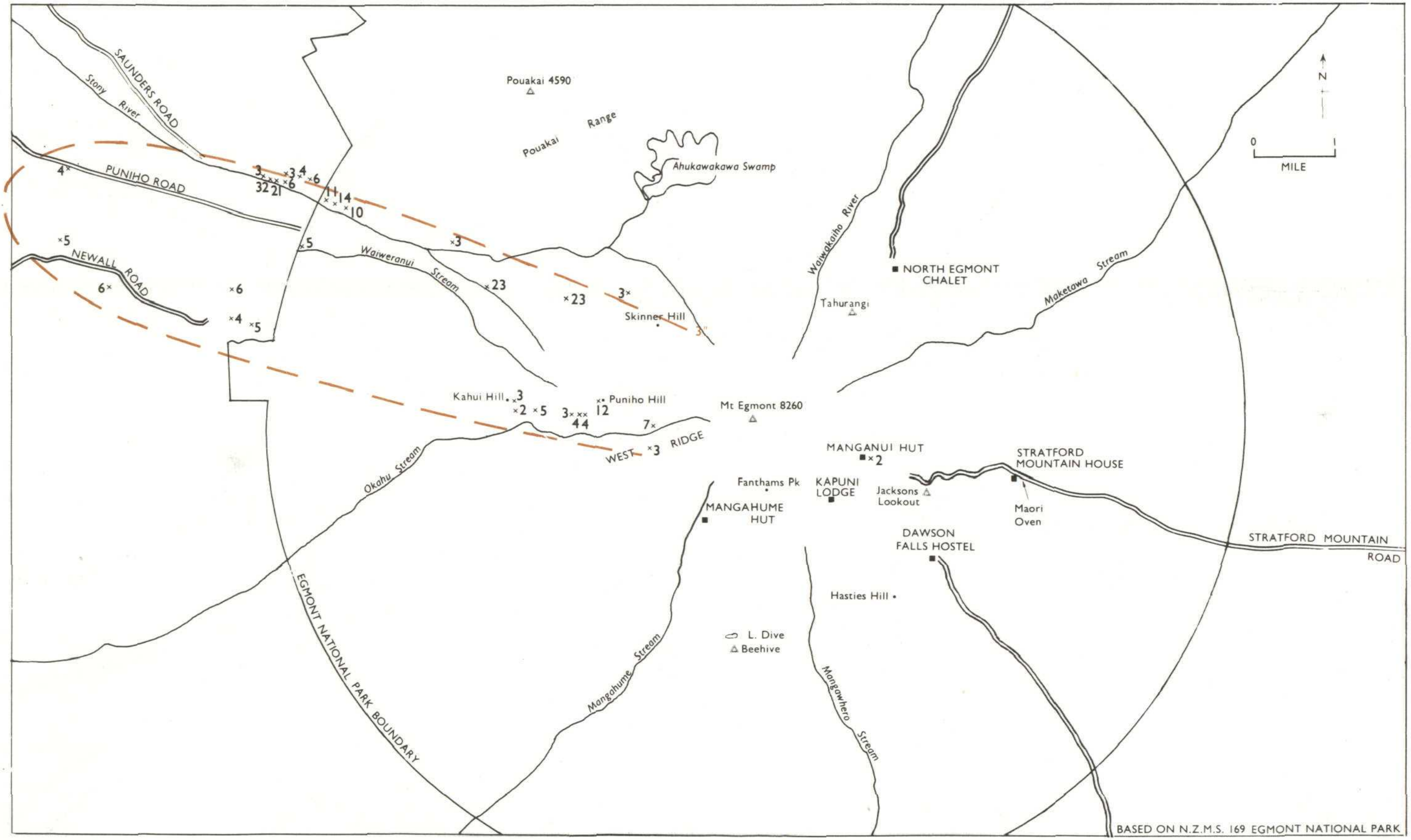


FIG. 22—Isopach map showing distribution of Newall Lapilli.

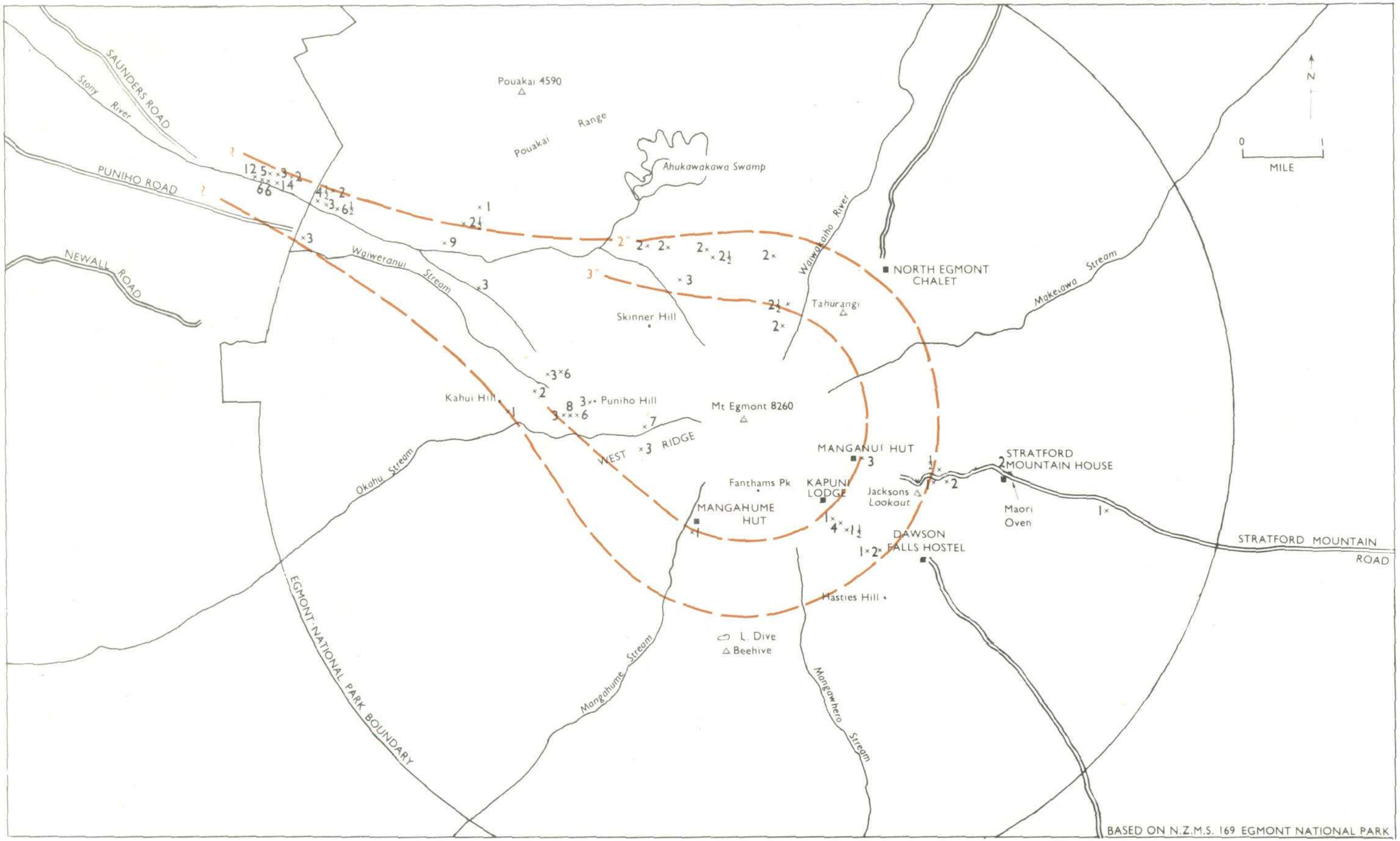


FIG. 23—Isopach map showing distribution of Newall Ash.

led me to believe it would be possible to date Burrell Ash and Lapilli accurately from counts of annual growth rings. The first feature was the presence of kanuka trees in the forest. In the development of new vegetation kanuka establishes early and can be used to date the destruction of the previous vegetation (e.g., Druce, 1957). The second feature was the presence of kaikawaka trees whose boles were without root flanges at the ground surface (Fig. 24). It was evident that these trees were older than Burrell Ash and Lapilli, their bases having been buried by these deposits and perhaps earlier ones as well. If the deposition of Burell Ash and/or Burrell Lapilli had led to a change in the width of the radial increment for one or more years, then one might be able to date the beds by counting the annual rings back to the first ring showing such change.

In postulating a change in the rings it was necessary to consider how this might come about and whether it would show as an increase or decrease in width. Although the west side of the mountain is the only side where carbonised wood is known to occur in Burrell Ash (Figs. 6 and 7), it has already been pointed out that the shower was probably hot enough elsewhere within the zone of woody vegetation to scorch the leaves of at least some plants and so induce a sudden leaf fall. In the Dawson Falls – Jacksons Lookout area where Burrell Lapilli is 12–15 in. thick (Fig. 18) the fall of pumice would have stripped leaves and twigs from most plants not already damaged by the preceding fall of ash. It is probable that many trees and shrubs resprouted after the showers, but the present vegetation indicates that, at the very least, numerous gaps remained in the plant cover. The presence of the kanuka scattered through the forest near Dawson Falls and the abundance of fuchsia (*Fuchsia excorticata*) on interfluves both point to well lit sites having been available for the establishment and continued growth of these plants. Dead trunks of Hall's totara projecting through the beds, as first recorded by Oliver (1931), indicate that many individuals of this species were killed, though a number of pre-Burrell trees are alive today.

In the Dawson Falls – Jacksons Lookout area most of the few hundred surviving kaikawaka are found scattered through a stretch of forest lying ENE of Jacksons Lookout (Fig. 25); only a few are present near Dawson Falls. Very few occur above 3,500 ft, though elsewhere on the mountain the species commonly ascends to 4,000 ft. The surviving kaikawaka and Hall's totara are both characterised by very short boles, generally shorter than those of post-Burrell trees. In kaikawaka the boles are usually less than 10 ft (Fig. 24) and may be as short as 4 ft. These trees were therefore of no great height at the time of the ash and lapilli showers. This is in keeping with the findings from increment borings which show that the kaikawaka were of small diameter and, with one exception, not very old. Whether they survived because they were protected by other plants or because their foliage was able to withstand the ash and lapilli, is an open question. It was thought that if the crowns of the surviving kaikawaka had been damaged, the subsequent annual increments might show a decrease, particularly as the tree is incapable of forming new shoots from old wood. If, however, the crowns had not been damaged and interference from other plants had been reduced by partial destrucion of the vegetation, it was thought the increments might show an increase. The possible effect of the ash and lapilli beds on uptake

FIG. 24—Bole of kaikawaka seen in Fig. 25 showing absence of root flange at ground level. The bole is 7 ft long and the height to the first branch 5 ft.

of nutrients by the buried root systems had also to be considered. The nutrient return from litter would have been reduced for several years until a new layer formed on top of the lapilli bed (R. B. Miller, pers. comm.). Aeration in the buried soil, however, would probably not have been affected (M. W. Gradwell, pers. comm.).

At the start of the present investigation I expected, both from the ^{14}C age of the charcoal in the oven and the presence of kanuka in the forest, that the eruptions would not have occurred more than about 300 years ago. A change in the width of the rings in surviving trees was considered highly probable and a reduction was favoured rather than an increase. As there was no soil-forming or erosional break between Burrell Ash and Burrell Lapilli, I assumed that the two had the same date.

After the completion of the work I learnt that Lawrence (1954), dating an eruption of Mt St Helens, Washington, had found a reduction in the growth rings of old Douglas firs that had had their bases buried by a deposit of lapilli. The reduction was attributed to a combination of crown damage, toxic concentrations of soluble salts leached from the lapilli, and reduced aeration.

Results

Between November 1959 and September 1963 cores were extracted from 30 kaikawaka trees growing between 3,000 and 3,400 ft, some near Dawson

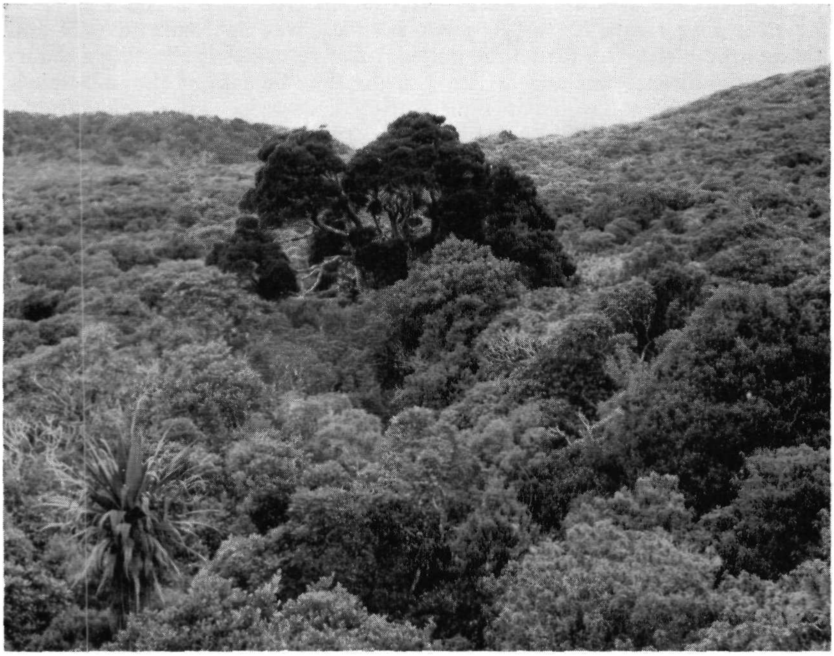


FIG. 25—Short upland forest beside Stratford Mountain Road, 3,400 ft, showing emergent pre-Burrell kaikawaka 24 ft high and 30 in. d.b.h. Core C16 was taken from this tree and showed its age to be greater than 340 years.

Falls Hostel and some below Jacksons Lookout. Cores from 10 of these trees were discarded because the older wood had rotted. One core was taken from a rimu growing beside Stratford Mountain Road and one kanuka was felled near Dawson Falls.

The counts of annual rings in cores from 17 of these trees (d.b.h. 14–49 in.) are shown in Table 3. (The counts in cores from four pre-Burrell kaikawaka have not been included, since the cores proved to be not long enough to include rings formed before the deposition of the ash beds.) Of the 16 kaikawaka trees, eight were pre-Burrell (d.b.h. 18–49 in.) and eight post-Burrell (d.b.h. 14–25 in.). Some extraordinary differences in growth rate were found. For instance, of two trees only a few yards apart, 22 and 24 in. d.b.h. respectively, one had an age of 222+ (post-Burrell), the other an age of 464+ (pre-Burrell). The pre-Burrell trees ranged in age from 313+ to 464+, and the post-Burrell trees from 177+ to 226+.

The sequence of interim results that led to the adoption of A.D. 1655 as the most probable date for Burrell Ash and Lapilli is outlined below.

The first kaikawaka sampled had root flanges at ground level and was assumed to be a post-Burrell tree. Core C5a (Table 3) taken 4 ft above ground level had 315 rings and core C5b taken from 3 ft had 335 rings. Both cores extended to the centre of the tree. The tree thus took 20 years to grow 1 ft and the age was estimated to be not less than 350 and possibly greater than 400 years. In view of what was expected this was a disquieting result. Core C6 from a smaller diameter post-Burrell tree gave a count of 183. The next ring count (core C8, from a rimu) was approximate only and although the 301st ring (from the outside) was recorded as showing a reduction, no significance was attached to it at the time because of the uncertainty in the count. Core C16 from a pre-Burrell kaikawaka (Figs. 24 and 25) contained 341 rings. With this result a contradiction became apparent, for supposedly pre- and post-Burrell trees had similar numbers of rings (Table 3). Moreover, core C16 showed an unmistakable decrease in the width of three rings beginning with the 303rd (307th corrected to winter 1963) (Figs. 26 and 27). This seemed to indicate the date of Burrell Ash and Lapilli, for it agreed with expectation. The results from the first tree were rejected as being fallacious and the date was tentatively put at A.D. 1656. Of the next two cores taken (No. C23a and b) only one showed any change that might support the tentative date—a very slight decrease in the 306th ring.

Shortly after this a kaikawaka was seen that had root flanges on one side only; on the other side the bole clearly descended through the Burrell beds. A return to the first kaikawaka bored soon showed that that tree was not a post-Burrell tree as had been assumed, but a pre-Burrell one that had sent out adventitious roots from the trunk and produced a second flange system. Re-examination of the cores, however, failed to show any change to support the tentative date. A core (No. C26) from the tree with root flanges on one side only also failed to show any change. Core C25 from a post-Burrell tree had 222 rings and provided an upper limit for the date of the eruption (A.D. 1738).

Up to this time kanuka had not been used in dating for two reasons; firstly, the wood could not be bored, and secondly, the trees were of such

TABLE 3—Annual-ring counts in cores from 17 trees growing on the eastern slopes of Mt Egmont. Cores were taken at a height of 3–4 ft

Core No.	Species	Date	Alt. (ft)	Pre- or Post-Burrell Tree	D.B.H. (in.)	No. of Annual Rings in Core	Correction (to Winter 1963)	Radius of Central Portion of Tree Not Included in Core (in.)*	No. of Rings Back to and Including First Showing Reduction in Width	Date of Burrell Ash and Lapilli (A.D.)
C5a†	kaikawaka	21/11/59	3000	pre	29	315	+4	0	no reduction	—
C5b†	,,	,,	,,	,,	29	335	+4	0	no reduction	—
C6	,,	,,	3200	post	20	183	+4	1·25	—	—
C8	rimu	23/11/59	2600	pre	28	*c*. 374	+4	1	*c*. 301	*c*. 1658
C16	kaikawaka	11/12/59	3400	,,	30	340	+4	1	303	1656
C18	,,	,,	,,	post	20	177	+4	0	—	—
C23a‡	,,	12/2/60	,,	pre	26	313	+3	2	306	1654
C23b‡	,,	,,	,,	,,	26	341	+3	0	no reduction	—
C25	,,	24/2/60	3150	post	22	222	+3	1	—	—
C26	,,	,,	,,	pre	24	464	+3	1	no reduction	—
62/2	,,	19/5/62	3300	,,	18	388	+1	1·5	no reduction	—
62/3	,,	,,	3200	post	25	181	+1	2	—	—
62/4	,,	,,	,,	,,	14	210	+1	0	—	—
62/5	,,	,,	,,	pre	27	338	+1	1·25	307	1655
63/2	,,	9/9/63	,,	post	22	181	0	0	—	—
63/3	,,	,,	,,	pre	42	333	0	0·4	no reduction	—
63/4	,,	,,	3100	post	21	226	0	0	—	—
63/5	,,	,,	,,	,,	22	202	0	1	—	—
63/B	,,	10/9/63	3200	pre	49	322	0	4	309	1654

*Estimated from curvature of rings at end of core.

†Cores C5a and C5b were taken from one tree at heights, respectively, of 4 ft and 3 ft.

‡Cores C23a and C23b were taken from one tree at the same height, but along different radial lines.

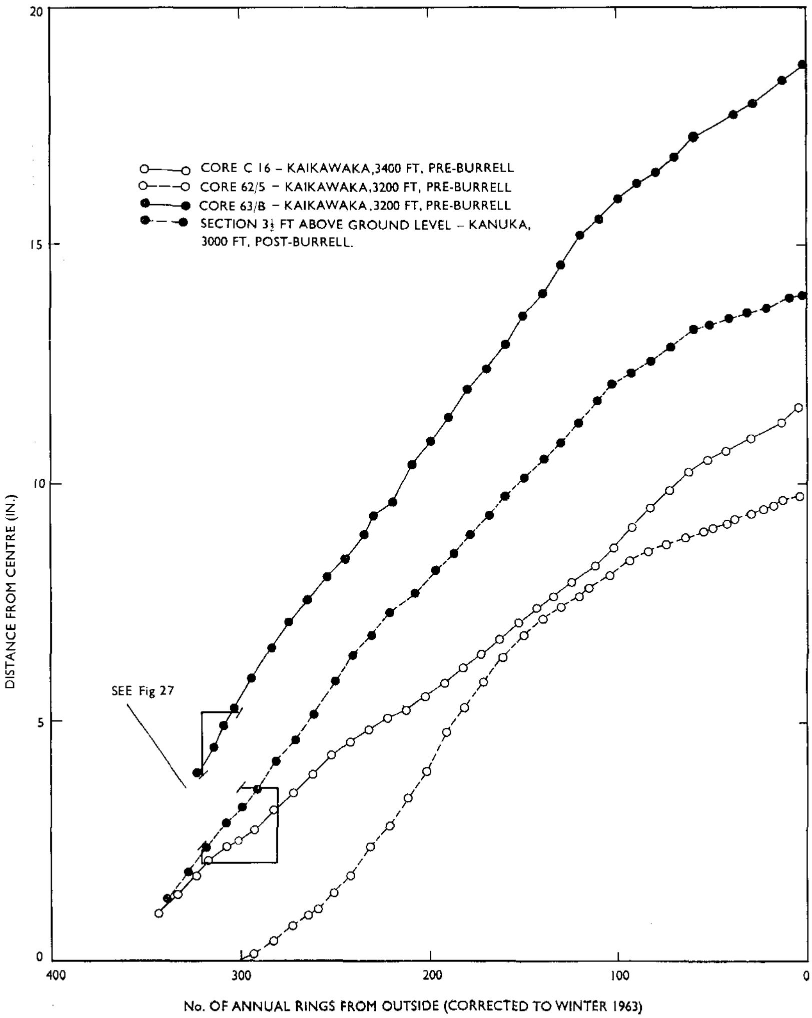


FIG. 26—Radial growth in three pre-Burrell kaikawaka and one post-Burrell kanuka from the eastern slopes of Mt Egmont. The age of the post-Burrell kanuka indicates a date earlier than A.D. 1662 (301 years before 1963) for Burrell Ash and Burrell Lapilli.

a size (up to 40 in. d.b.h.) and so many appeared to have rotten heartwood that felling held the prospect of being wasted effort. However, a suitable tree (d.b.h. 17 in.) was eventually found at 3,000 ft and in February 1960 was cut 2½ ft above ground level. Although the centre turned out to be partially rotten, an approximate count was obtained on the spot giving an age of not less than 260 years. Even allowing a certain time for the young tree to reach 2½ ft, this age seemed to indicate a date for the eruption less than that previously favoured.

So far there was not enough evidence to propose a definite date for the beds. The work was taken up again two years later, when the chief ranger, Mr G. G. Atkinson, offered to chain saw a section of the kanuka previously examined. On May 1962 a section was cut 3½ ft from the base of the tree. When a planed segment was examined under bright light it was found that a large number of closely spaced annual increments near the outside of the tree had been missed in the previous count. The revised count gave 298

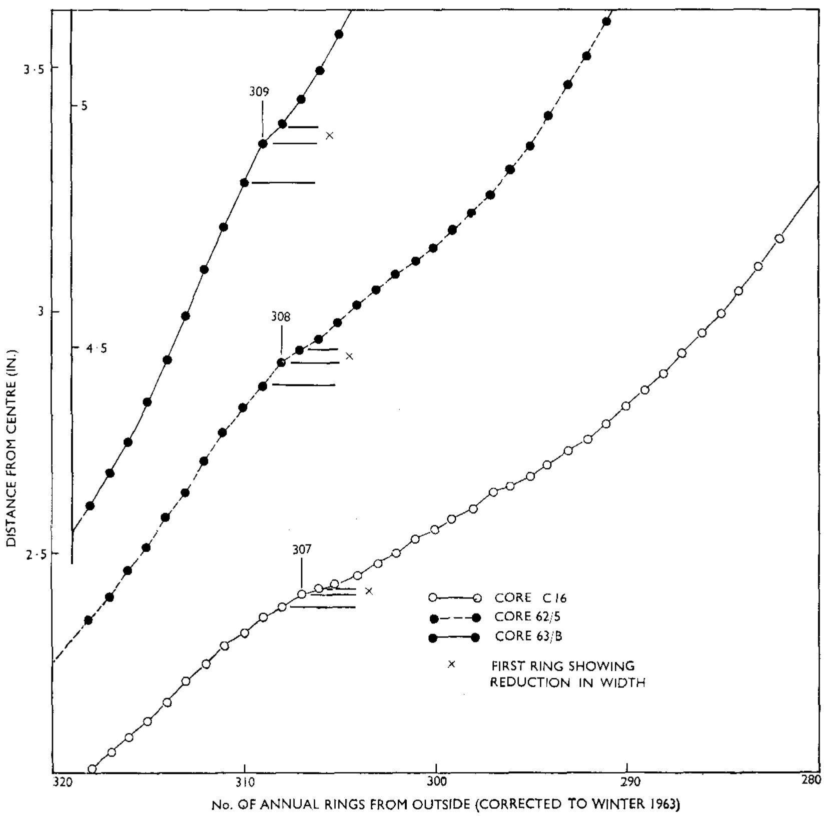


FIG. 27—Radial growth over the interval between rings 320 and 280 in the same three pre-Burrell kaikawaka as in Fig. 26. The age of Burrell Ash and Burrell Lapilli is indicated by the first ring showing a marked reduction in width.

rings (301 corrected) (Fig. 26) or a date for the time when the kanuka was 3½ ft high of A.D. 1662; the beds must have been deposited some years earlier. Of two more cores taken from pre-Burrell kaikawaka at this stage, one (No. 62/5) yielded convincing support for the tentative date first put forward. A decrease beginning with the 307th ring in this core (308th corrected) (Figs. 26–28) and continuing for some 10 years was the sort of evidence wanted.

There remained still the remote possibility that the decreases found in the rings were fortuitous, related perhaps to a particular storm or unfavourable climatic interval. But if the kanuka could be shown to have established at about the same time, these doubts would be removed, for only a major catastrophe would have allowed sufficient light to reach the ground for the kanuka to establish. To find out approximately how long it would take a kanuka to reach 3½ ft at 3,000 altitude six saplings 3 to 4 ft high, growing in the open near Dawson Falls Hostel, were cut at ground level. The ring counts ranged from five to nine, with a mean of seven. If this last figure is added to the 301 previously obtained, the probable age of the kanuka becomes 308 and the date of the beds A.D. 1654 (allowing one year for the seedling kanuka to establish).

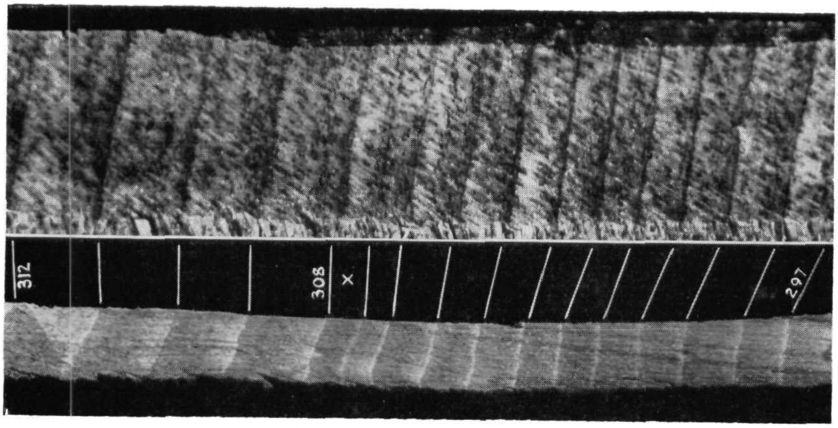
Two more cores from pre-Burrell kaikawaka were obtained later, but they did not alter the picture: core 63/B showed a decrease at the 309th ring (Figs. 26 and 27); core 63/3 showed no change. The results obtained from the five cores showing a decrease and the combined kanuka sections are as follows:

Species	Date of Burrell Ash and Lapilli (A.D.)
rimu	*c.* 1658
kaikawaka	1656
,,	1655
,,	1654
,,	1654
kanuka	*c.* 1654

The mean of the four best dates is A.D. 1655.

This date assumes that the showers occurred during the winter half of the year and that the first ring showing a reduction represents the following season's growth. It is possible that the first ring is a false one, the densewood having formed as a result of defoliation during the growing season. The date would then be A.D. 1656/7. Nevertheless, the densewood of the first ring does not differ greatly in width or distinctness from that formed in other years (Fig. 28). For this reason the older date is favoured.

Two problems remain. Why do only four of the eight cores taken from pre-Burrell kaikawaka show a reduction in the width of the rings? And why is the oldest post-Burrell kaikawaka only 226+ years? If the reduction is related to crown damage, a possible answer to the first question is that some kaikawaka were shielded by taller trees. In core C26 the rings for some distance on either side of the 308th are extremely small, suggesting that



Upper photo—R. R. Julian

FIG. 28—Annual rings in portion of core 62/5. The densewood is seen by scattered light (above) and by reflected light (below). The numbers indicate the count of rings from the outside (corrected to winter 1963); x marks the first ring showing a reduction in width.

the tree was growing beneath a canopy of other plants. The second question may not be justified, for 226 is only a minimum figure. A healthy kaikawaka sapling, ¾ in. basal diameter and 4 ft high, growing in 80-year-old manuka - mountain fivefinger scrub above Dawson Falls Hostel at 3,100 ft, was found to have approximately 55 annual rings at 1 in. above ground level; and a sapling, 1 in. basal diameter and 3½ ft high, growing in mature kamahi forest beside the Stratford Mountain Road at 3,300 ft, was found to have over 100 rings at a similar height. Taking the kaikawaka from the secondary scrub rather than that from the mature forest as being more comparable to the kaikawaka that entered the vegetation developing on Burrell Lapilli, it can be seen that the ages determined in cores taken at 3 to 4 ft are not inconsistent with a community age of 308 years.

DATE OF PUNIHO LAPILLI 1 AND PUNIHO LAPILLI 2

Discussion

The absence of any significant break between Puniho Lapilli 1 and Puniho Lapilli 2 indicated that the beds were separated by a short interval only. The possibility of a somewhat longer interval between Burrell Lapilli and Puniho Lapilli 1, however, was suggested by the erosional break as seen in profile 144, Fig. 7. Nevertheless, the lack of any trace of buried soil under the Puniho beds made this appear unlikely. The small amount of carbonised wood in each bed was thought to have come from the charred remains of pre-Burrell plants left standing, rather than from new vegetation developing on Burrell Ash. An independent check on the date of the beds did not at first appear possible, for neither early entrants, such as kanuka, nor surviving members of the preceding vegetation could be found. However, the chance finding of a kaikawaka growing on alluvium of post-Puniho age and a ring count from a mountain fivefinger growing on Puniho Lapilli 2 enabled this to be made.

Results

The kaikawaka was found just south of Kahui Hill at 2,800ft. The absence of Burrell Ash and Puniho Lapilli from a nearby soil pit (profile 79, Fig. 7), in an area where both were distributed (Figs. 17 and 19), and the absence of buried soil above Waiweranui Lapilli, could only mean that the alluvium post-dated Puniho Lapilli 2 and that Waiweranui Ash, Burrell Ash, and Puniho Lapilli 1 and 2 had been erorded prior to or at the time of deposition of the alluvium. The tree, 23 in. d.b.h. and 32 ft high, was cut 2 ft above ground level in May 1964; the count of rings was 263 (262 corrected to winter 1963). After allowing for growth of the seedling to 2 ft the date of Puniho Lapilli 2 was estimated to be not less than 275 years before 1963.

A number of shrubs and small trees growing on Puniho Lapilli 2 below Puniho Hill at 3,000–3,300 ft were then cut to find out if any were older than 275 years. Broadleaf (*Griselinia littoralis*) and mountain fivefinger appeared promising, but only one fivefinger, 8 in. d.b.h. and 12 ft high, the lower part of whose trunk was horizontal and overlain by Tahurangi Ash, yielded a ring count greater than 275. The figure obtained, at 1½ ft from the base of the tree, was 304 (303 corrected). If allowance is made for growth of the fivefinger to 1½ ft, it seems probable that the date of Puniho Lapilli 2, and consequently of Puniho Lapilli 1 also, is the same as that of Burrell Ash and Lapilli.

It could be argued that since mountain fivefinger is not normally an initial species but enters the community at a later stage, the ring count above indicates an age for Puniho Lapilli 1 and 2 greater than that of Burrell Ash and Lapilli. As this conflicts with the stratigraphic evidence, and as more weight should be given to the date obtained for the latter beds than to that obtained for the former, one or other of the following conclusions must be drawn: the fivefinger did enter the community early; it was not a seedling but a shoot from a pre-Burrell plant; some of the rings counted were false (intra-annual).

DATE OF TAHURANGI ASH

Discussion

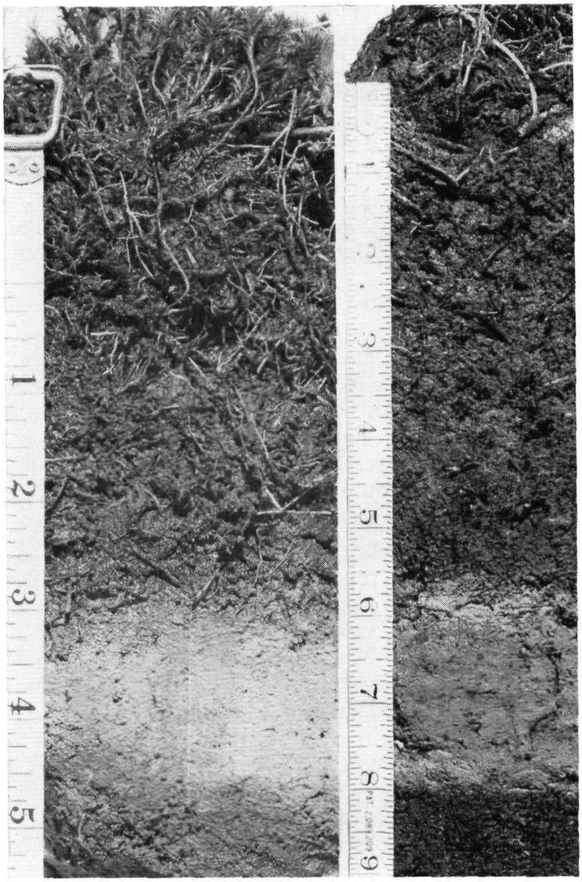
It was early suspected that there was a considerable interval between the deposition of the Burrell beds and the deposition of Tahurangi Ash. The ash was found in the forks of many post-Burrell trees, on horizontal portions of their trunks, and on their root flanges. For example, the post-Burrell kaikawaka near Kahui Hill (mentioned above) had Tahurangi Ash both on its root flanges and in a fork 13 ft above ground level. No direct method presented itself, however, whereby Tahurangi Ash could be dated—no damage had been done to vegetation and consequently there were no initial plants to use for ring counting—so an indirect method was sought. An examination of several bogs showed that the ash was separated from Burrell Lapilli by a layer of peat and that this layer was thinner than the layer of peat overlying the ash. If a constant rate of peat accumulation over the 308 years of post-Burrell time was assumed and some allowance made for humification of the surface layer, the peat could be used as a time scale and the date of Tahurangi Ash roughly estimated. As it turned out, the estimate suggested that the ash shower and an independently dated widespread deposition of alluvium from the Okahu and other streams on the western slopes might be historically related events, since the stratigraphic record showed that similar erosion and deposition had followed each of the earlier eruptive phases.

Results

The depths of peat above and below Tahurangi Ash were measured in two bogs—one on the eastern slopes of Egmont, the other on the southern slopes. The profiles are shown in Fig. 29 and one of them is described in Appendix 1. The upper 2 to 3 in. of peat in each profile was spongy compared with the underlying layers. Humification, proceeding more rapidly at the surface, would in time reduce the thickness of this peat, so in estimating the age of Tahurangi Ash (Table 4) I have allowed for an arbitrary 25 per cent reduction.

The estimate of 215–225 years is very rough, not only because of the uncertainty regarding humification but also because of the difficulty in deciding on an upper boundary to the peat were it merges into litter and vegetation (Fig. 29). The estimate did, however, bring to mind the date already obtained for the alluvial surface on the western slopes. This date was derived from ring counts on kanuka in two ways. Firstly, a kanuka, 21 in. d.b.h. and 41 ft high, growing at 2,260 ft near Okahu Stream, was cut (May 1963) 4 ft above ground level; the ring count was 192. Secondly, a dead overturned kanuka found in 80-year-old vegetation at 2,000 ft near Waiweranui Stream give a count of approximately 120 rings 3 ft from its base. The surrounding vegetation had developed after a flood in the 1880s (Druce, 1964)—this date was determined from ring counts on many trees. That the dead kanuka had probably been overturned at the time of the flood was indicated by the age of a young kanuka, 6 in. d.b.h., growing on the upturned flange; the ring count (Feb. 1963) was 70 at 1 ft. Ring counts were also made on 20 young kanuka growing on gravelly, coarse sand in nearby open sites. The results indicated that on the average a plant 3 ft high would have an age of nine years and one 4 ft high an age of 12 years. The dates (before 1963) for establishment of the two kanuka on the supposed post-Tahurangi alluvium were therefore 204 (192 + 12) and 209 (120 + 9 + 80). After allowing a further year for the initial arrival and germination of the kanuka seed the date of the alluvium was put at about A.D. 1755.

It can be seen in Fig. 10, which summarises the information from all profiles examined, that erosion and deposition have followed each small group of eruptions on Egmont: Newall Ash and Lapilli, Waiweranui Lapilli and Ash, Burrell Ash and Lapilli, Puniho Lapilli 1 and 2—each of these pairs is overlain somewhere or other by a considerable depth of alluvium (Figs. 6 and 7, profiles 79, 106, 110, 144). The large amounts of volcanic



Photos—R. R. Julian

FIG. 29—Profiles from two bogs showing very dark brown peat above and below dark greyish brown fine sandy loam (Tahurangi Ash). *Left:* profile 39, near Manganui Hut, eastern slopes of Mt Egmont, 4,100 ft. *Right:* profile 70, near Mangahume Hut, southern slopes of Mt Egmont, 4,400 ft. Both profiles were overlying Burrell Lapilli (see Fig. 6).

debris deposited on the steep upper slopes close to the crater have been readily eroded by the heavy falls of rain that occur on Egmont (Druce, 1964). On the east side (Fig. 2) most of Burrell Lapilli has been removed from the mountain above 5,500ft; on the west side (Fig. 3) scree slopes and alluvial fans cover the greater part of the area between Okahu Stream and Stony River from the summit down to the park boundary. Until more definite evidence is obtained I suggest then, that the shower or showers that deposited Tahurangi Ash preceded and indirectly led to the formation of the alluvial surfaces dated above.

TABLE 4—Estimated date of Tahurangi Ash in peat

Locality: Profile No.:	Near Manganui Hut (39)	Near Manga-hume Hut (69)	Near Manga-hume Hut (70)
Depth of peat above ash (d_2) (in.)	3	$6\frac{1}{2}$	$5\frac{1}{2}$
Depth of peat below ash (d_1) (in.)	1	2	$1\frac{1}{2}$
Estimated date of ash (before 1963)			
(i) not allowing for any reduction of d_2 by humification $\left(\frac{d_2}{d_1 + d_2} \times 308\right)$	230	235	240
(ii) allowing for 25% reduction of d_2 by humification $\left(\frac{0 \cdot 75d_2}{d_1 + 0 \cdot 75d_2} \times 308\right)$	215	220	225

DATE OF NEWALL ASH, NEWALL LAPILLI, WAIWERANUI LAPILLI, AND WAIWERANUI ASH

Discussion

The absence of buried soil, and of interbedded peat in bogs, indicated that the intervals in the Newall Formation were very short (Fig. 10). It was assumed therefore that the members had a common date, i.e., that they were laid down within a year. That there was, however, an appreciable interval between the Newall Formation and the overlying Burrell Formation was indicated by the buried soils formed from Waiweranui Ash. A comparison of the depth of peat overlying Waiweranui Ash with that overlying Burrell Lapilli in a bog south of Stratford Mountain Road (Fig. 6, profile 31) suggested that the interval might be about 70 years, though the small size of the carbonised wood in Burrell Ash, up to $\frac{3}{8}$ in. diam., made this figure seem rather high.

It was realised that the Newall beds might be dated by tree-ring methods, for the preceding vegetation had been destroyed over an extensive area, and an initial species, northern rata, growing terrestrially, was present in large numbers. Nevertheless, I was unable to find any partially burnt surviving trees which could be used for dating from burn scars (cf. Druce, 1957), and the large diameters of the rata ruled out cutting any down for ring counting. No kanuka trees were found associated with the rata. Fortunately a few rata were found just outside the park already cut; though not strictly terrestrial in origin, they enabled a rough estimate of the date of the Newall beds to be made. It was then found that one of the kaikawaka cores taken for dating Burrell Ash and Lapilli showed a reduction in the width of the annual increments commencing at about the same date.

Results

In June 1961, north of Stony River at 1,600 ft, a portion of stem of northern rata was found beside the tree from which it had been recently cut. The tree, approximately 90 ft high and 10 ft overall d.b.h., had been dead for an estimated 10 years, to judge from the absence of branchlets of less than 1 in. diam. The base of the tree was underlain by Newall Ash containing small fragments of carbonised wood. Ring counts on the two ends of the log (3 ft diam.) were 290 and 292 respectively. A tree destroyed by fire had probably served as the site of establishment for the rata and the point of epiphytic origin was estimated to be 15 ft above ground level. As the log had come from 30 ft up the tree, an allowance had to be made for growth to a height of 15 ft from the point of origin. Ring counts on a pole rata 46 ft high, a sapling 48 ft high, and a sapling 27 ft high, growing terrestrially south of Stony River at about the same altitude, indicated an average annual height extension of 6 in. The date of establishment of the rata was therefore estimated to be 333 years before 1963 (291 + 30 + 10 + 2 years correction 1961–63), i.e., A.D. 1630.

In May 1963 a felled rata was found on the slopes of Pouakai Range about 1 mile north of the previous tree. The rata, 8 ft overall d.b.h., had been cut 7 ft above ground level but below the point of origin. The date of cutting was judged to have been not more than five years prior to 1963. Small fragments of carbonised wood associated with a thin layer of ash were found nearby and, as in the previous case, it was thought that the rata had germinated on a log after a fire started by one of the Newall showers had spread through the forest (Druce, 1964). A fresh section was cut with a chain saw from the lower end of one of the stems of the compound trunk and a segment taken for examination under bright light; the ring count was 331. No estimate of the time taken for the stem (originally a root) to grow down to 7 ft above the ground was possible, so the date of establishment of the tree was put at a figure greater than 336 years before 1963 (331 + 5), i.e., before A.D. 1627.

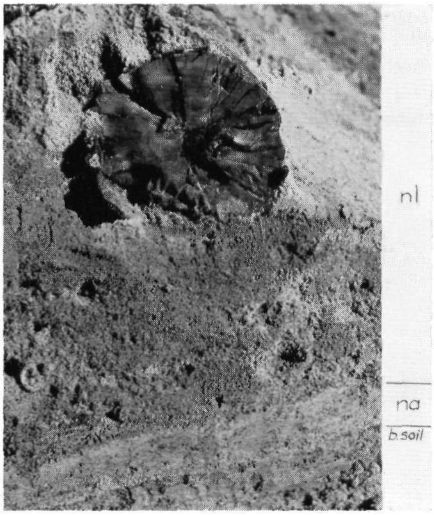
As both these rata trees began on stumps rather than on the ground, they may not have germinated immediately after the Newall beds were deposited; they could have entered the community at any time up to that at which the surrounding vegetation covered the sites of establishment. Taking into account the evidence from buried soil and peat it seemed likely that the date of the Newall beds would be at least 340 years before 1963.

Of the cores taken for dating Burrell Ash and Lapilli only No. C8, C26, and 62/2 had appreciably more than this number of rings (Table 3). In one of the cores, No. C26, taken from a kaikawaka, I had recorded (Feb. 1960) a sharp decrease in the width of the annual increments commencing with the 356th ring counting from the outside (359th corrected to winter 1963). No conspicuous change was apparent in the preceding 108 rings (rings 357 to 464). The core came from a tree growing beside the track leading from Dawson Falls Hostel to Fantham Peak. A quarter of a mile further up abundant small fragments of carbonised wood are present along the track cuttings both in Newall Ash and below it. I think it possible that the decrease in the annual increments is related to damage done to the foliage by this ash and the date of the Newall beds is therefore estimated to be about A.D. 1604.

DATE OF UNNAMED ASH BED

In profile 41, near Manganui Hut (Fig. 6), the buried soil formed from the unnamed ash underlying Newall Ash was deeper than the buried soil formed from Waiweranui Ash. As this latter ash had undergone soil development for some 50 years, the interval between the unnamed ash and Newall Ash was thought to be considerably in excess of that figure.

The carbonised logs seen in the Newall beds on the west side of the Mountain led to a similar conclusion. A log, 7 in. diam., lying in Newall Lapilli in a profile near No. 110, Maero Stream, had approximately 100 rings (Fig. 30). In this profile Newall Ash was underlain by some 9 ft



Photo—G. C. Kelly

FIG. 30—Profile near No. 110, Maero Stream, 2,290 ft, western slopes of Mt Egmont, showing 7 in. diam. log carbonised except on the underside where there is about 1 in. of humus. The log contains about 100 growth rings, has its bark in position and lies in the bedding plane of Newall Lapilli (nl). (Newall Ash —na.)

of alluvium containing further carbonised logs and it was assumed that the deposition of the alluvium had followed the deposition of the unnamed ash. As few logs of greater than 7 in. diam. have been seen in the Newall beds, the length of the pre-Newall interval may not be much more than 100 years. The date of the unnamed ash is therefore tentatively put at about A.D. 1500 (a round figure).

VOLCANIC HISTORY OF MT EGMONT OVER THE LAST 500 YEARS

Before A.D. 1500 there must have been a period of quiescence on Mt Egmont lasting from several hundred to many hundreds of years, for the soil buried under the upper ash and lapilli beds is more developed than any subsequent soil (buried soil 8, Fig. 4). About A.D. 1500 the first of the recent eruptions (Fig. 31) showered the upper slopes with fine ash. The crater of Egmont was breached on its west side, possibly for the first time, and a hot shower destroyed vegetation on the western slopes as is shown by the carbonised logs buried in pre-Newall alluvium beside Maero Stream.

The Newall series of eruptions began about A.D. 1604 (Fig. 31). Newall Ash (Fig. 23) was laid down by a number of showers, some if not all of which had a component directed toward Stony River (Fig. 8). The vegetation was probably destroyed on all the upper slopes and fire spread down tc 3,500 ft on the eastern slopes of Fantham Peak. On the west side of Egmont the ash was hot enough to char logs at a distance of 6 miles from the crater (Fig. 9) and fire probably spread beyond that distance. Very shortly afterwards the most violent of the recent eruptions deepened the breach in the

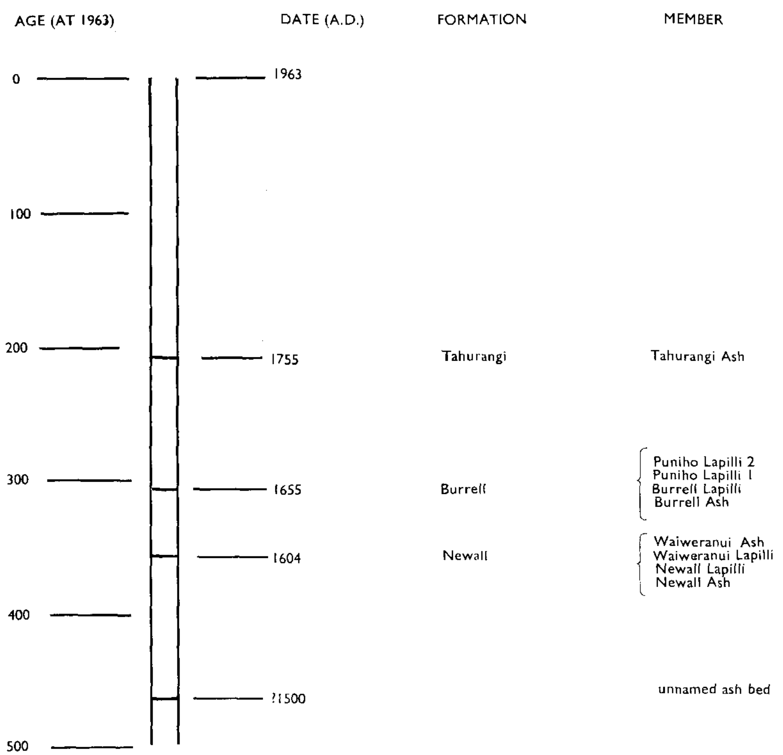


FIG. 31—Chronological table for upper ash beds, Mt Egmont.

crater and laid down Newall Lapilli in a single deposit (Fig. 22). Vegetation was burnt up to a distance of at least 10 miles from the crater; standing trees, perhaps already killed by one of the preceding showers, were flattened, buried, and carbonised throughout or nearly so (Figs. 9 and 30). In Fig. 32 the inverted stick with its end beside a hole of similar diameter is probably a portion of a branch from the tree above and appears to have been driven through Newall Ash into the underlying buried soil by the falling tree. Since none of the buried logs seen in Newall Lapilli have been associated with stumps, it seems likely that the upper portion of each tree was blown some distance from its base, as happened on Lassen Peak in northern California early this century (Loomis, 1926; D. B. Lawrence, pers. comm.). The elongate distribution of Newall Lapilli (Fig. 22) indicates that the shower had the very low trajectory necessary for such a blast to be engendered.

During these first eruptions the vegetation was destroyed over a 90° segment of Egmont, from Ahukawakawa Swamp to Okahu Stream. The vegetation was also destroyed on the steep southern faces of Pouakai Range above Stony River and the fires that were started spread across the western slopes of the range several miles beyond the limit of immediate destruction. After a short interval, during which erosion occurred, another similar

Photo—G. C. Kelly

FIG. 32—Profile 117 (Fig. 9) cut away further to reveal inverted carbonised stick, 1½ in. diam., with its broken end freely resting on buried soil beneath Newall Ash. Immediately to the right of the end of the stick there is an ash-filled depression in the buried soil 2 in. diam. and 1½ in. deep. (For explanation see text.) Bark is in position on both the stick and the log above.

explosion laid down the coarser textured Waiweranui Lapilli (Fig. 21), but by this time there was probably little vegetation left to be destroyed in the area. In the last of the Newall eruptions Waiweranui Ash was deposited on the upper slopes (Fig. 20).

In A.D. 1655, after some 50 years of erosion and of vegetation and soil development, the Burrell series of eruptions began (Fig. 31). Burrell Ash, like Newall Ash, was formed by a number of showers directed in part toward Stony River (Fig. 19). Once again the vegetation both on the upper slopes and on the lower western slopes was destroyed by fire. Elsewhere, notably in the area at the head of the Stratford Mountain Road, plants dropped their leaves, presumably as a result of scorching. Almost immediately afterwards andesite highly charged with gas was shot into the air; the resulting pumice, blown ESE as it fell, formed Burrell Lapilli in a single deposit (Fig. 18). As the shower was not sufficiently hot to char, the damage done to vegetation was by impact and burial. Lapilli were spread to a distance of about 10 miles from the crater and blocks to a distance of 3 miles. At a distance of 2½ miles the largest blocks were of about 2½ in. diameter, at a distance of 1½ miles, 7 in., and at a distance of 1 mile, over 12 in. A short time later two showers, directed toward the west, laid down in quick succession Puniho Lapilli 1 and Puniho Lapilli 2 (Fig. 17).

About A.D. 1755 after an interval of 100 years Egmont again erupted, showering the upper slopes with fine ash (Tahurangi Ash, Fig. 16). The present period of quiescence has now lasted more than 200 years; if one is to predict from the past record, it will be terminated by a series of explosions directed toward Stony River from the upper western face of Egmont (Fig. 3).

CONCLUSION

In attempting to use tree rings to date some of the more recent ash deposits on Mt Egmont I have had to rely at times on inadequate data. I have some confidence in the date derived for the Burrell Formation, but more evidence is needed before the dates of the Tahurangi and Newall Formations can be accepted. The most likely source of error in tree-ring dating on Egmont appears to be the formation of false rings following salt "burn", though this may well be something that happens only at infrequent intervals. There is also the possibility of false rings arising from frost injury.

Further study needs to be made of the recent ash and lapilli beds on the west side of Egmont to elucidate the history of the numerous showers that have been directed there as a result of breaching of the crater wall. The main difficulty lies in finding suitable profile sites, for over most of the area the beds have been either buried under alluvium or subjected to erosion. To judge from its past record Egmont will almost certainly erupt again, and in view of the present form of the crater the most likely type of eruption would seem to be an explosion toward the west. Each such eruption in the past has produced a shower that has blasted and burnt vegetation for a distance of many miles from the crater.

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APPENDIX 1—DESCRIPTION OF STANDARD PROFILES

(Note: the colour names are those of the Munsell system.)

No. 31 (Figs. 6, 13, 14). Bog south of Stratford Mountain Road. Alt. 2,250 ft. N.Z.M.S. 169 Grid ref. 723607.

$4\frac{1}{2}$ in.	very dark brown peat with trace fine sand (*Tahurangi Ash*) in bottom $1\frac{1}{2}$ in.; sharp boundary;
11 in.	dark reddish brown gravel, mostly pumice (*Burrell Lapilli*); loose; buried twigs at bottom; sharp boundary;
1–3 in.	dark greyish brown fine sandy loam (*Burrell Ash*); firm; sharp boundary;
1 in.	very dark brown peat (*buried soil*); indistinct boundary;
$\frac{1}{2}$ in.	dark brown peaty fine sandy loam (*Waiweranui Ash*); distinct boundary;
$1\frac{1}{2}$ in.	dark greyish brown loamy sand with fine gravel (*Waiwarenui* and/or *Newall Lapilli*); distinct boundary;
1 in.	brown peaty fine sandy loam (*Newall Ash*); indistinct boundary;
1 in.	very dark brown peat with trace fine sand (*buried soil*); diffuse boundary;
on	very dark brown to black peat.

No. 37 (Figs. 4, 6, 7, 12). Cutting, Stratford Mountain Road. Alt. 3,400 ft. N.Z.M.S. 169 Grid ref. 685617.

3 in.	dark reddish brown fine sandy loam (*Tahurangi Ash*); sharp boundary;
$12\frac{1}{2}$ in.	dark brown stony gravel, mostly pumice (*Burrell Lapilli*); loose; distinct boundary;
$\frac{1}{2}$ in.	very dark brown humic fine sandy loam (*buried litter*) (*Burrell Ash*); distinct boundary;
$\frac{3}{4}$ in.	dark brown fine sandy loam (*Burrell Ash*); distinct boundary;
1 in.	dark greyish brown fine sandy loam (*Burrell Ash*); firm; distinct boundary;
$2\frac{1}{4}$ in.	brown fine sandy loam (*buried soil*) (*Waiweranui Ash*); distinct boundary;
$\frac{1}{2}$ in.	dark greyish brown loamy sand with fine gravel (*Waiweranui* and/or *Newall Lapilli*); distinct boundary;
$\frac{1}{2}$ in.	dark greyish brown fine sandy loam (*Newall Ash*); firm; indistinct boundary;
on	brown fine sandy loam (*buried soil*) (*unnamed ash*).

No. 41 (Figs. 5, 6). Cutting, new site for Manganui Hut. Alt. 4,150 ft. N.Z.M.S. 169 Grid ref. 670619. Type locality for Tahurangi Ash, Burrell Lapilli, and Burrell Ash.

4 in.	dark brown fine sandy loam (*Tahurangi Ash*); sharp boundary;
3 in.	dark brown sandy gravel, mostly pumice (*buried soil*) (*Burrell Lapilli*); loose; indistinct boundary;
10 in.	brown stony gravel, mostly pumice (*Burrell Lapilli*); loose; sharp boundary;
7 in.	dark greyish brown fine sandy loam (*Burrell Ash*); lower two-thirds firm and finely bedded; sharp boundary;

1 in. brown humic sandy loam (*buried soil*) (*Waiweranui Ash*); distinct boundary;
1½ in. dark greyish brown loamy sand with fine gravel (*Waiweranui Lapilli*); indistinct boundary;
2 in. dark greyish brown loamy sand with fine gravel (*Newall Lapilli*); distinct boundary;
2 in. dark greyish brown fine sandy loam (*Newall Ash*); very firm; finely bedded; distinct boundary;
1 in. yellowish brown fine sandy loam (*Newall Ash*); sharp boundary;
2 in. brown humic fine sandy loam (*buried soil*) (*unnamed ash*); indistinct boundary.
3½ in. dark greyish brown fine sandy loam (*unnamed ash*); sharp boundary.
on brown humic fine sandy loam (*buried soil*).

No. 69 (Fig. 6). Bog 50 yd south of Mangahume Hut. Alt. 4,400 ft. N.Z.M.S 169 Grid ref. 633604.

2½ in. very dark brown spongy peat; diffuse boundary;
4 in. very dark brown peat with trace fine sand (*Tahurangi Ash*) in bottom 1 in.; sharp boundary;
2 in. dark greyish brown fine sandy loam (*Tahurangi Ash*), firm; sharp boundary;
2 in. very dark brown peat (*buried soil*); sharp boundary;
1 in. fine pumice gravel (*Burrell Lapilli*); sharp boundary;
2 in. dark greyish brown sand (*Burrell Ash*); indistinct boundary;
2 in. dark greyish brown loamy sand (*Burrell Ash*); firm; sharp boundary;
2 in. dark brown peaty fine sandy loam (*buried soil*) (*Waiweranui Ash*) with trace fine gravel (*Waiweranui* and/or *Newall Lapilli*) at bottom; distinct boundary;
1 in. dark greyish brown fine sandy loam (*Newall Ash*); indistinct boundary;
2 in. dark brown peaty fine sandy loam (*buried soil*) (*unnamed ash*); sharp boundary;
on stony gravelly sand (*alluvium*).

No. 84 (Fig. 6). North side of Ohaku Stream above Puniho Hill. Alt. 4,560 ft. N.Z.M.S. 169 Grid ref. 623625.

1½ in. dark brown fine sandy loam (*Tahurangi Ash*); distinct boundary;
4 in. dark brown gravelly loamy sand with a few stones (*Puniho Lapilli*); sharp boundary;
¼ in. brown fine pumice gravel (*Burrell Lapilli*); sharp boundary;
1 in. dark greyish brown loamy sand (*Burrell Ash*); indistinct boundary;
1 in. brown sandy loam (*buried soil*) (*Waiweranui Ash*); distinct boundary;
7 in. dark grey stony gravelly coarse sand (*Waiweranui Lapilli*); loose; distinct boundary;
7 in. dark grey gravelly coarse sand (*Newall Lapilli*); loose; sharp boundary;
½ in. pale brown loamy sand (*Newall Ash*); distinct boundary;
1 in. dark grey sand with fine gravel (*Newall Ash*); sharp boundary;
1½ in. pale brown loamy sand (*Newall Ash*); distinct boundary;
3 in. dark grey sand with fine gravel (*Newall Ash*); sharp boundary;
1 in. pale brown loamy sand (*Newall Ash*); sharp boundary;
on brown fine sandy loam (*buried soil*) (*unnamed ash*).

No. 90 (Figs. 6, 7). North-west of Puniho Hill (17 yd south-west of signpost at junction of Puniho Track with track round the mountain). Alt. 3,140 ft N.Z.M.S. 169 Grid ref. 601635. Type locality for Puniho Lapilli 2, Puniho Lapilli 1, Waiweranui Ash, and Waiweranui Lapilli.

2 in. dark brown fine sandy loam (*Tahurangi Ash*); distinct boundary;
5 in. dark reddish brown gravelly loamy sand (*Puniho Lapilli 2*); distinct boundary;
6 in. dark brown gravelly loamy sand (*Puniho Lapilli 1*); diffuse boundary;

3 in. brown gravelly loamy sand (*Puniho Lapilli 1*); indistinct boundary;
3 in. dark greyish brown gravelly sand (*Puniho Lapilli 1*); loose; sparse small carbonised wood fragments; sharp boundary;
2 in. dark greyish brown coarse sand (*Burrell Ash*—redeposited?); sparse small carbonised wood fragments; sharp boundary;
2 in. dark greyish brown fine gravelly sand (*Burrell Ash*); loose; sparse small carbonised wood fragments; sharp boundary;
½ in. pale brown loamy sand (*Burrell Ash*); distinct boundary;
3 in. dark greyish brown coarse sand with some fine gravel (*Burrell Ash*); abundant small carbonised wood fragments; distinct boundary;
½ in. pale brown loamy sand (*Burrell Ash*); sharp boundary;
2 in. dark brown fine sandy loam (*buried soil*) (*Waiweranui Ash*); distinct boundary;
16 in. dark grey stony gravelly coarse sand (*Waiweranui Lapilli*) over dark grey gravelly coarse sand (*Newall Lapilli*); loose; sparse carbonised wood fragments; sharp boundary;
½ in. greyish brown loamy sand (*Newall Ash*); finely bedded; sharp boundary;
2 in grey loamy sand (*Newall Ash*); finely bedded; sharp boundary;
½ in. greyish brown loamy sand (*Newall Ash*); sharp boundary;
on brown fine sandy loam (*buried soil*) (*unnamed ash*).

No. 94 (Fig. 6). Puniho Hill. Alt. 3,630 ft. N.Z.M.S. 169 Grid ref. 610630.

2 in. dark brown fine sandy loam (*Tahurangi Ash*); distinct boundary;
7 in. dark reddish brown gravelly loamy sand (*Puniho Lapilli 2*); sharp boundary;
0–2 in. pale brown loamy sand (redeposited?—matches *Burrell Ash* below); sharp boundary;
2 in. dark brown gravelly loamy sand (*Puniho Lapilli 1*); sharp boundary;
3 in. pale brown loamy sand (*Burrell Ash*); firm; trace coarse sand at bottom; sharp boundary;
4 in. dark brown sandy loam (*buried soil*) (*Waiweranui Ash*); distinct boundary;
24 in. dark grey stony gravelly coarse sand (*Waiweranui Lapilli*); loose; sparse carbonised wood fragments; distinct boundary;
12 in. dark grey gravelly sand (*Newall Lapilli*); loose; sharp boundary;
3 in. dark greyish brown loamy sand (*Newall Ash*); sharp boundary;
on brown fine sandy loam (*buried soil*) (*unnamed ash*).

No. 117 (Figs. 8, 9, 32). North bank of Stony River, 5 chains east of top end of Saunders Road. Alt. 1,250 ft. N.Z.M.S. 169 Grid ref. 540679. Type locality for Newall Lapilli and Newall Ash.

2 in. dark brown loamy coarse sand with some fine gravel (*Puniho Lapilli*); distinct boundary;
10 in. brown gravelly coarse sand (*Newall Lapilli*); loose; sparse small carbonised wood fragments; diffuse boundary;
32 in. dark grey gravelly coarse sand (*Newall Lapilli*); loose; abundant carbonised wood, including two logs, 6 in. and 5 in. diam., lying horizontally with bark in position; sharp boundary;
4–9 in. dark greyish brown coarse sand (*Newall Ash*); small carbonised wood fragments; log at bottom charred on top only; sharp boundary;
on brown loam (*buried soil*).

No. 163 (Fig. 7). Cutting beside track, northern slopes of Mt Egmont. Alt. 3,625 ft. N.Z.M.S. 169 Grid ref. 638661.

4 in. dark brown fine sandy loam (*Tahurangi Ash*) with trace fine pumice gravel (*Burrell Lapilli*) at bottom; distinct boundary;
1–2½ in. dark greyish brown fine sandy loam (*Burrell Ash*); firm; distinct boundary;
2 in. dark brown fine sandy loam (*buried soil*) (*Waiweranui Ash*); indistinct boundary;

1½ in. dark brown loamy sand with fine gravel (*Waiweranui* and/or *Newall Lapilli*); distinct boundary;
2½ in. dark greyish brown fine sandy loam (*Newall Ash*); firm; distinct boundary;
on brown fine sandy loam (*buried soil*).

APPENDIX 2—KEY TO COMMON NAMES USED IN THE TEXT

broadleaf—*Griselinia littoralis*
fuchsia—*Fuchsia excorticata*
gorse—*Ulex europaeus*
kaikawaka—*Libocedrus bidwillii*
kamahi—*Weinmannia racemosa*
kanuka—*Leptospermum ericoides*
manuka—*L. scoparium*
matai—*Podocarpus spicatus*
mountain fivefinger—*Neopanax colensoi*
northern rata—*Metrosideros robusta*
rimu—*Dacrydium cupressinum*
totara—*Podocarpus totara*
totara, Hall's—*P. hallii*