LATE QUATERNARY VOLCANIC STRATIGRAPHY OF THE SOUTHEASTERN SECTOR OF THE MOUNT RUAPEHU RING PLAIN NEW ZEALAND

A thesis presented as partial fulfilment of the requirements
for the degree of

Doctor of Philosophy in Soil Science

by

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Plate 1.1 CRATER LAKE, MT RUAPEHU
View of Crater Lake from the top of Mangaturuturu Glacier looking toward Pyramid Peak (left centre) and Mitre Peak (right centre). To the right of the photograph is the outlet of Crater Lake [arrow] below Ruapehu summit, Tahurangi (2797 m).

Plate 1.2 MT RUAPEHU RING PLAIN
Northern view from the Whangaehu escarpment overlooking Whangaehu River (at right of photograph) and sparsely vegetated laharic surfaces of eastern Rangipo Desert. Note locations of The Chute [right arrow] and Scorpion Gully [left arrow]. Mt Ruapehu, Mt Ngauruhoe, and Mt Tongariro are seen in the background.

Plate 1.3 MT RUAPEHU RING PLAIN
Southeastern view overlooking Whangaehu River [left arrow] (altitude *c.* 1200 m) and The Chute [right arrow]. To the left of the photograph are Whangaehu Valley moraines, and to the centre and right are lava flows of Whangaehu Valley and laharic surfaces of the Whangaehu Fan, Rangipo Desert.

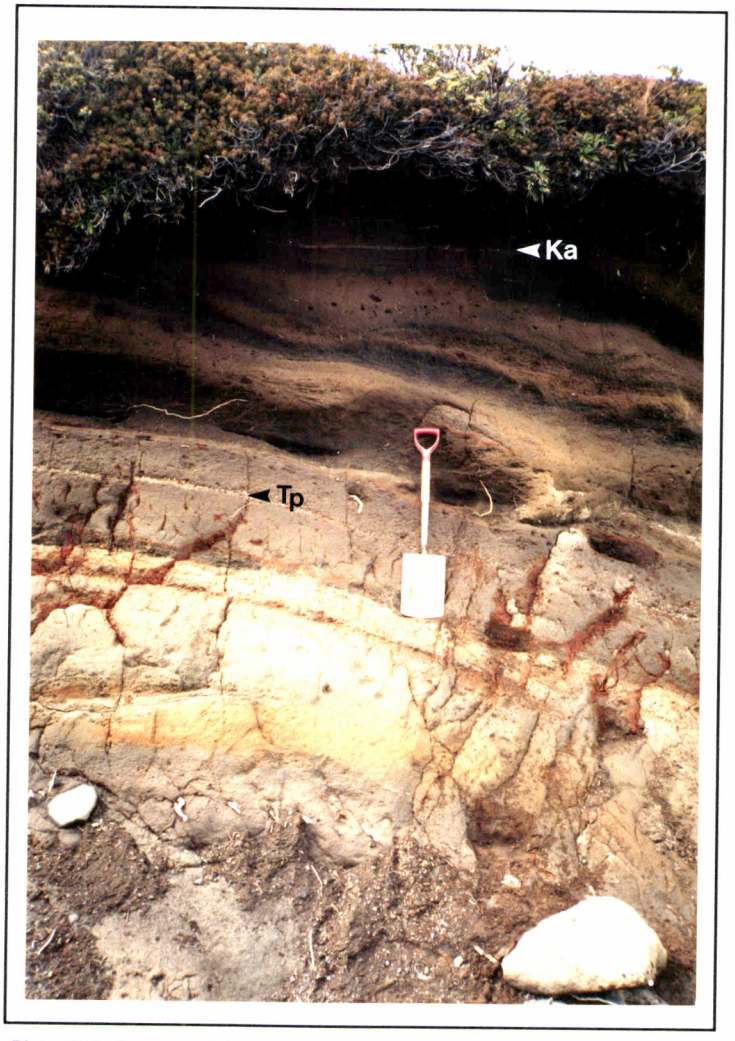


Plate 2.1 OHAKUNE MOUNTAIN ROAD [S20/271074]
Kaharoa Tephra [Ka], interbedded with Makahikatoa Sands (brown) and Tufa Trig Formation tephras (black). Note the position of Taupo Pumice [Tp] (Taupo Ignimbrite Member).

Plate 2.2 OHAKUNE MOUNTAIN ROAD [S20/271074]
Kaharoa Tephra [Ka] interbedded with Makahikatoa Sands (brown) and Tufa Trig Formation tephras (black).

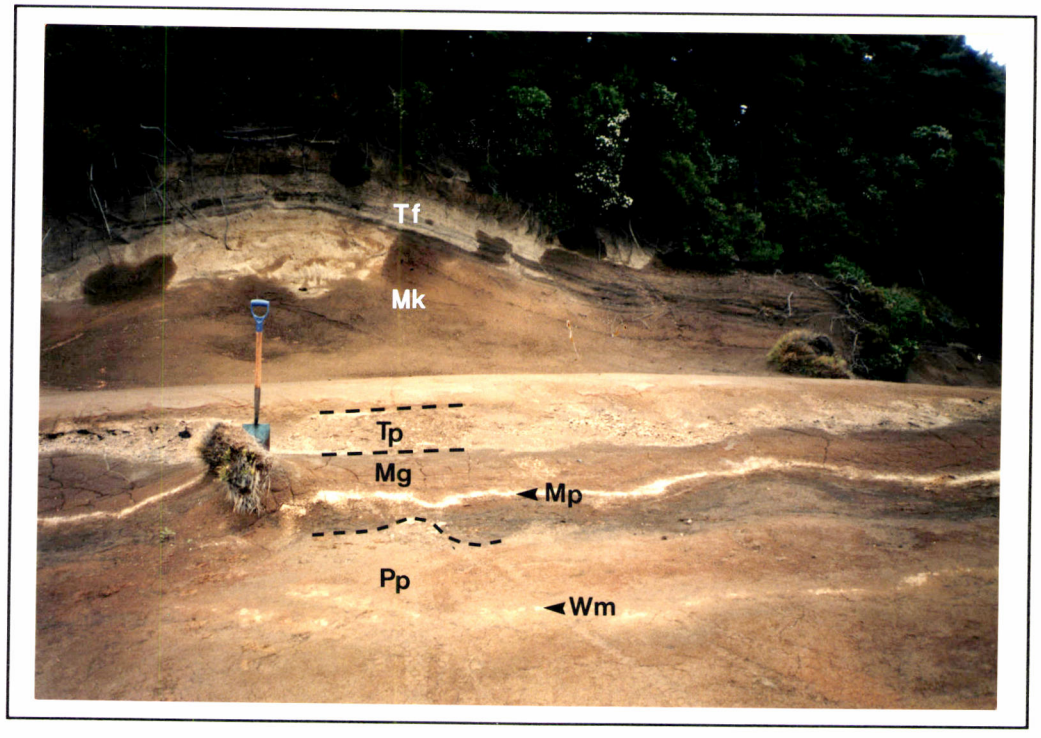


Plate 2.3 TUFA TRIG S.2 [T20/375046]
Taupo Pumice [Tp] (Taupo Ignimbrite Member) overlying Mangatawai Tephra [Mg] and interbedded Mapara Tephra [Mp], and Papakai Formation [Pp] and interbedded Waimihia Tephra [Wm]. Note charcoalised logs in the ignimbrite to the left of the spade blade. Overlying Taupo Ignimbrite are interbedded black Tufa Trig Formation tephras [Tf] and brownish-grey Makahikatoa Sands [Mk].

Plate 2.4 DESERT ROAD S.11 [T20/464092]
Taupo Pumice [Tp] (Taupo Ignimbrite Member) showing pink coloration, overlying Mangatawai Tephra [Mg] and white Waimihia Tephra [Wm], interbedded within Papakai Formation [Pp]. Papakai Formation overlies bedded sands [bs] on Mangamate tephras (obscured). Taupo Ignimbrite is overlain by Makahikatoa Sands and interbedded Tufa Trig Formation tephras (member Tf5 arrowed).

Plate 2.5 AQUEDUCT S.1, SOUTHERN RANGIPO DESERT [T20/418982]
Taupo Pumice [Tp] (Taupo Ignimbrite Member) showing maximum thickness (3 m) in study area. Overlying this are Onetapu Formation laharic deposits, and interbedded Tufa Trig Formation tephras and Makahikatoa Sands.

Plate 2.6 RANGIPO DESERT
Partially eroded Taupo Pumice [Tp] (Taupo Ignimbrite Member) overlain by Onetapu Formation gravels, southern Rangipo Desert. Note positions of Mangatawai Tephra [Mg], and Papakai Formation [Pp] with interbedded Motutere Tephra 'cream cakes' [arrow].

Plate 2.7 NGAMATEA SWAMP [T21/413874] LOOKING TO THE SOUTH
Taupo Ignimbrite [arrow] interbedded within peat exposed along the length of a drainage channel in Ngamatea Swamp (figure for scale).

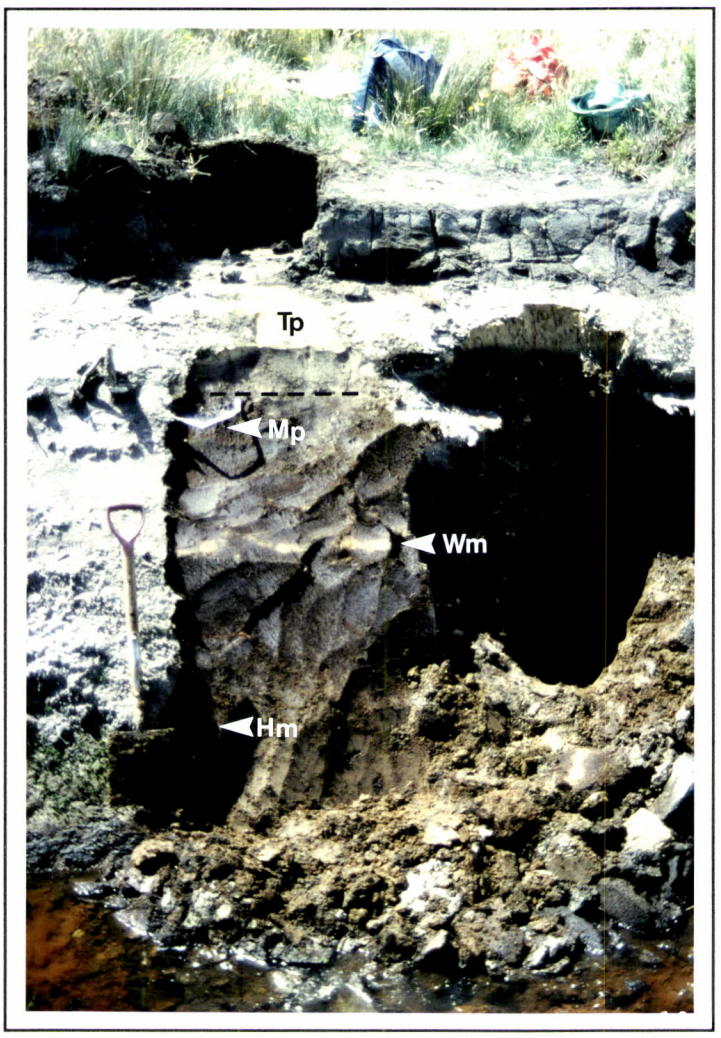


Plate 2.8
NGAMATEA SWAMP [T21/413874]
Taupo Pumice [Tp] (Taupo Ignimbrite Member), Waimihia Tephra [Wm], and stratigraphic positions of Mapara Tephra [Mp] and Hinemaiaia Tephra [Hm] are indicated. All tephras are interbedded within peat.

Plate 2.9 TUFA TRIG S.2 [T20/375046]
Mapara Tephra [Mp] interbedded within Mangatawai Tephra [Mg]. Note overlying Taupo Pumice [Tp] (Taupo Ignibrite Member).

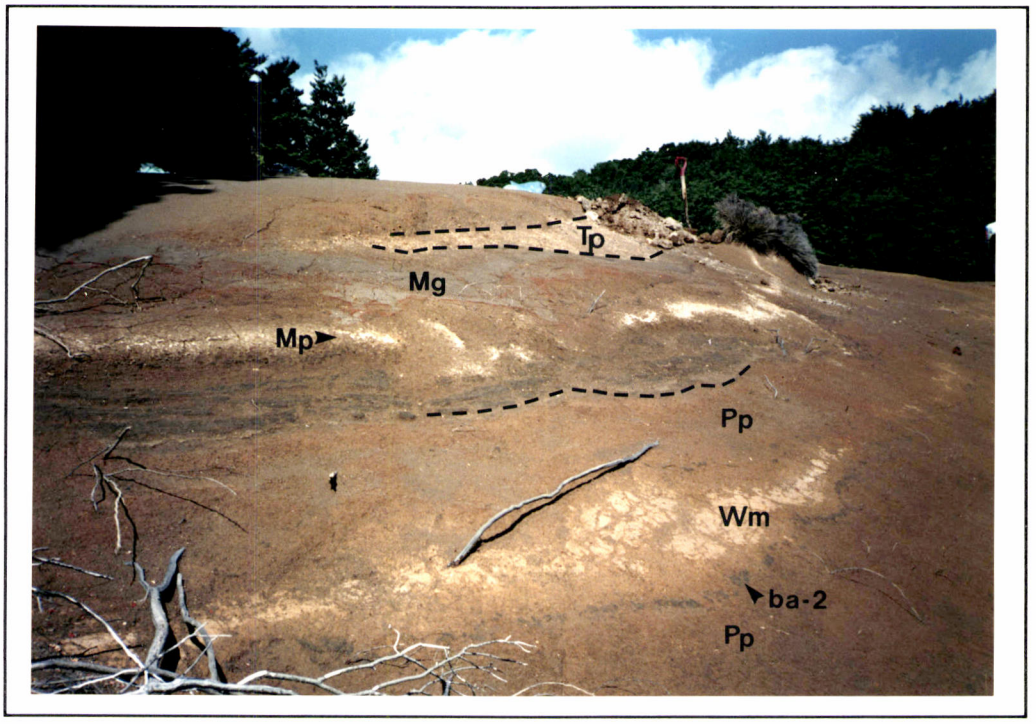


Plate 2.10 TUFA TRIG S.2 [T20/375046]
Waimihia Tephra [Wm] interbedded within Papakai Formation [Pp]. Note overlying Mangatawai Tephra [Mg] with interbedded white Mapara Tephra [Mp], and Taupo Pumice [Tp] (Taupo Ignibrite Member). Also shown is the andesitic black ash-2 member [ba-2] of Papakai Formation.

Plate 2.11
TUFA TRIG S.2 [T20/375046]
Taupo Pumice [Tp] (Taupo Ignimbrite Member), Mapara Tephra [Mp] (interbedded within Mangatawai Tephra [Mg]), and Waimihia Tephra [Wm] (interbedded within Papakai Formation [Pp]). Note stratigraphic positions of black ash-1 [ba-1] and black ash-2 [ba-2] members of Papakai Formation.

Plate 2.12 DESERT ROAD S.12 [T20/458119]
Yellowish-white Hinemaiaia Tephra [Hm], showing diffuse contacts, interbedded within grey Papakai Formation [Pp]. Note the distinctive surface cracking of Papakai Formation denoting paleosol development.

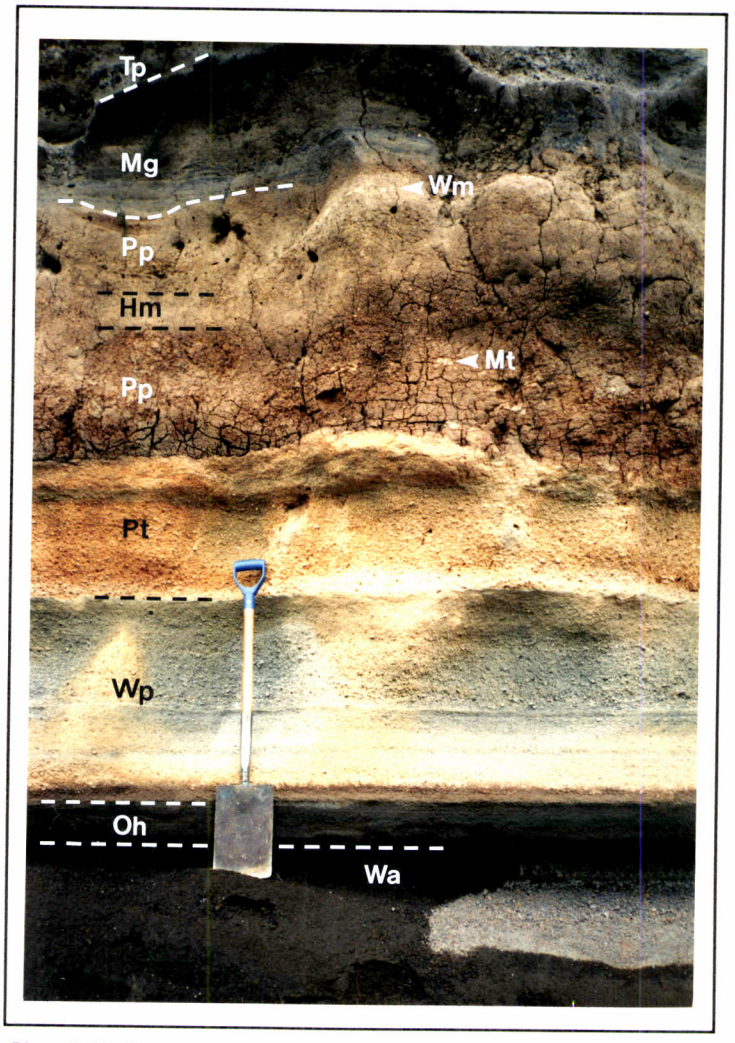


Plate 2.13 DESERT ROAD S.15 [T20/462135]
Hinemaiaia Tephra [Hm] appearing as a pale yellow horizon within cracked Papakai Formation [Pp]. Also interbedded within Papakai Formation are Motutere Tephra [Mt] and Waimihia Tephra [Wm]. Note the overlying black andesitic Mangatawai Tephra [Mg] and Taupo Pumice [Tp] (Taupo Ignimbrite Member). Papakai Formation overlies Mangamate Tephra members Poutu Lapilli [Pt], Wharepu Tephra [Wp], Ohinepango Tephra [Oh], and Waihohonu Lapilli [Wa].

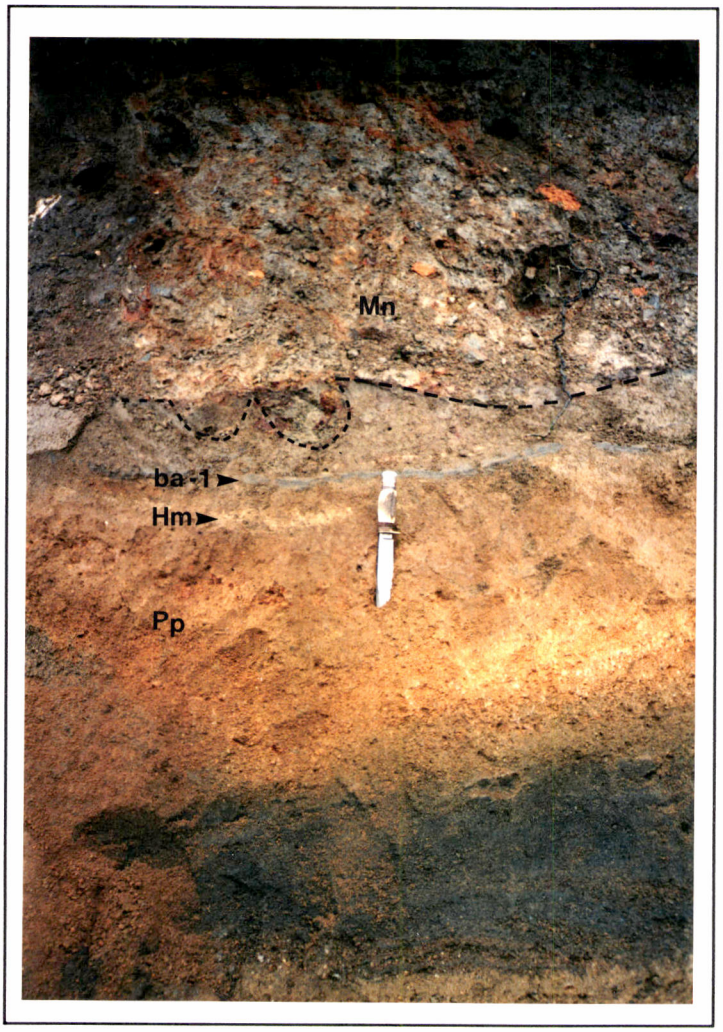


Plate 2.14
DEATH VALLEY TYPE LOCALITY
Hinemaiaia Tephra [Hm] preserved as a pocketing lens of coarse yellowish-white ash within Papakai Formation [Pp]. It is overlain by black ash-1 [ba-1] member of Papakai Formation and the Mangaio Formation debris flow [Mn].

Plate 2.15 DEATH VALLEY S.5 [T20/409045]
Whakatane Tephra [Wk] interbedded with Manutahi Formation gravels. Note position of Motutere Tephra [Mt].

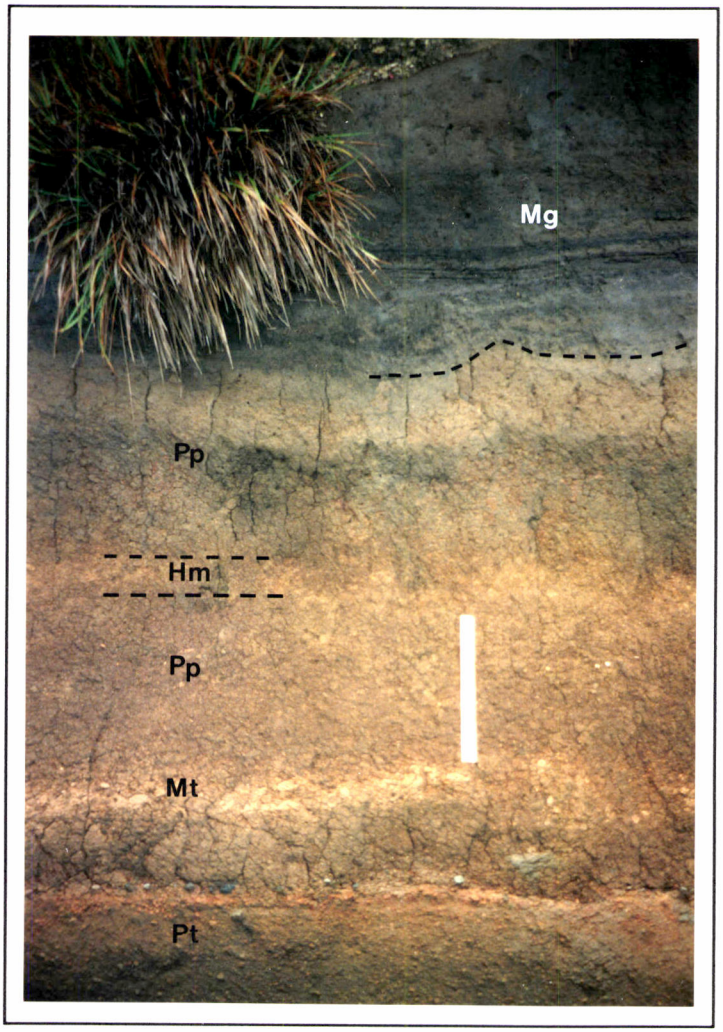


Plate 2.16
DESERT ROAD S.17 [T19/482199]
Motutere Tephra [Mt] interbedded near the base of Papakai Formation [Pp]. Note positions of Poutu Lapilli Member [Pt] of Mangamate Tephra, Hinemaiaia Tephra [Hm] (indistinct pale horizon), and Mangatawai Tephra [Mg].

Plate 2.17 DEATH VALLEY S.3 [T20/409042]
Primary Motutere Tephra [Mt] is indicated by lower arrow. Upper arrow indicates reworked Motutere Tephra, interbedded within Manutahi Formation deposits.

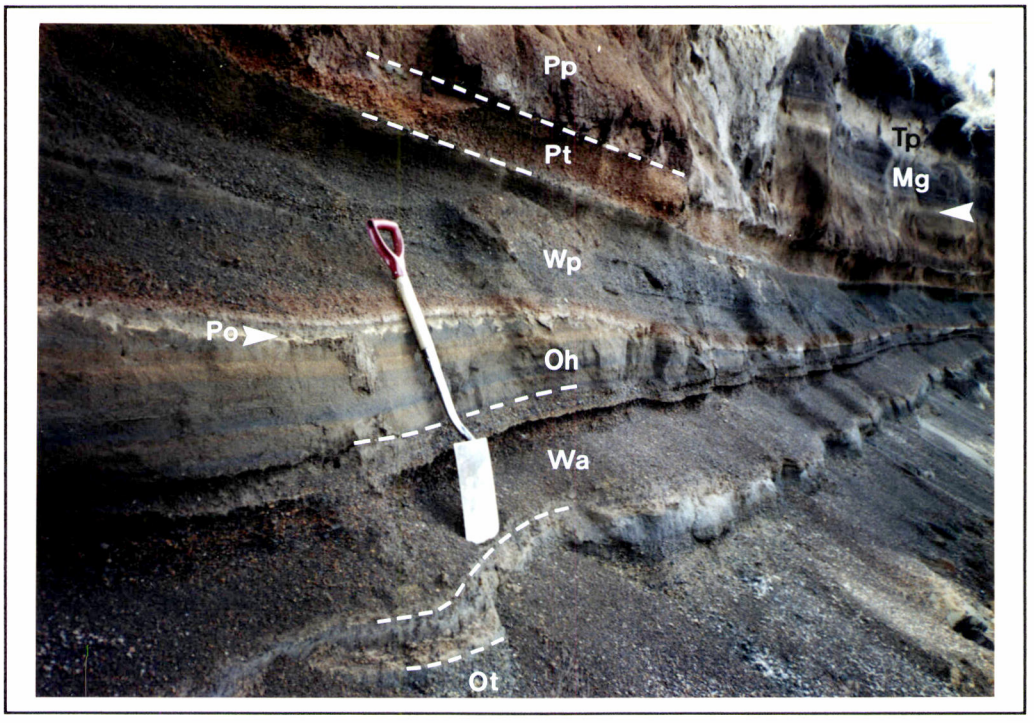


Plate 2.18 DESERT ROAD S.15 [T20/462135]
Poronui Tephra [Po] occurs between Wharepu Tephra [Wp] and Ohinepango Tephra [Oh] members of the Mangamate Tephra. Note the distinctive orange and black colour-banding in Ohinepango Tephra, the basal orange bed of Wharepu Tephra, and the positions of Mangamate Tephra members Poutu Lapilli [Pt], Waihohonu Lapilli [Wa], and Oturere Lapilli [Ot] (partially obscured). Also shown are Papakai Formation [Pp], Waimihia Tephra [arrow], Mangatawai Tephra [Mg], and Taupo Pumice [Tp] (Taupo Ignimbrite Member).

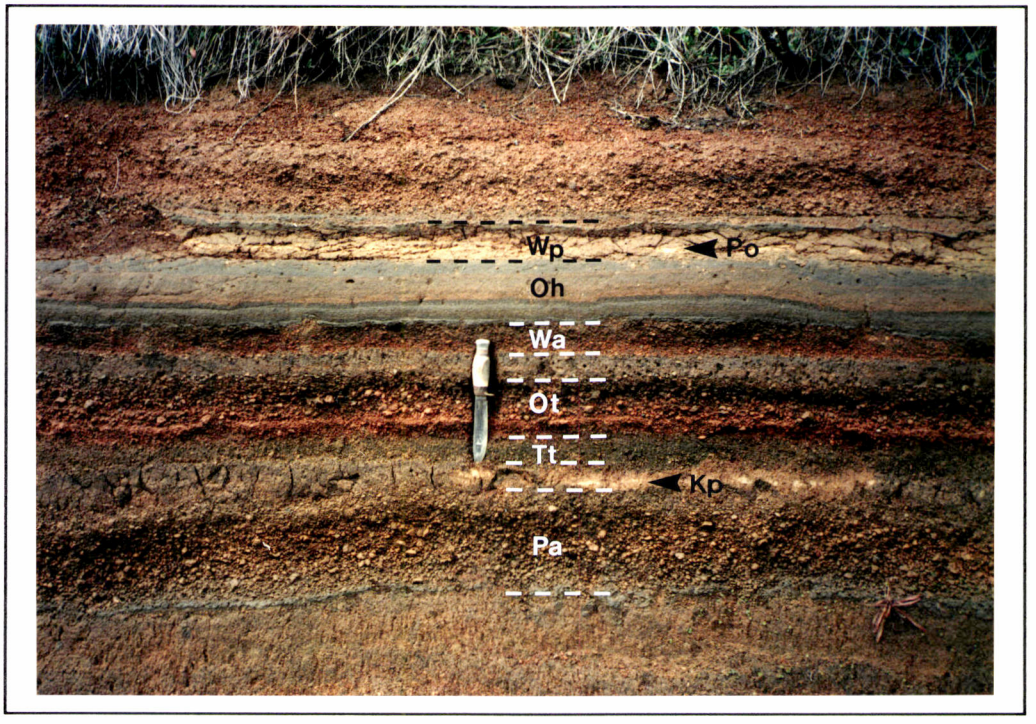


Plate 2.19 DESERT ROAD [T19/524283]
Karapiti Tephra [Kp] occurring between the dark grey Te Rato Lapilli member [Tt] of Mangamate Tephra and Pahoka Tephra [Pa]. Note position of Poronui Tephra [Po] and Mangamate Tephra members Wharepu Tephra [Wp], Ohinepango Tephra [Oh], Waihohonu Lapilli [Wa], and Oturere Lapilli [Ot].

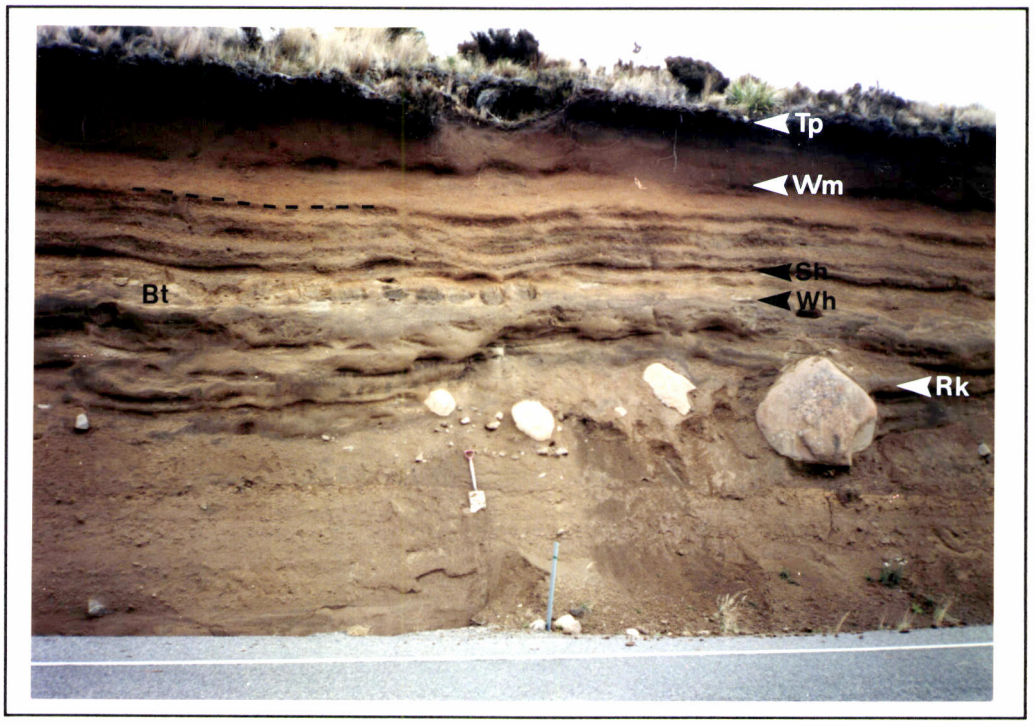


Plate 2.20 WAHIANOA AQUEDUCT S. [T20/435990]
Waiohau Tephra [Wh] interbedded with Bullot Formation tephras [Bt]. Rerewhakaaitu Tephra [Rk] overlies Te Heuheu Formation laharic deposits. Stratigraphic positions of Shawcroft Tephra [Sh], Waimihia Tephra [Wm], and Taupo Pumice [Tp] (Taupo Ignimbrite Member) are also indicated.

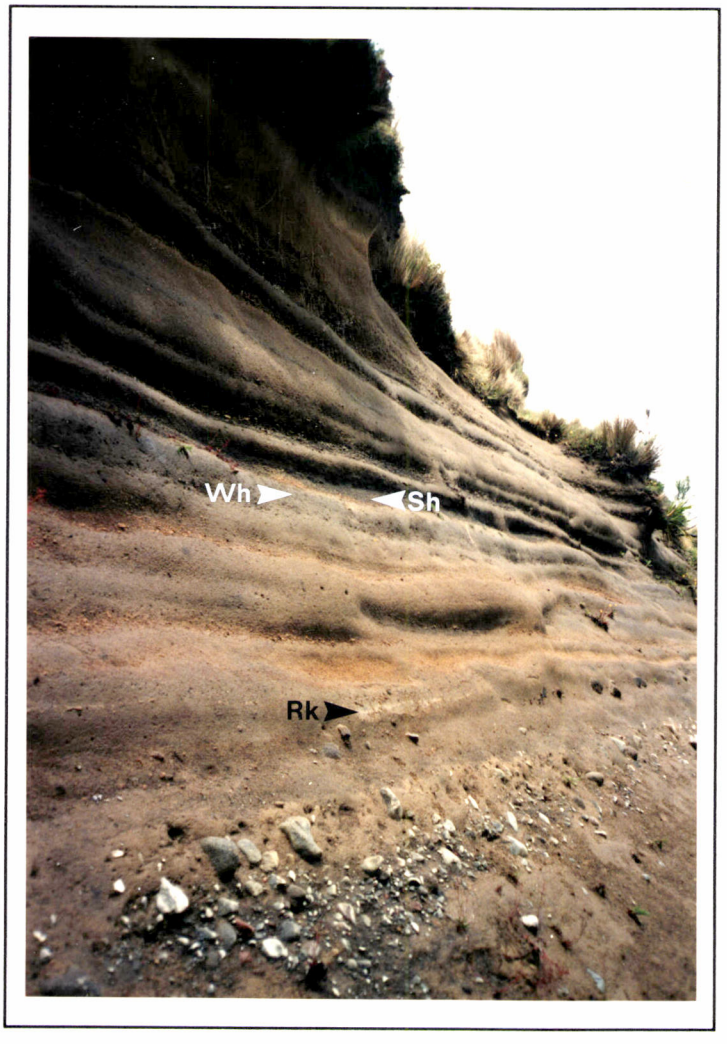


Plate 2.21
WHANGAEHU RIVER S.1 [T20/399954]
Stratigraphic positions of Waiohau Tephra [Wh] and overlying Shawcroft Tephra [Sh] are indicated. Rerewhakaaitu Tephra [Rk] is exposed near the base of the section, and overlies Te Heuheu Formation andesitic diamictons.

0.5 m

Plate 2.22
WHANGAEHU RIVER S.1 [T20/399954]
Waiohau Tephra [Wh] preserved as a pocketing white fine ash below Shawcroft Tephra [Sh] member of Bullot Formation. Note the distinctive orange base of Shawcroft Tephra.

1 m

Plate 2.23 BULLOT TRACK S.1 [T20/412108]
Okareka Tephra [Ok] interbedded between Bullot Formation members L3 (hokey pokey lapilli) and L4.

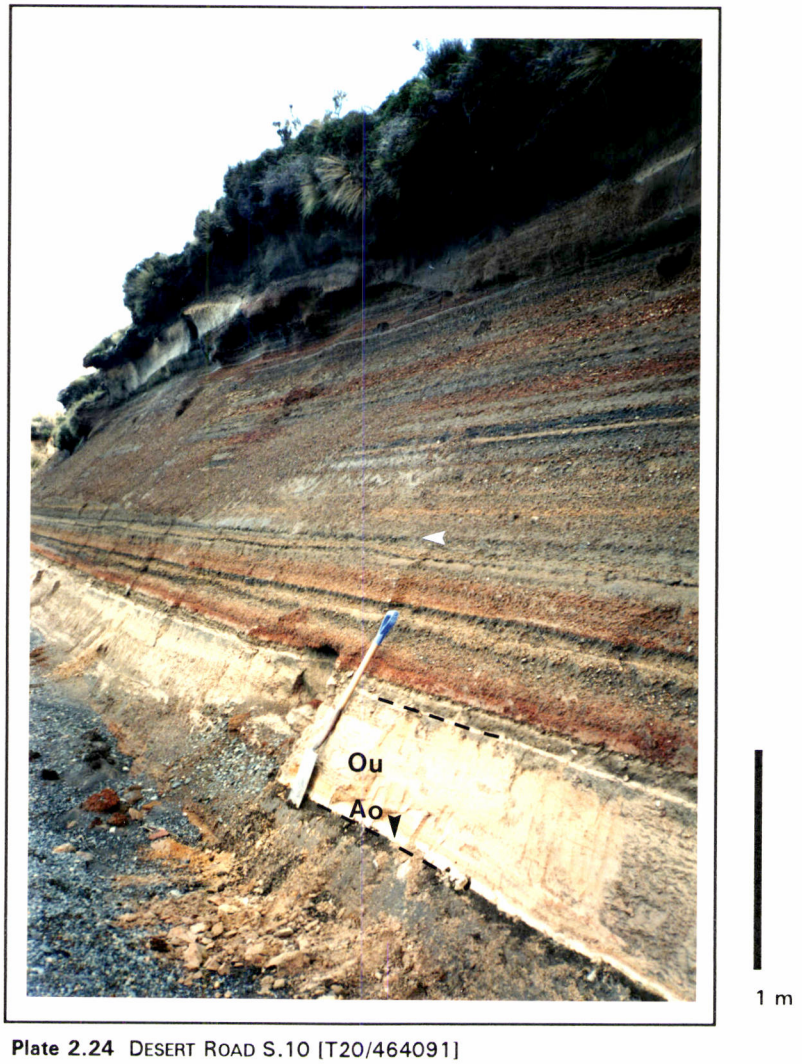


Plate 2.24 DESERT ROAD S.10 [T20/464091]
Kawakawa Tephra Formation: Oruanui Ignimbrite [Ou] and Aokautere Ash [Ao] members indicated. Bullot Formation tephras and interbedded Rerewhakaaitu Tephra [white arrow] overlie Kawakawa Tephra Formation.

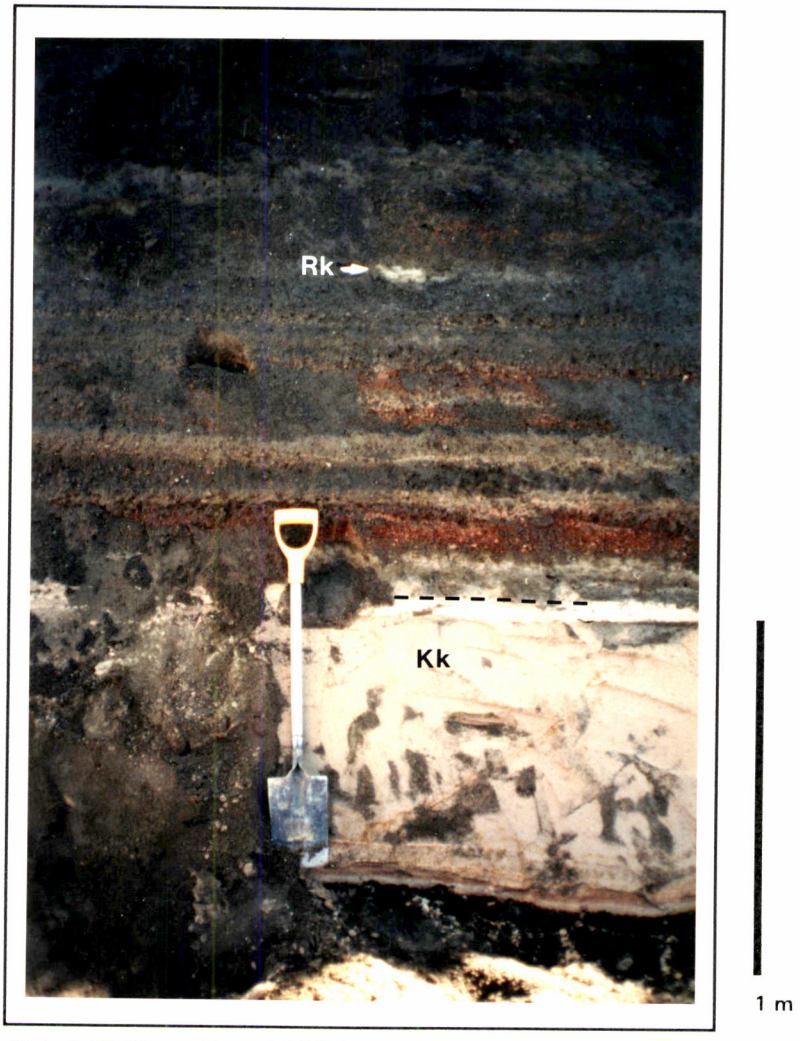


Plate 2.25 DESERT ROAD S.10 [T20/464091]
Kawakawa Tephra Formation [Kk] overlain by lower Bullot Formation tephras and interbedded Rerewhakaaitu Tephra [Rk].

1 m

Plate 2.26 WAIKATO STREAM S.2 [T20/469102]
White Kawakawa Tephra Formation infilling a pull-apart structure [white arrow] which cross-cuts tephras older than Bullot Formation member L1 [black arrow] and pre-22 500 years B.P. andesitic diamictons.

0.5 m

Plate 2.27 WAIKATO STREAM S.2 [T20/469102]
Vein of Kawakawa Tephra Formation. Lobes of ash are preserved within the vein and show original stratification of a fine white ash base overlain by a thicker grey massive unit.

Plate 3.1
TUFA TRIG S.1 [T20/378045]
Tufa Trig Formation members exposed at the type section. Stratigraphic positions of members Tf2, Tf4, Tf5, Tf6, Tf8, and Tf14 are indicated.

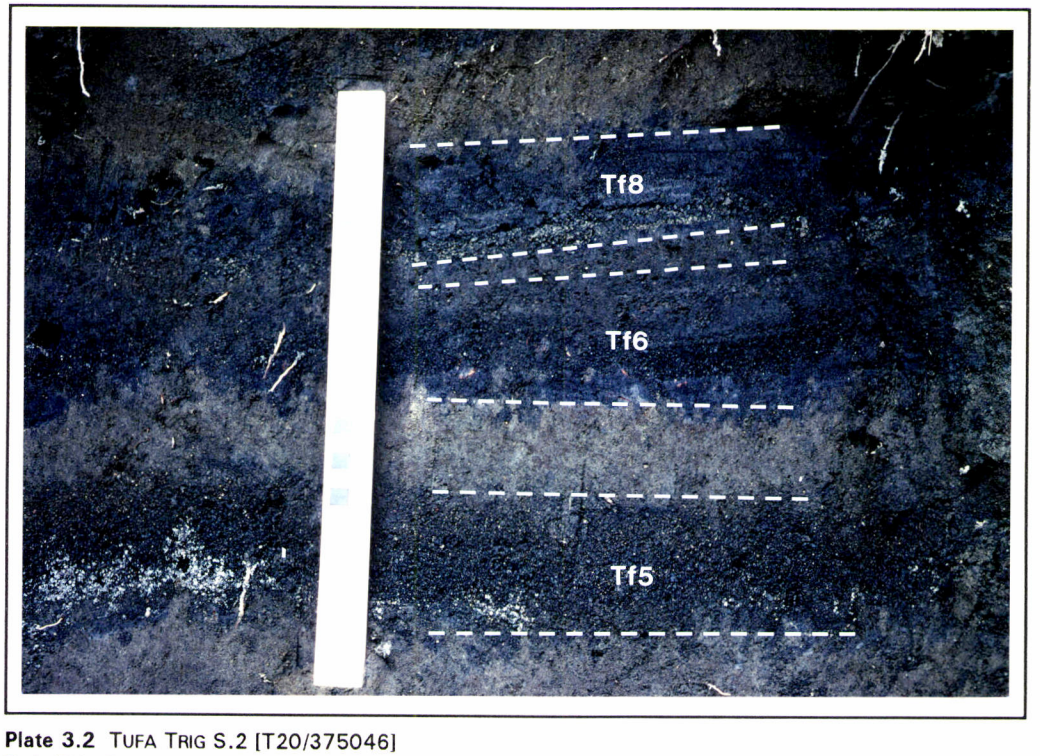
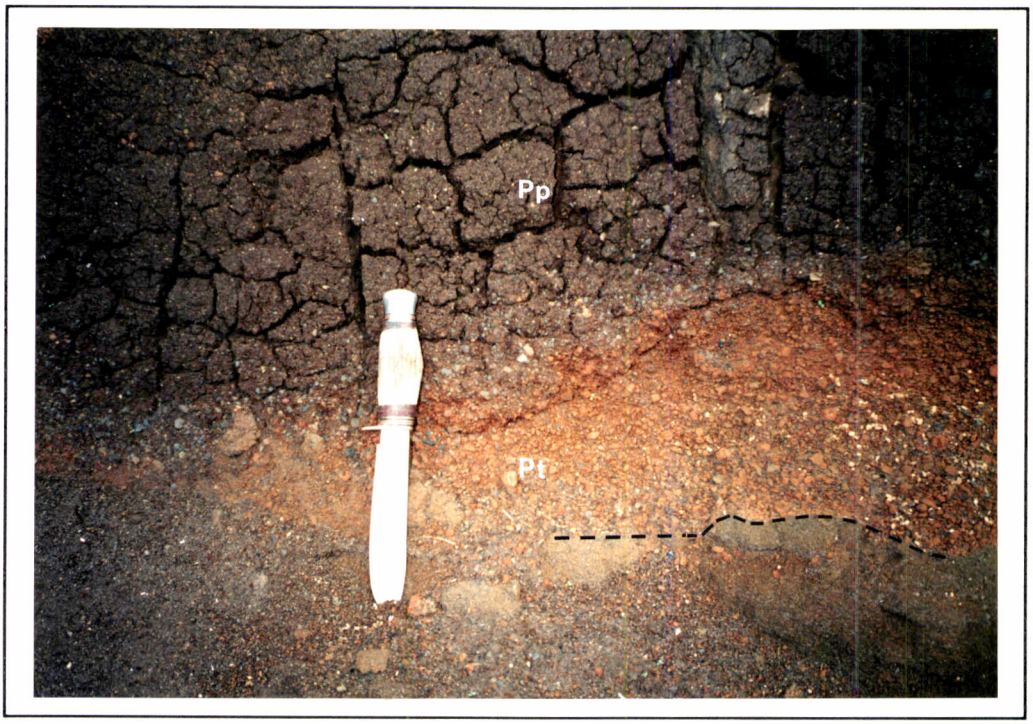


Plate 3.2 TUFA TRIG S.2 [T20/375046]
Tufa Trig Formation members Tf5, Tf6 and Tf8 are indicated. Note the olive-brown pumice-rich bed at the base of member Tf8 which distinguishes it from all other Tufa Trig Formation members, and the distinctly coarser grain size of member Tf5. Dashed lines indicate contacts between members.

Plate 3.3 TUFA TRIG S.2 [T20/375046]
Two white unnamed tephras [arrows] occur between Tufa Trig Formation members Tf3 and Tf4, and above Tufa Trig Formation member Tf8.

Plate 3.4
MANGATOETOENUI QUARRY [T20/459153]
Mangatawai Tephra [Mg] underlying Taupo Pumice [Tp] (Taupo Ignimbrite Member) and overlying Papakai Formation [Pp]. Note the dark greyish-brown paleosol developed in the top of Mangatawai Tephra. Underlying this are dark purplish-grey coarse ash beds containing beech leaves which are characteristic of the formation.

0.5 m



0.1 m

Plate 3.5 PARADISE VALLEY ROAD [T20/494046]
Papakai Formation [Pp] overlying Poutu Lapilli Member [Pt] of Mangamate Tephra. Note the distinctive surface cracking and fine bluish-grey lapilli (reworked Poutu Lapilli) scattered throughout the base of the formation.

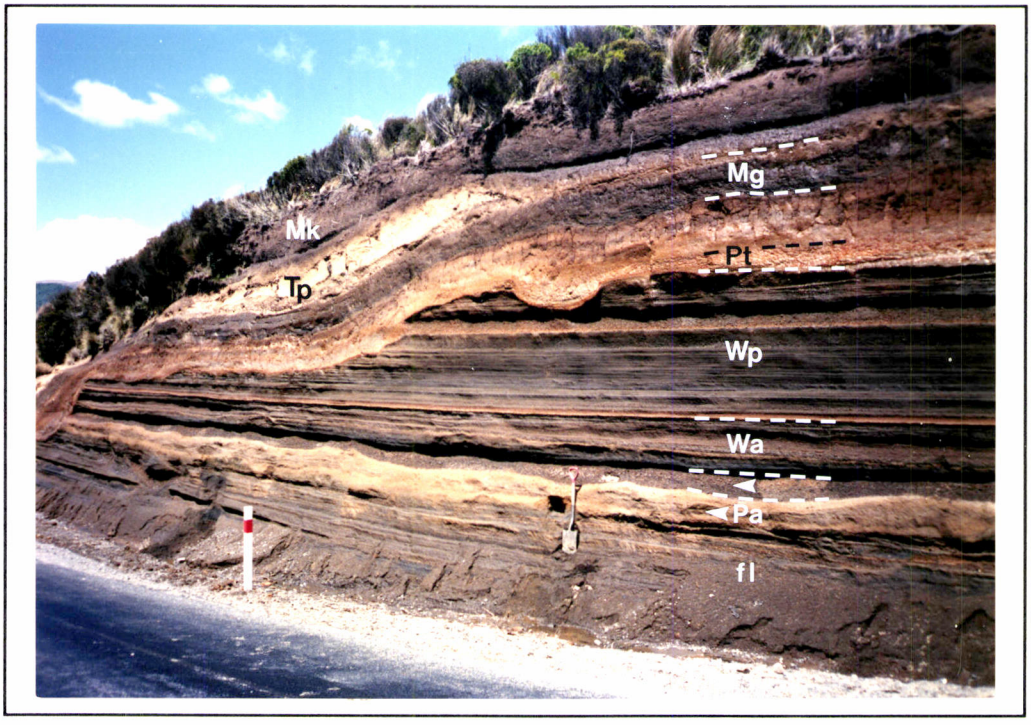


Plate 3.6 DESERT ROAD UNNAMED SECTION [T20/465099]
Note the erosional unconformity above Poutu Lapilli Member [Pt] of Mangamate Tephra. A discontinuous bed comprising reworked Poutu Lapilli, and Papakai Formation unconformably overlie older tephras (*i.e.* Wharepu Tephra [Wp], Waihohonu Lapilli [Wa], Oturere Lapilli [arrow], Pahoka Tephra [Pa]), and fluvial sediments [fl]. Mangatawai Tephra [Mg], Taupo Pumice [Tp] (Taupo Ignimbrite Member) and Makahikatoa Sands [Mk] are also indicated.

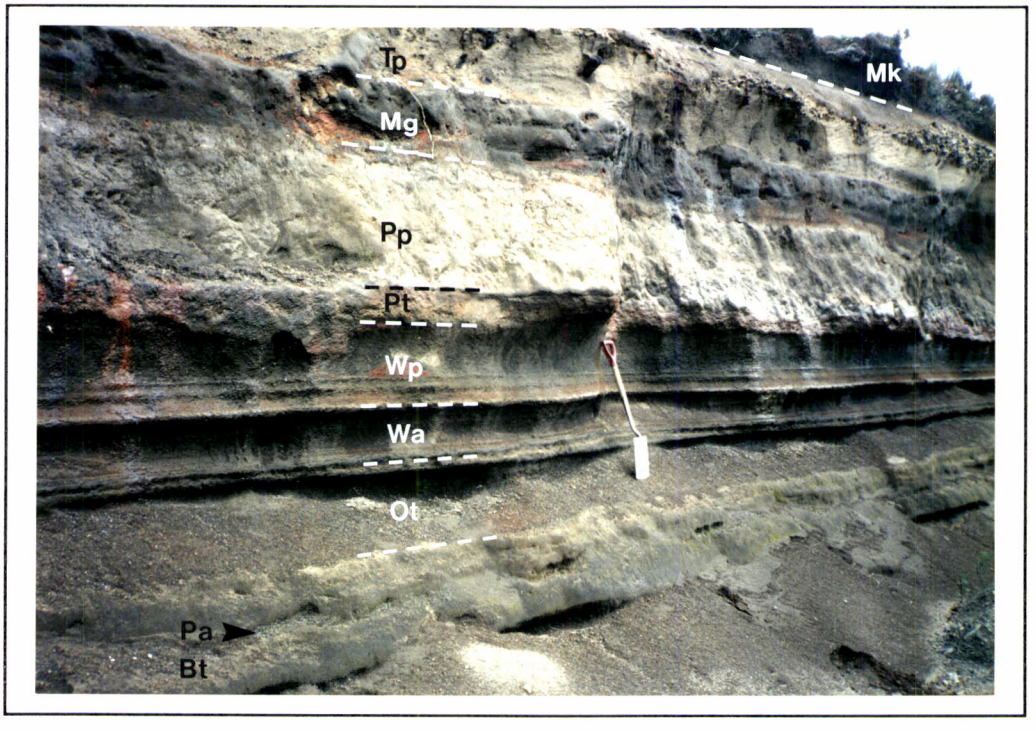


Plate 3.7 DESERT ROAD S.12 [T20/458119]
Gleyed Papakai Formation [Pp] overlies reworked Poutu Lapilli. Note Mangatawai Tephra [Mg], Taupo Pumice [Tp] (Taupo Ignimbrite Member), and Makahikatoa Sands [Mk] above Papakai Formation, and Poutu Lapilli [Pt], Wharepu Tephra [Wp], Waihohonu Lapilli [Wa] and Oturere Lapilli [Ot] members of Mangamate Tephra. Grey Pahoka Tephra [Pa], and underlying Bullot Formation tephras [Bt] are also shown.

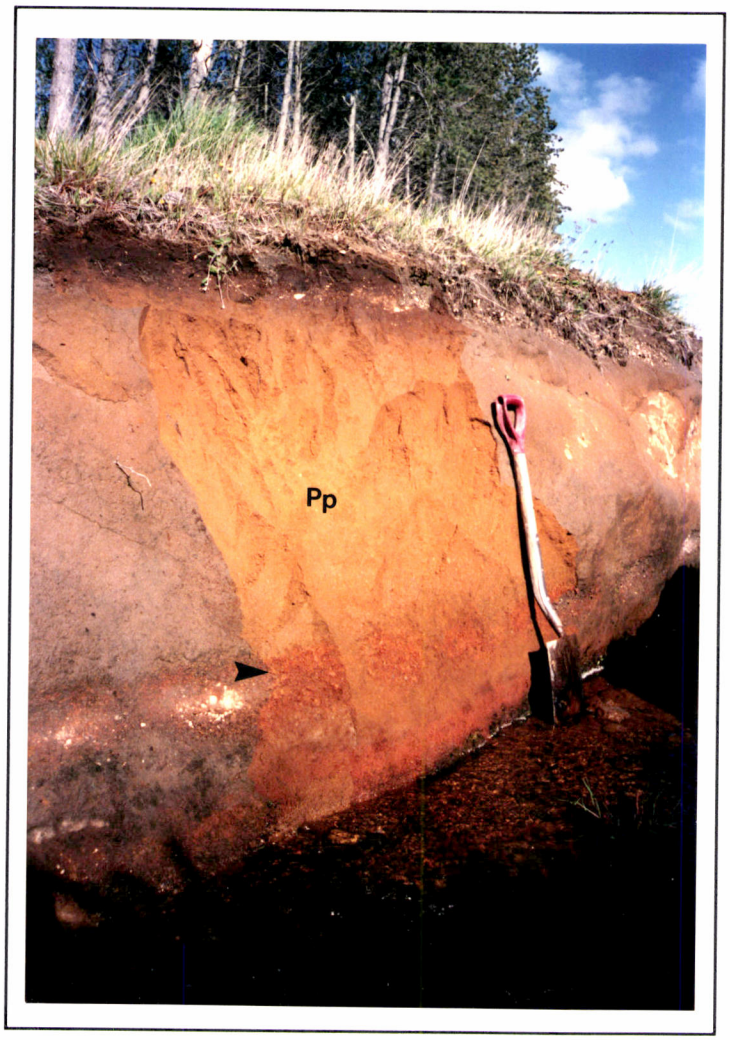


Plate 3.8
ROCK ROAD, KARIOI FOREST
[T20/322941]
Massive yellowish-brown sandy loam textured Papakai Formation [Pp] overlying Bullot Formation tephra (Ngamatea lapilli-2 member arrowed). Here Papakai Formation lacks the distinctive surface cracking seen in more northern exposures.

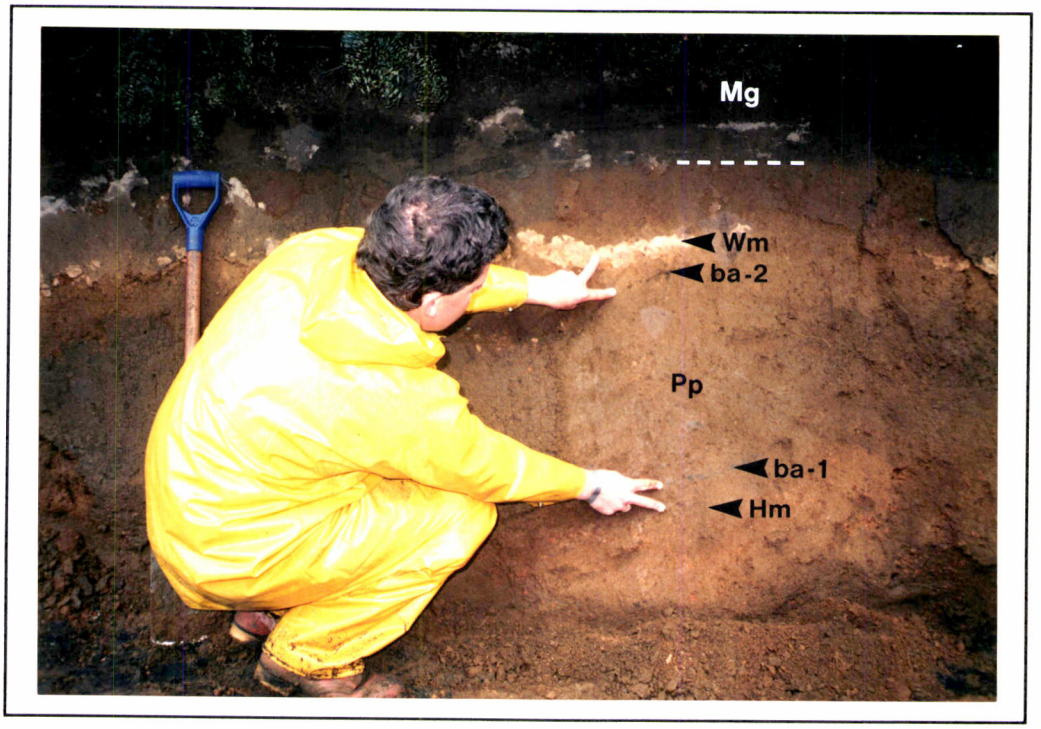


Plate 3.9 DEATH VALLEY TYPE LOCALITY
Massive yellowish-brown sandy loam textured Papakai Formation [Pp] underlying Mangatawai Tephra [Mg]. Interbedded within Papakai Formation are the rhyolitic Waimihia Tephra [Wm] and Hinemaiaia Tephra [Hm]. Note relative stratigraphic positions of black ash-1 [ba-1] and black ash-2 [ba-2] members of Papakai Formation to these rhyolitic tephras.

Plate 3.10 POUTU [T19/481325]
Type section for Poutu Lapilli Member [Pt] of Mangamate Tephra. Here Mangamate Tephra members Wharepu Tephra, Ohinepango Tephra, Waihohonu Lapilli, and Oturere Lapilli are thin and overlie the prominent basal member Te Rato Lapilli [arrow]. Note also Papakai Formation [Pp], Rotoaira Lapilli [Rt], and thin orange lapilli units occurring between Te Rato Lapilli and Rotoaira Lapilli which are correlated with Bullot Formation.

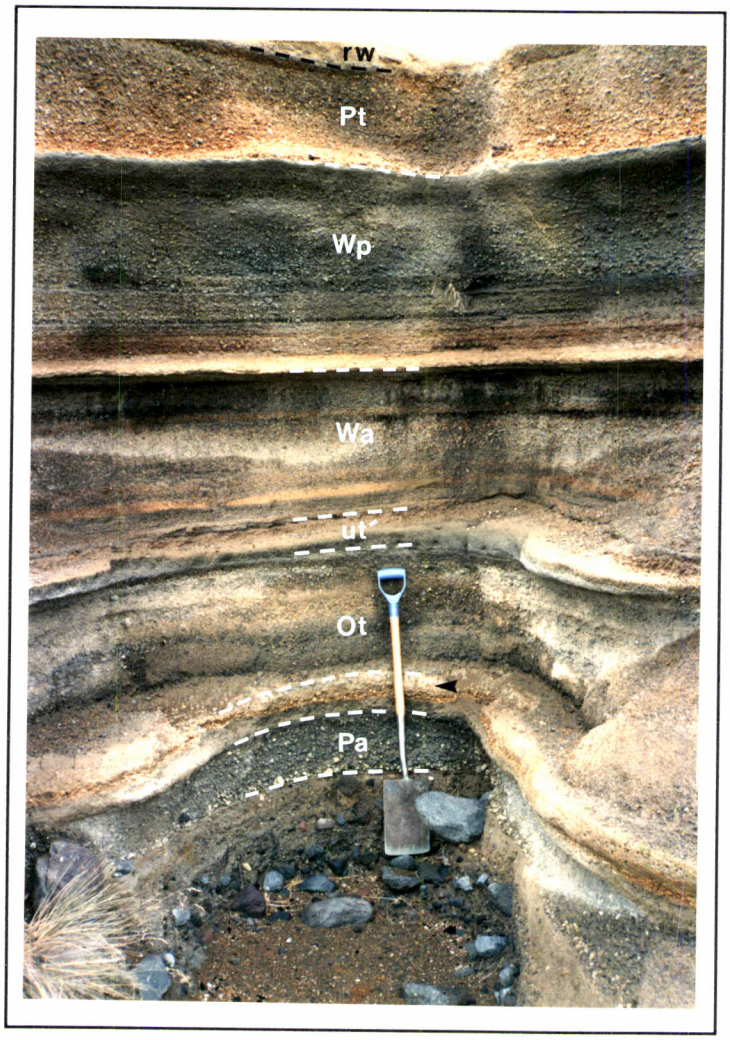


Plate 3.11
MANGATOETOENUI QUARRY [T20/459153]
Type section for Oturere Lapilli. Labelled are the Poutu Lapilli [Pt], Wharepu Tephra [Wp], Waihohonu Lapilli [Wa], unnamed tephra [ut'] and Oturere Lapilli [Ot] members of Mangamate Tephra. Also shown are reworked Poutu Lapilli [rw], and Pahoka Tephra [Pa] which overlies Tangatu Formation-aged diamictons. The position of Karapiti Tephra within unnamed tephra below Mangamate Formation is arrowed. The thin black ash immediately underlying Poutu Lapilli, the orange basal bed of Wharepu Tephra, and the orange pumice-rich beds near the base of Waihohonu Lapilli are used to identify these members.

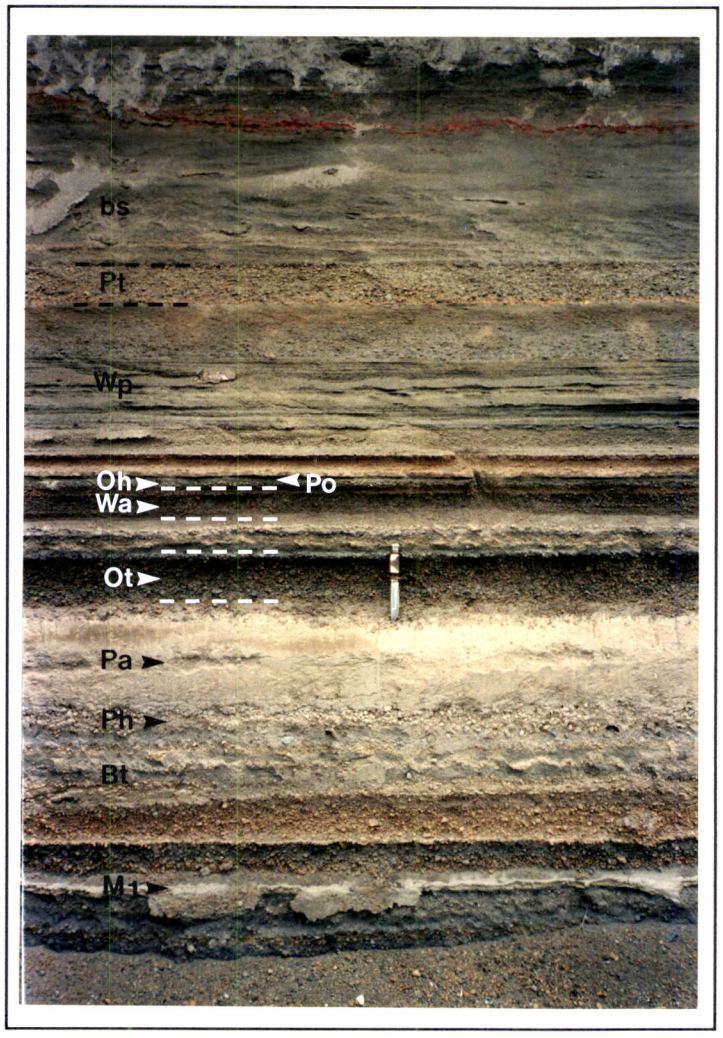


Plate 3.12
DESERT ROAD S.11 [T20/464092]
Mangamate Tephra members identified at this site are Poutu Lapilli [Pt], Wharepu Tephra [Wp], Ohinepango Tephra [Oh], Waihohonu Lapilli [Wa] and Oturere Lapilli [Ot]. Thin Poronui Tephra [Po] overlies Ohinepango Tephra. Mangamate Tephra and Papakai Formation are separated by bedded sands [bs]. Note stratigraphic positions of Pahoka Tephra [Pa] and Bullot Formation tephras [bt], including Pourahu Member [Ph] and marker ash sequence [M_1].

Plate 3.13 MANGATOETOENUI QUARRY [T20/459153]
Grey Pahoka Tephra [Pa] and overlying unnamed tephras [ut]. Note the distinctive grey and white colour-banding in the pumiceous lapilli, and the angular nature of the lapilli. Pahoka Tephra overlies Tangatu Formation-aged diamictons [Ta].

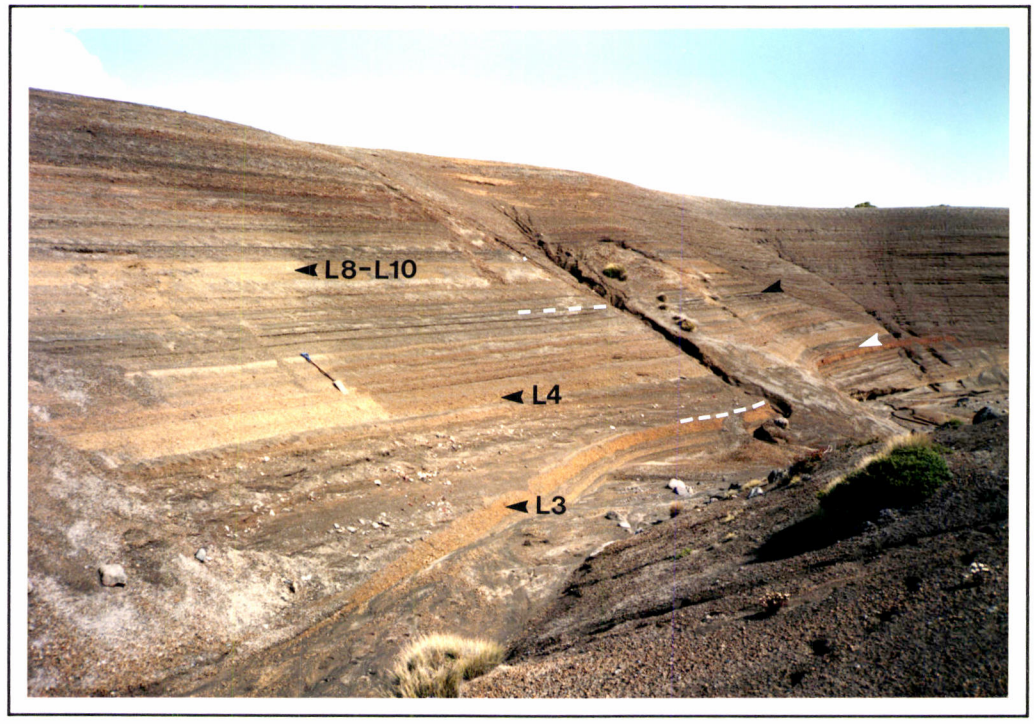


Plate 3.14 BULLOT TRACK S.1 [T20/412108]
Type section for Bullot Formation. Approximate boundaries of upper, middle and lower Bullot Formation units are indicated by dashed lines. Note stratigraphic positions of Okareka Tephra [white arrow], Rerewhakaaitu Tephra [black arrow], and the prominent Bullot Formation members L3, L4, L8–10. Kawakawa Tephra Formation, although not shown, is exposed at the base of this section, just to the right of the photograph.

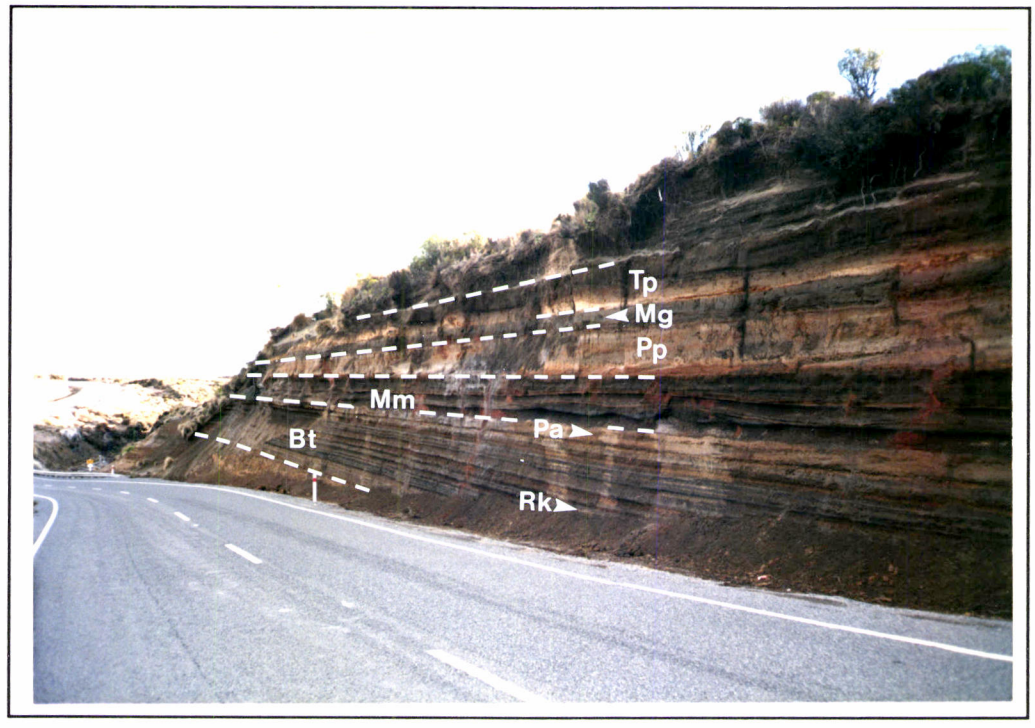


Plate 3.15 WAIKATO STREAM S.1 [T20/467102]
At this site, horizontally bedded Bullot Formation tephras [Bt] underlie Pahoka Tephra [Pa] and overlie andesitic diamictons of the Te Heuheu Formation (exposed at base of section). Note stratigraphic positions of Rerewhakaaitu Tephra [Rk], Mangamate Tephra [Mm], Papakai Formation [Pp], Mangatawai Tephra [Mg], Taupo Pumice [Tp] (Taupo Ignimbrite Member), and overlying interbedded Makahikatoa Sands and Tufa Trig Formation tephras.

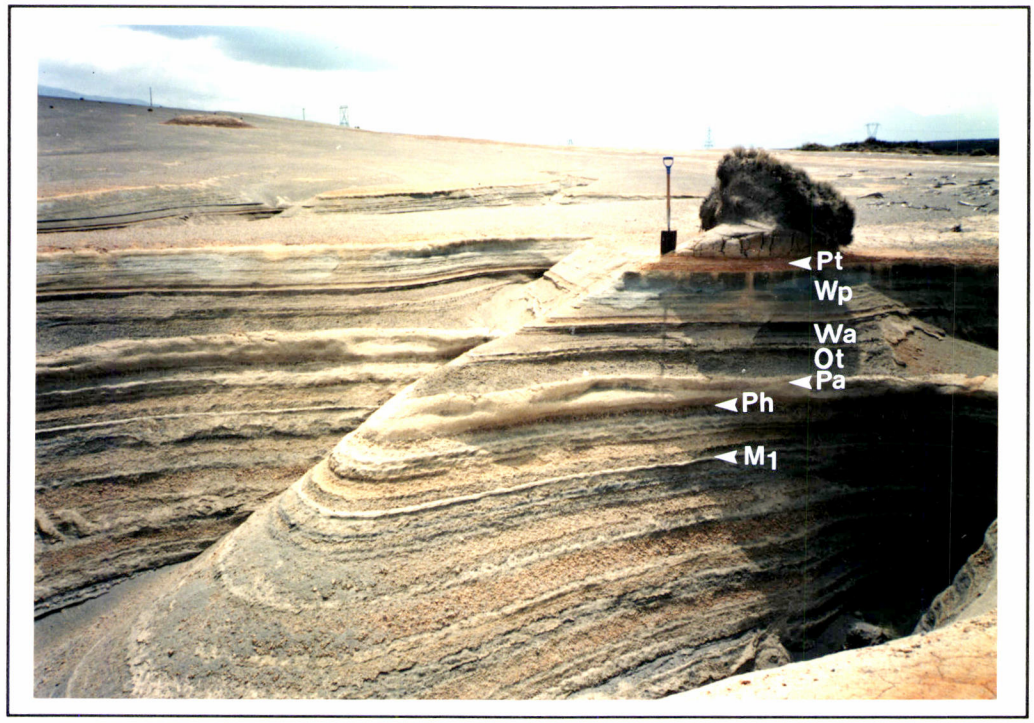


Plate 3.16 T20/463101]
Bullot Formation tephras exposed below Pahoka Tephra [Pa]. Note Pourahu Member [Ph] and marker ash sequence [M_1]. Above Pahoka Tephra are Mangamate Tephra members Poutu Lapilli [Pt], Wharepu Tephra [Wp], Waihohonu Lapilli [Wa], and Oturere Lapilli [Ot]. Note the tussock clad eroded remnant of Papakai Formation.

Plate 3.17 DESERT ROAD S.11 [T20/464092]
Upper Bullot Formation tephras [Bt] exposed below Mangamate Tephra [Mm] and bedded sands [bs]. Marker ash sequence [M_1] is arrowed. Also shown are Papakai Formation [Pp], Mangatawai Tephra [Mg], Taupo Pumice [Tp] (Taupo Ignimbrite Member), and overlying interbedded Makahikatoa Sands and Tufa Trig Formation tephras.

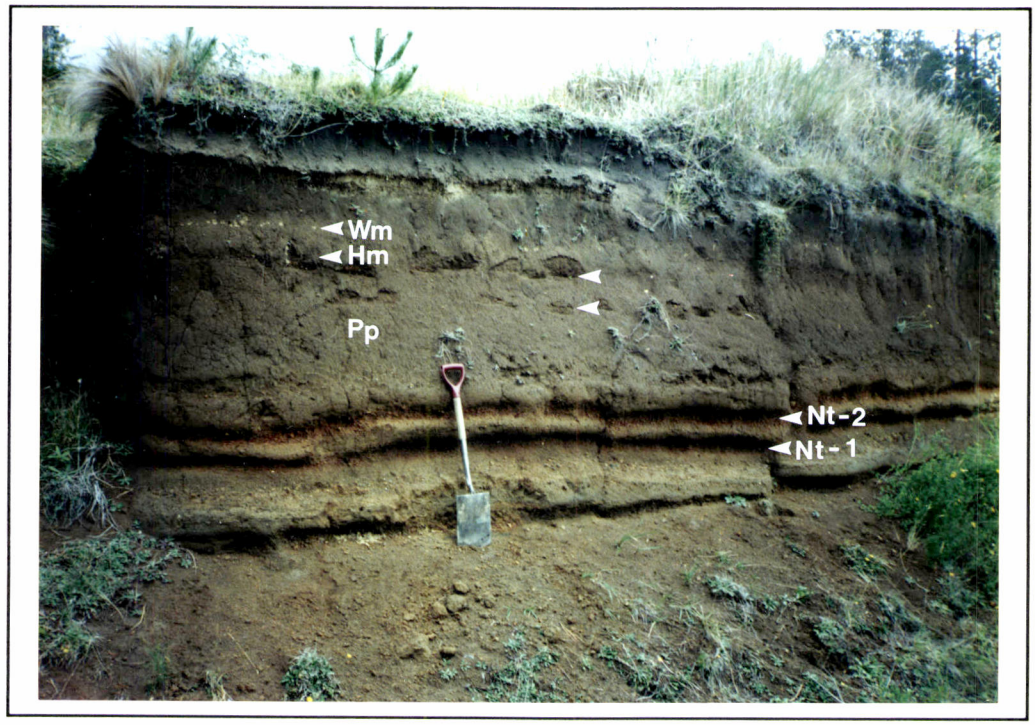


Plate 3.18 WAHIANOA ROAD S.1 [T20/391986]
Ngamatea lapilli-1 [Nt-1] and Ngamatea lapilli-2 [Nt-2] of upper Bullot Formation overlying older unnamed Bullot Formation tephras. Note the stratigraphic positions of the rhyolitic Waimihia Tephra [Wm], which occurs as 'cream cakes', and Hinemaiaia Tephra [Hm], which are interbedded within Papakai Formation [Pp]. The positions of orange lapilli-1 and orange lapilli-2 members of Papakai Formation are indicated by arrows.

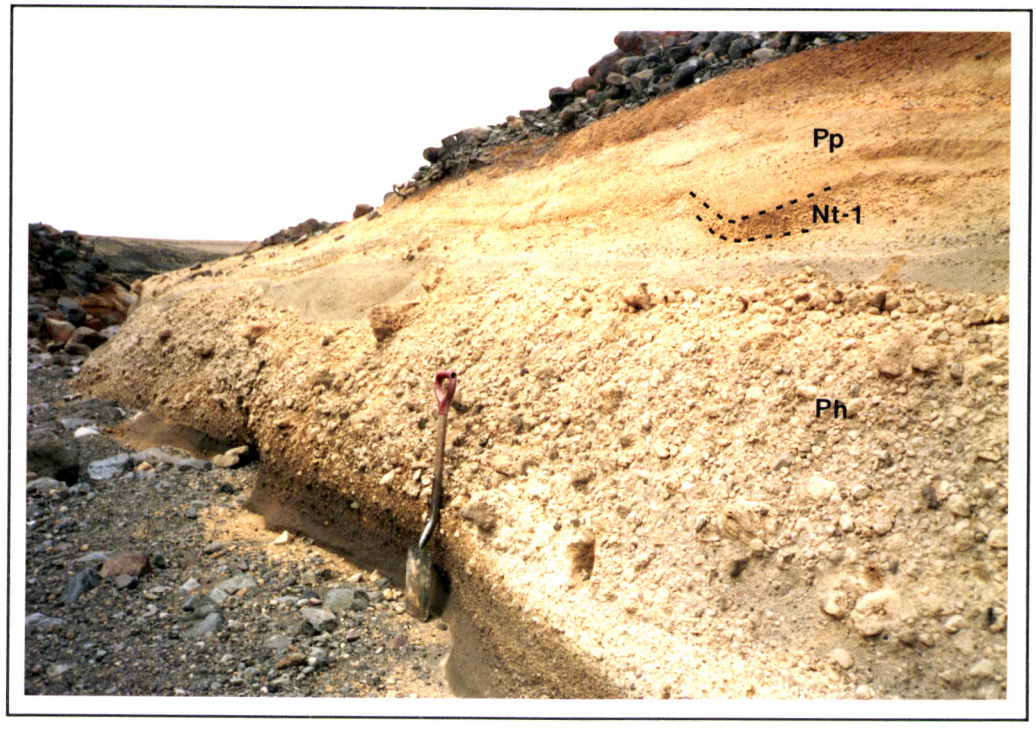


Plate 3.19 THE CHUTE S.3 [T20/437045]
Pourahu Member [ignimbrite unit] [Ph] comprising white pumice lapilli, blocks and bombs, and black scoria in a poorly sorted ash matrix. Note the overlying and discontinuous grey Tangatu Formation hyperconcentrated flood flow deposits and Ngamatea lapilli-1 [Nt-1] member of Bullot Formation. Also shown is Papakai Formation [Pp] which is unconformably overlain by Onetapu Formation debris flow deposits.

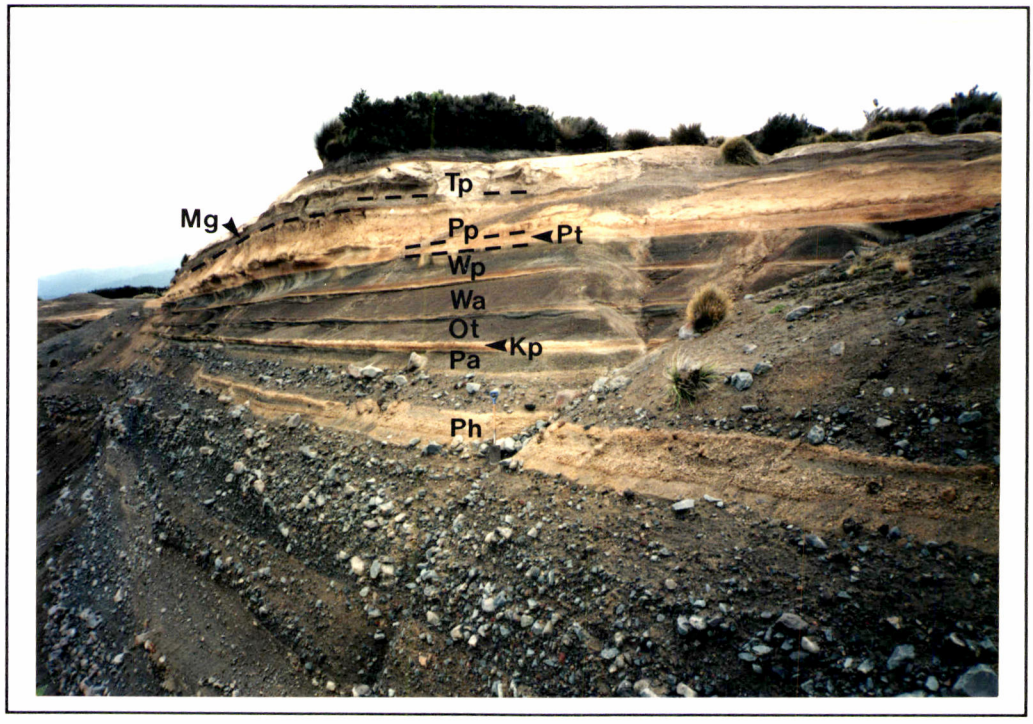


Plate 3.20 MANGATOETOENUI QUARRY [T20/459153]
Pourahu Member [Ph] interbedded with Tangatu Formation-aged debris flow deposits. Also shown are Taupo Pumice [Tp] (Taupo Ignimbrite Member), Mangatawai Tephra [Mg], Papakai Formation [Pp], Mangamate Tephra members (Poutu Lapilli [Pt], Wharepu Tephra [Wp], Waihohonu Lapilli [Wa], Oturere Lapilli [Ot]), and Pahoka Tephra [Pa]. The arrow indicates stratigraphic position of the rhyolitic Karapiti Tephra [Kp] within unnamed tephra.

Plate 3.21 THE CHUTE TYPE LOCALITY
Breadcrusted pumice bomb of the Pourahu Member found embedded within an andesitic diamicton of Tangatu Formation.

Plate 3.22 WHANGAEHU RIVER S.1 [T20/399954]
Upper Bullot Formation tephras found capping Te Heuheu Formation diamictons on the Whangaehu escarpment. Shown are Shawcroft Tephra Member [Sh], with its distinctive strong brown pumice-rich base, and the stratigraphic position of Waiohau Tephra [Wh].

Plate 3.23 HELWAN QUARRY [T20/408921]
Shawcroft Tephra Member of Bullot Formation [Sh] overlying a medial unit with interbedded Waiohau Tephra (position arrowed). Note the black lithic-rich top and distinctive strong brown pumice-rich base of Shawcroft Tephra.

Plate 3.24 RANGIPO DESERT
Eroded surfaces of Bullot Formation exposed at Missile Ridge in northwestern Rangipo Desert. Vegetated surfaces identify areas where the cover bed tephras (Papakai Formation, Mangatawai Tephra, Taupo Pumice, Tufa Trig Formation) and Makahikatoa Sands are preserved. Missile Ridge Dune [MRD] (reference section for Tufa Trig Formation) is marked. The stratigraphic position of Waiohau Tephra [Wh] within the upper Bullot Formation tephra sequence is indicated.

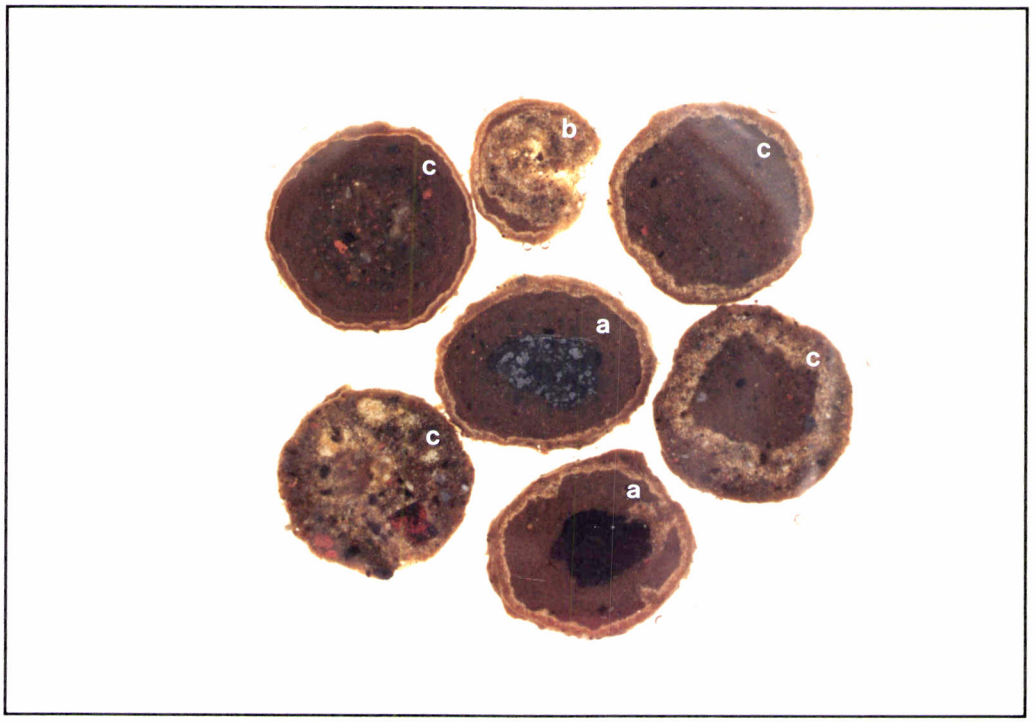


Plate 4.1 ACCRETIONARY LAPILLI
Cross sections of accretionary lapilli found in Mt Ruapehu tephra members L16 and L17: (a) armoured lapilli (b) rim-type (R-type) lapilli (c) core-type (C-type) lapilli.

Plate 4.2a

Plate 4.2b

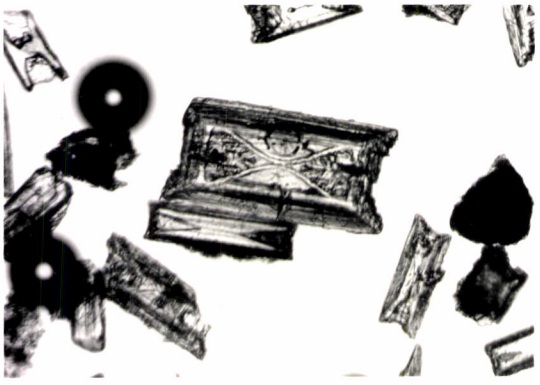


Plate 4.2c

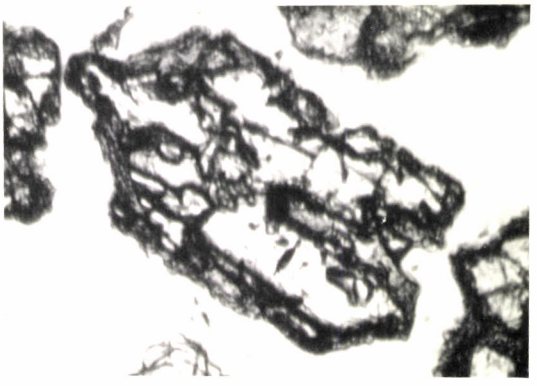


Plate 4.2d

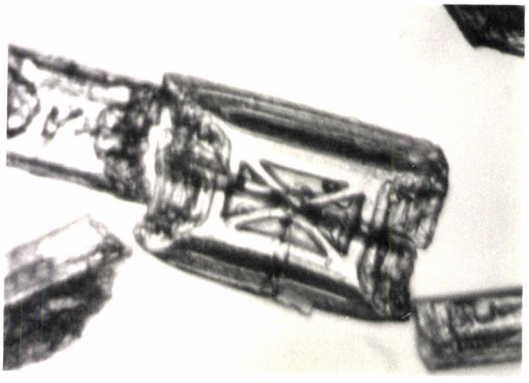


Plate 4.2e

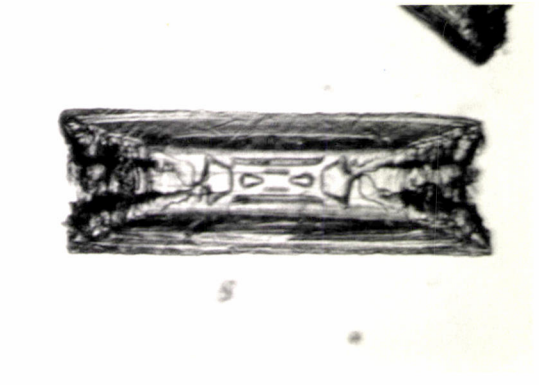


Plate 4.2f

Plate 4.2a Non-skeletal type [I] olivines. 0.250 – 0.500 mm fraction, thin section, Waihohonu Lapilli.

Plate 4.2b Skeletal type [II] olivines. Primitive skeletal habit of Drever and Johnston (1957) and skeletal hopper olivine morphology of Donaldson (1976). 0.125 – 0.250 mm fraction, thin section, Waihohonu Lapilli.

Plate 4.2c Skeletal hopper and H-shaped chain olivines of Donaldson (1976). 0.063 – 0.125 mm fraction, grain mount, Poutu Lapilli.

Plate 4.2d Skeletal lantern and chain habit of Fleet (1975). 0.125 – 0.250 mm fraction, thin section, Waihohonu Lapilli.

Plate 4.2e Skeletal olivine: showing stepped terminations and centrally located glass inclusions. 0.063 – 0.125 mm fraction, grain mount, Poutu Lapilli.

Plate 4.2f Skeletal olivine: showing stepped terminations and centrally located glass inclusions. 0.063 – 0.125 mm fraction, grain mount, Oturere Lapilli.

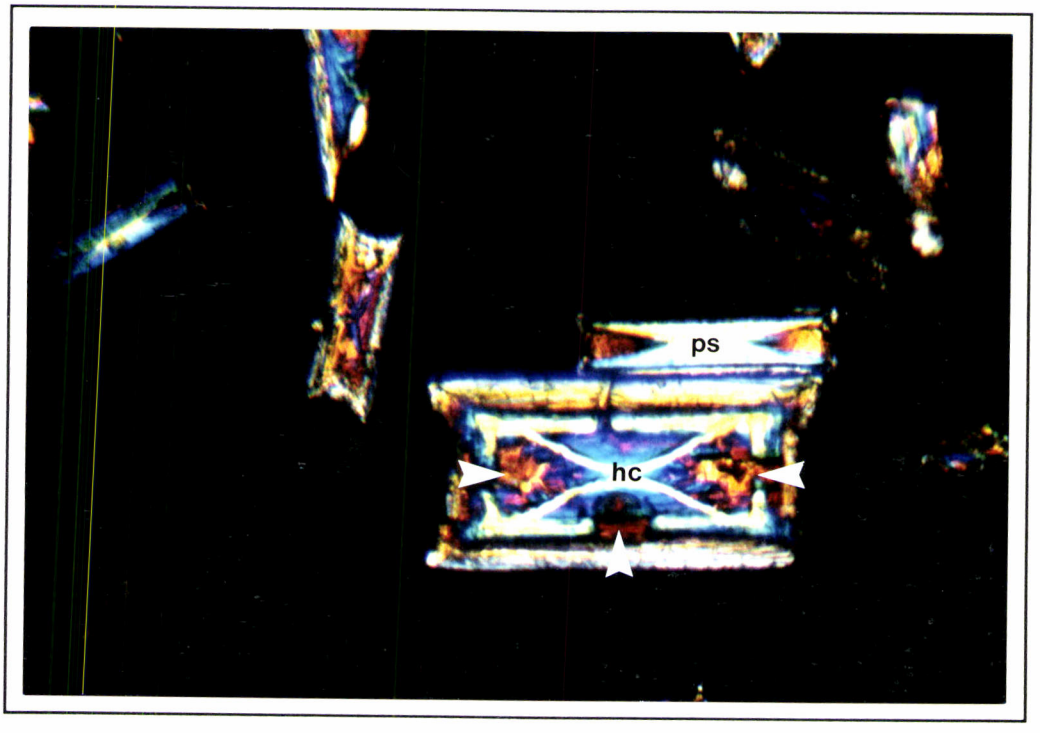


Plate 4.3 SKELETAL OLIVINES
Grain mount (0.063 – 0.125 mm fraction) of skeletal type [II] olivines showing primitive skeletal habit [ps] and H-shaped chain morphology [hc] of Donaldson (1976). Inclusions of brown glass within the olivines are arrowed.

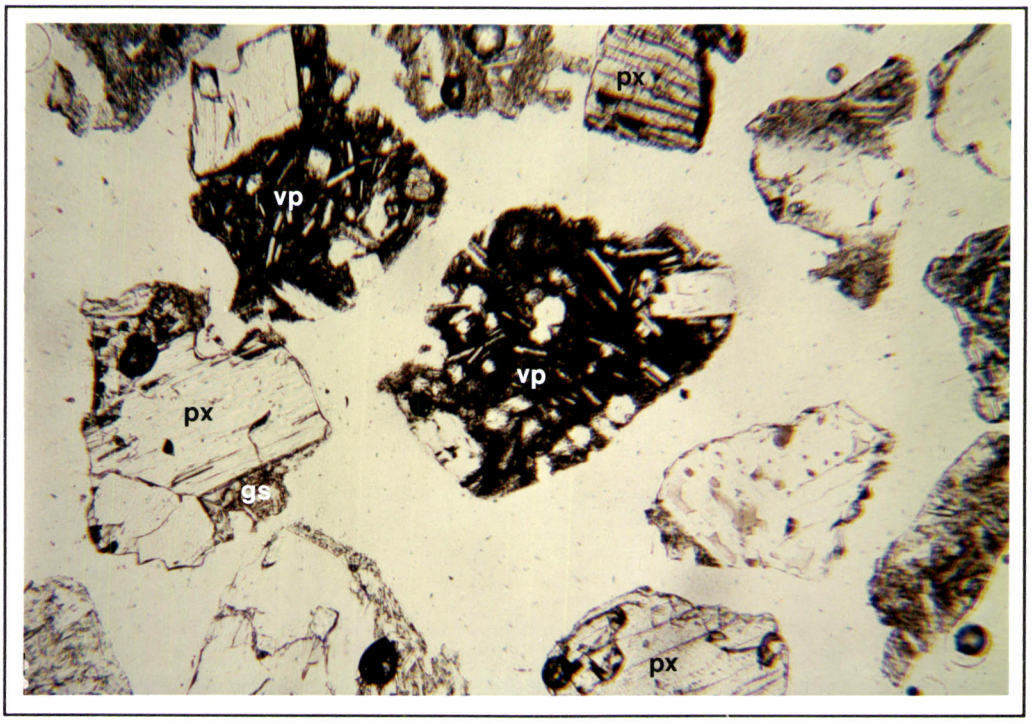


Plate 4.4a

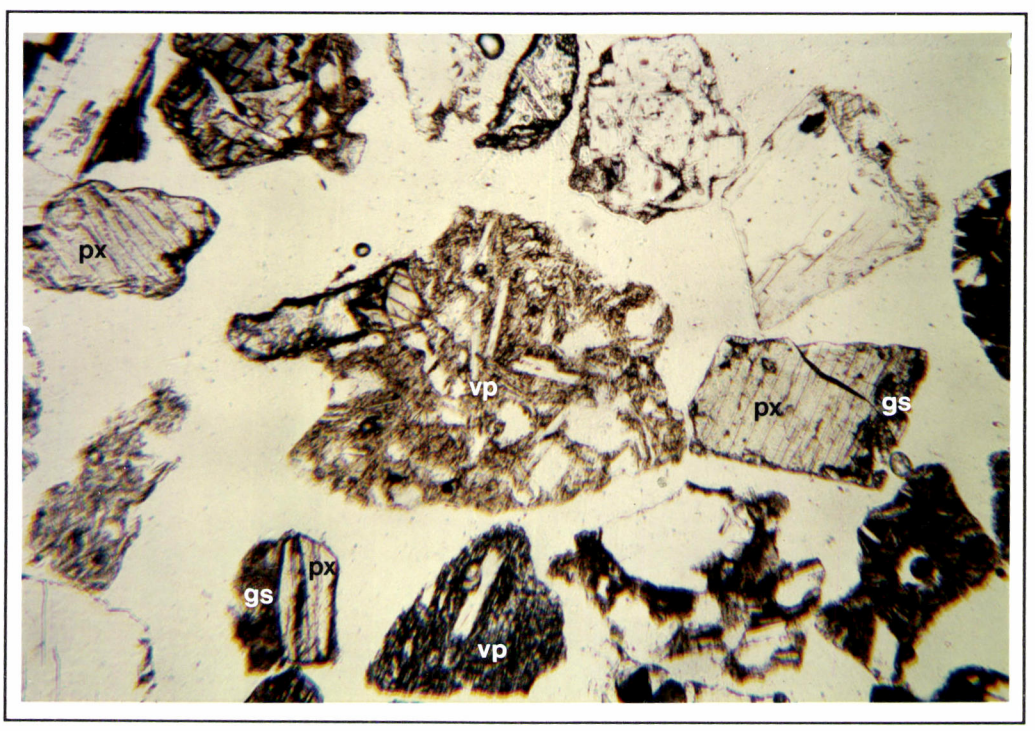


Plate 4.4b

Plates 4.4a & 4.4b VITRIC PYROCLASTS: TUFA TRIG FORMATION TEPHRAS
Thin sections showing poorly-vesicular vitric pyroclasts [vp] (0.250 – 0.500 mm fraction) with included euhedral and subhedral crystals of feldspar and pyroxene. Also shown are phenocrysts of pyroxene [px] with glassy selvedges [gs].

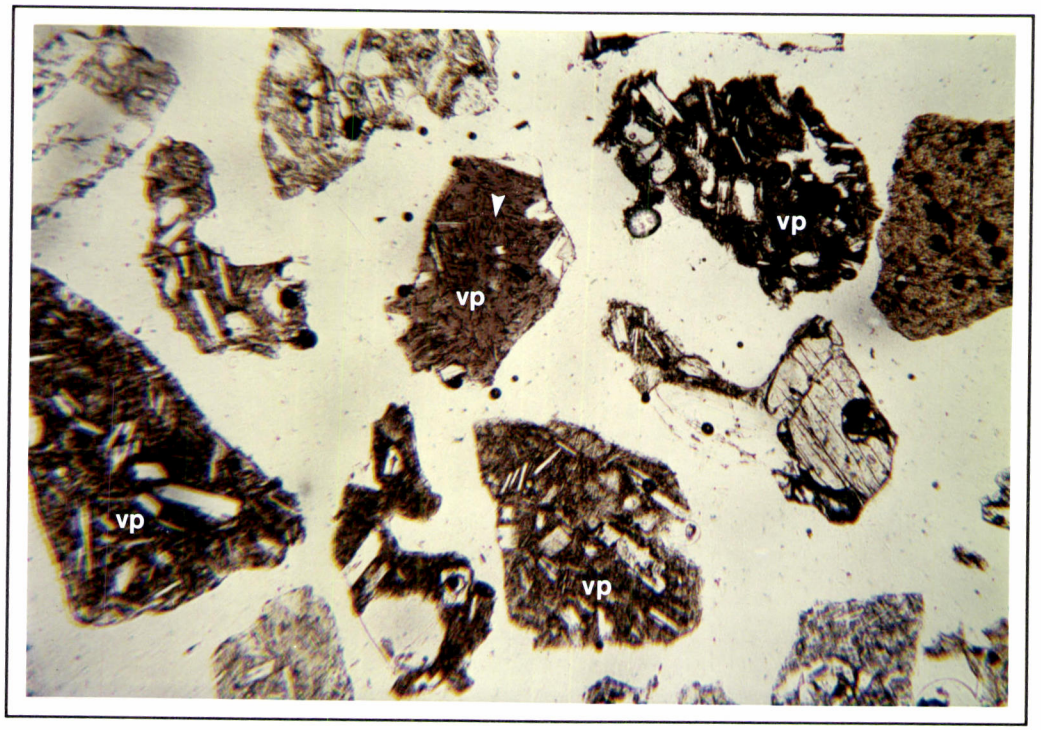


Plate 4.4c

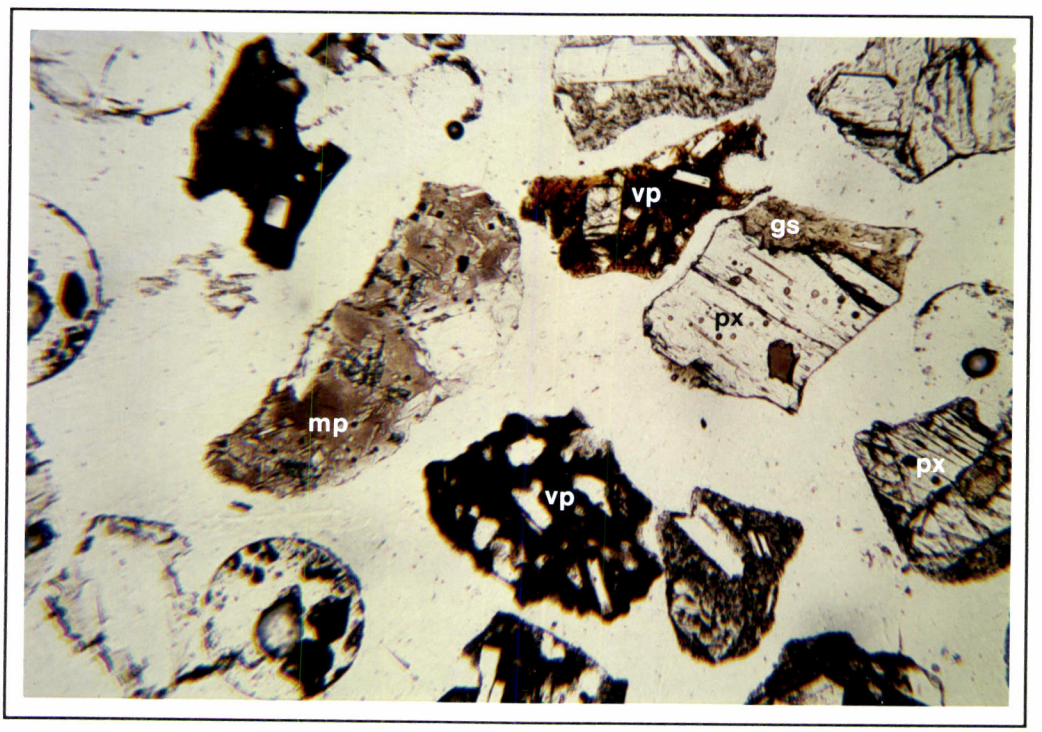


Plate 4.4d

Plates 4.4c & 4.4d VITRIC PYROCLASTS: TUFA TRIG FORMATION TEPHRAS
Thin sections showing poorly-vesicular vitric pyroclasts [vp] (0.250 – 0.500 mm fraction) with included euhedral and subhedral crystals of feldspar and pyroxene. While most pyroclasts contain abundant and obvious microlites [arrow], a few are microlite-poor [mp]. Also shown are phenocrysts of pyroxene [px] with glassy selvedges [gs].

Plate 4.5 COLOUR-BANDED LAPILLI
Pumice lapilli from Pourahu Member [ignimbrite unit] showing non-banded white phenocryst-rich pumice lapilli [a] with rhyolitic glass composition, and sections through a colour-banded phenocryst-rich lapilli [b,c] with dacitic to rhyolitic glass compositions. B1 – B7 identify colour bands, with the glass chemistry of bands B2, B5 and B7 analysed by electron microprobe *(see text)*.

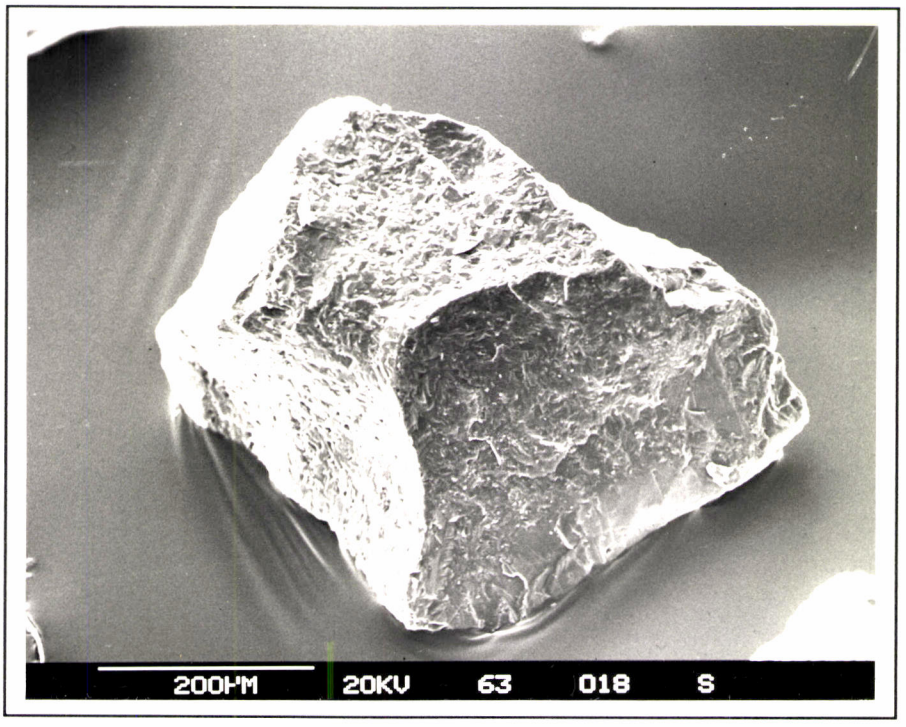


Plate 4.6a Magnification 149x.

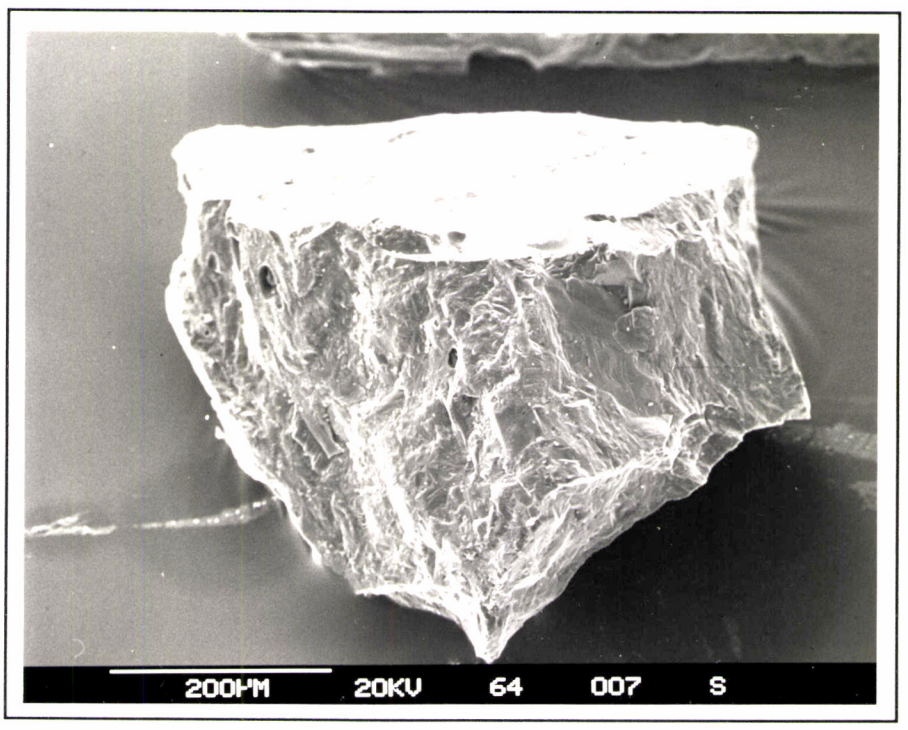


Plate 4.6b Magnification 145x.

Plates 4.6a & 4.6b VITRIC PYROCLAST MORPHOLOGY
Type-1 blocky equant shapes of brown (Plate 4.6a) and black (Plate 4.6b) poorly-vesicular vitric pyroclasts of Tufa Trig Formation tephras.

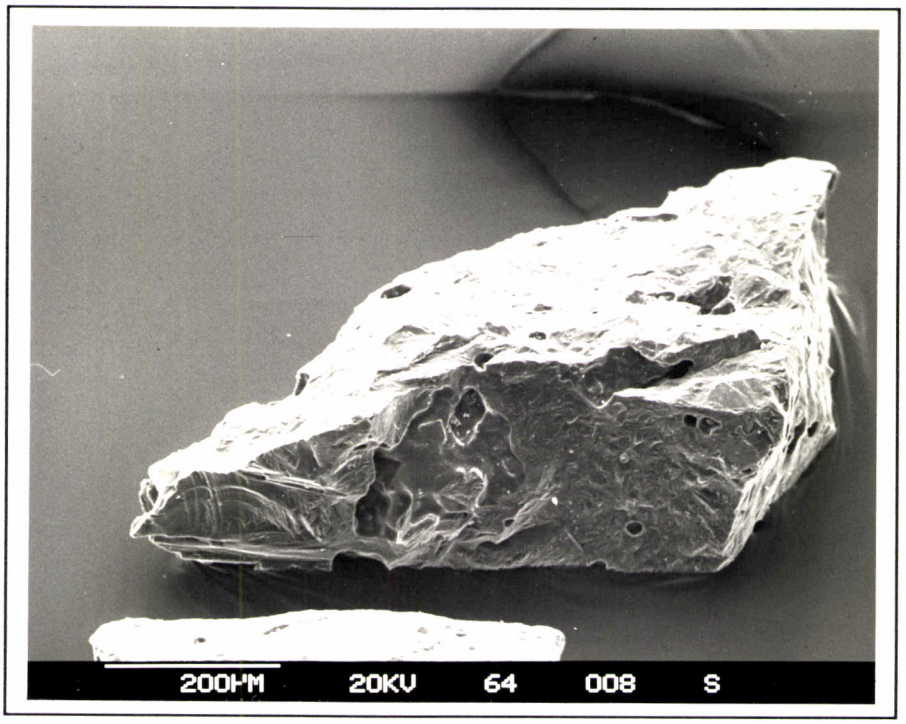


Plate 4.7 VITRIC PYROCLAST MORPHOLOGY
Type-1 blocky equant brown poorly-vesicular vitric pyroclast showing conchoidal facial fracture. Magnification 117x.

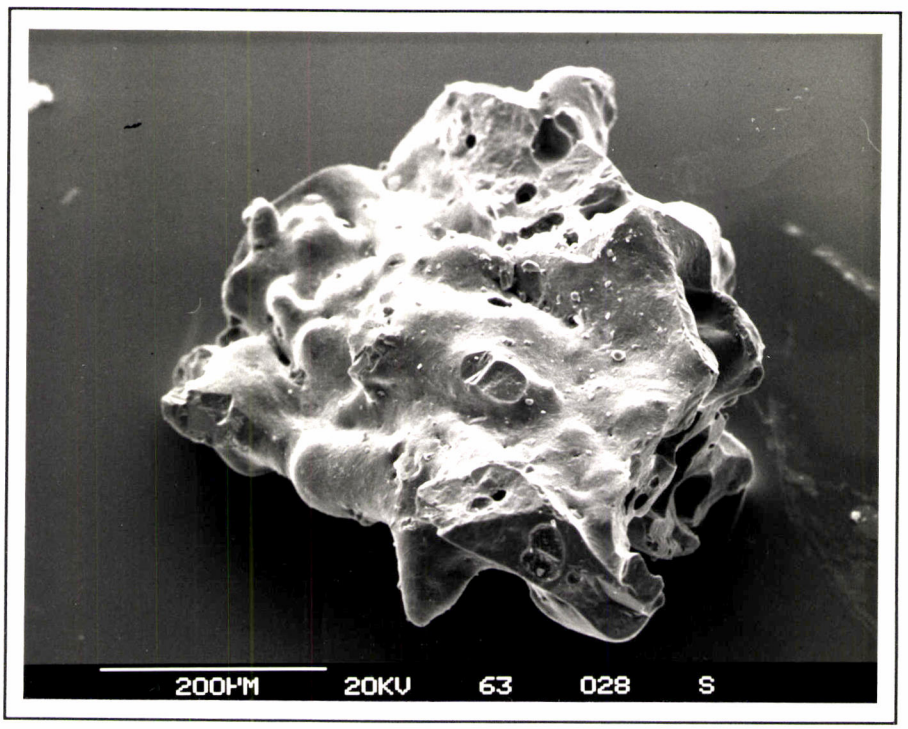


Plate 4.8 VITRIC PYROCLAST MORPHOLOGY
Black vitric pyroclast showing type-2 irregular shaped habit with rounded fluid-formed surfaces. Magnification 153x.

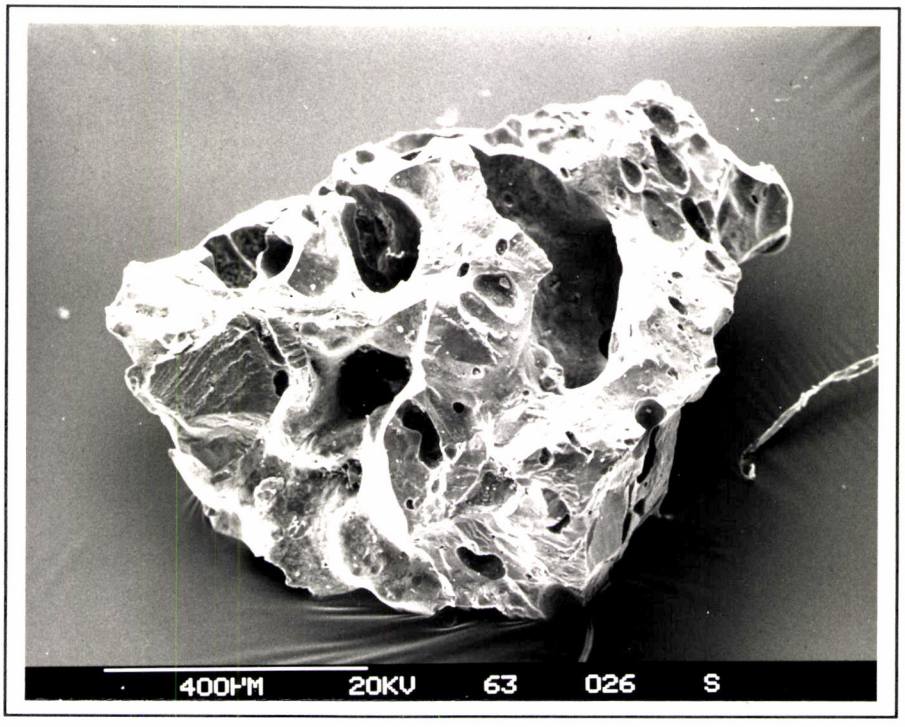


Plate 4.9a Magnification 88x.

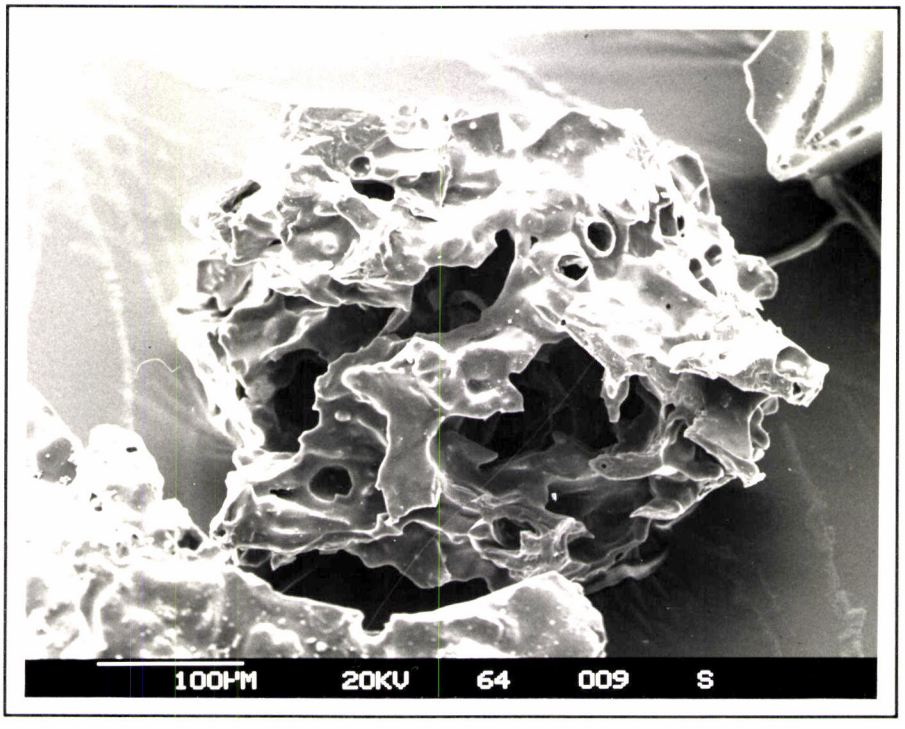


Plate 4.9b Magnification 180x.

Plates 4.9a & 4.9b VITRIC PYROCLAST MORPHOLOGY
Vesicular black (Plate 4.9a) and brown (Plate 4.9b) vitric pyroclasts.

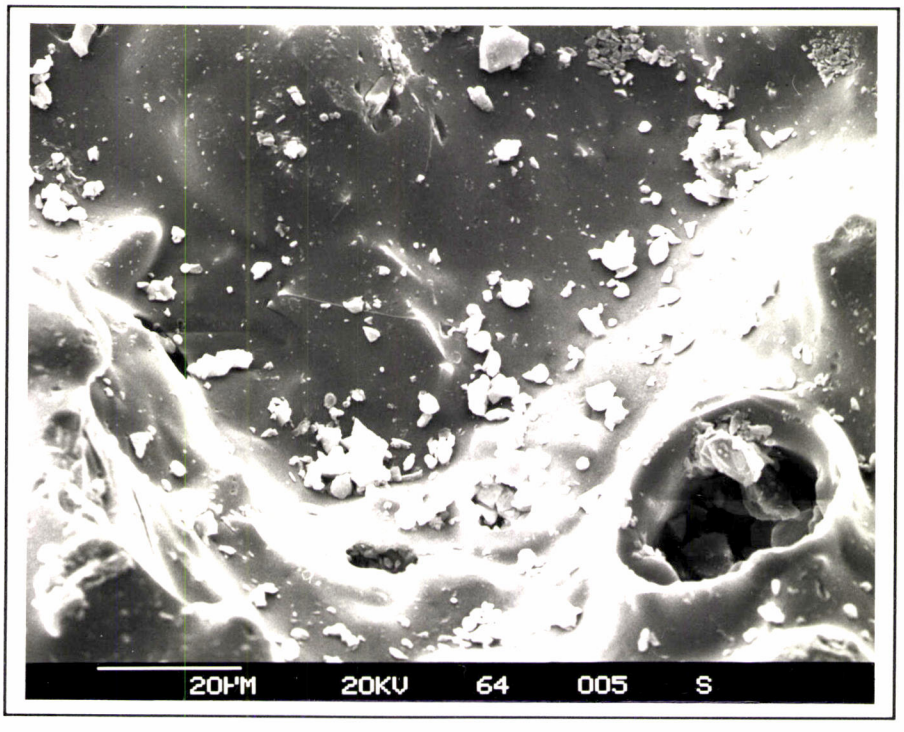


Plate 4.10a Magnification 960x.

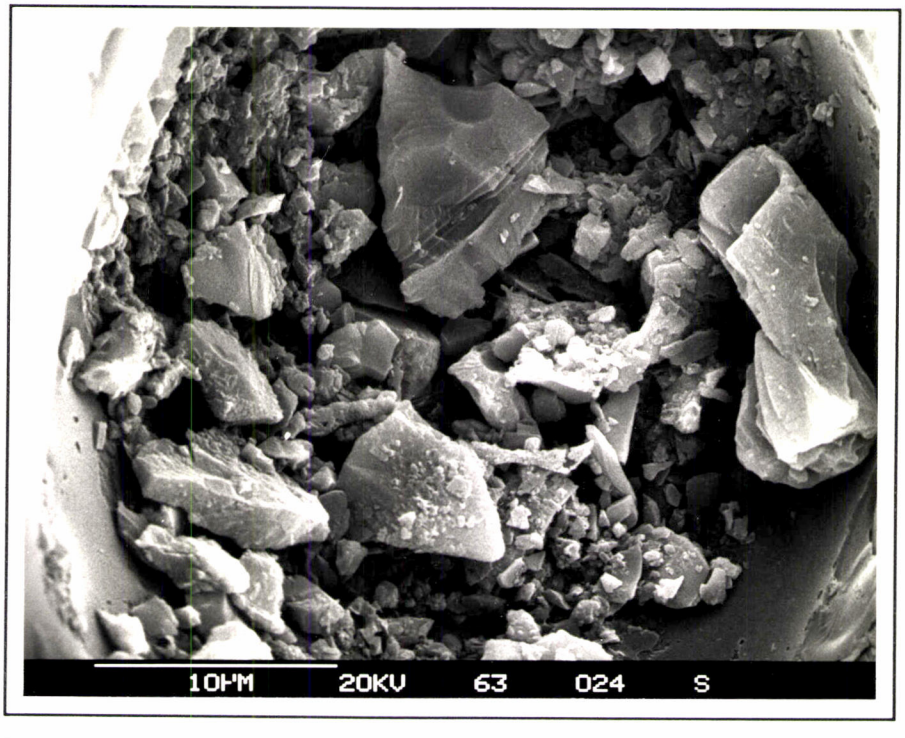


Plate 4.10b Magnification 3200x.

Plates 4.10a & 4.10b VITRIC PYROCLASTS
Adhering dust within vesicles of vitric pyroclasts.

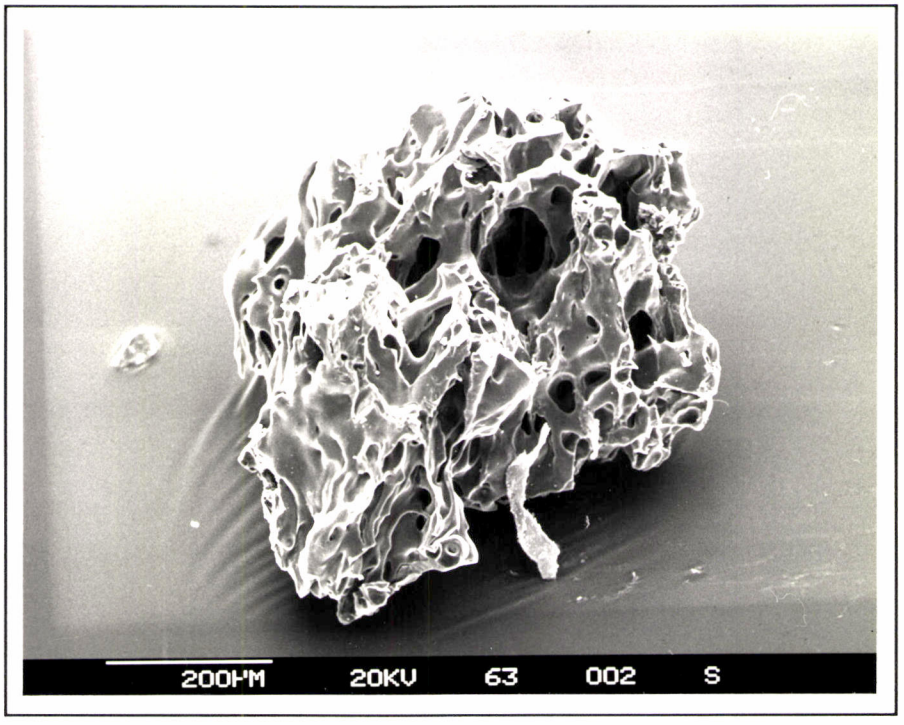


Plate 4.11 VITRIC PYROCLAST
Pumice fragment showing a greater degree of vesiculation than seen in both the type-1 blocky and the black and brown vesicular pyroclasts. Magnification 111x.

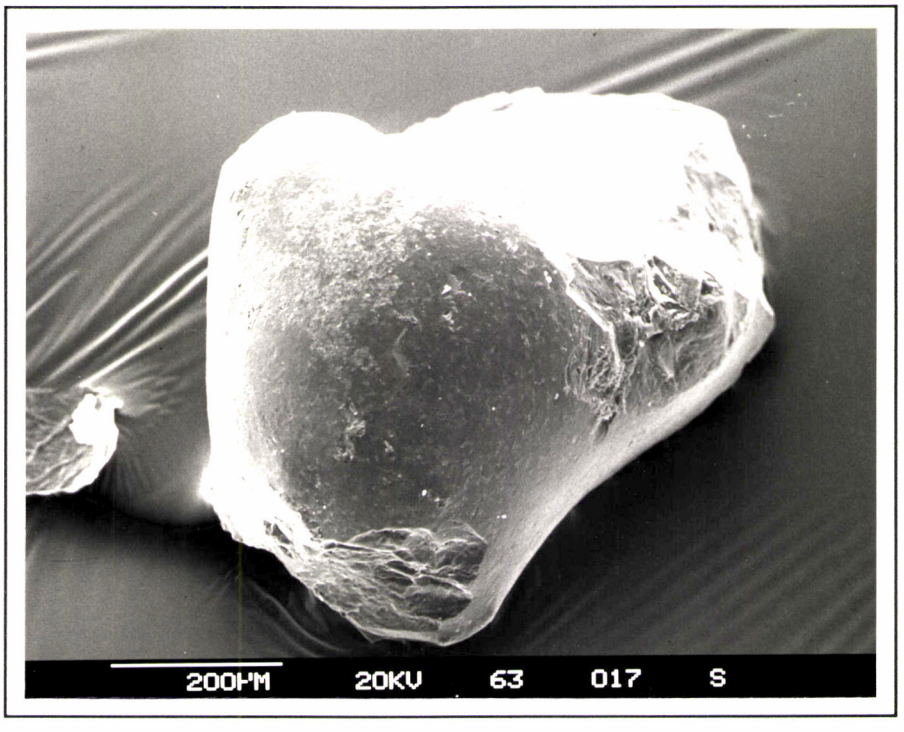


Plate 4.12 VITRIC PYROCLAST MORPHOLOGY
Type-4 drop-like shape of black glass. Magnification 115x.

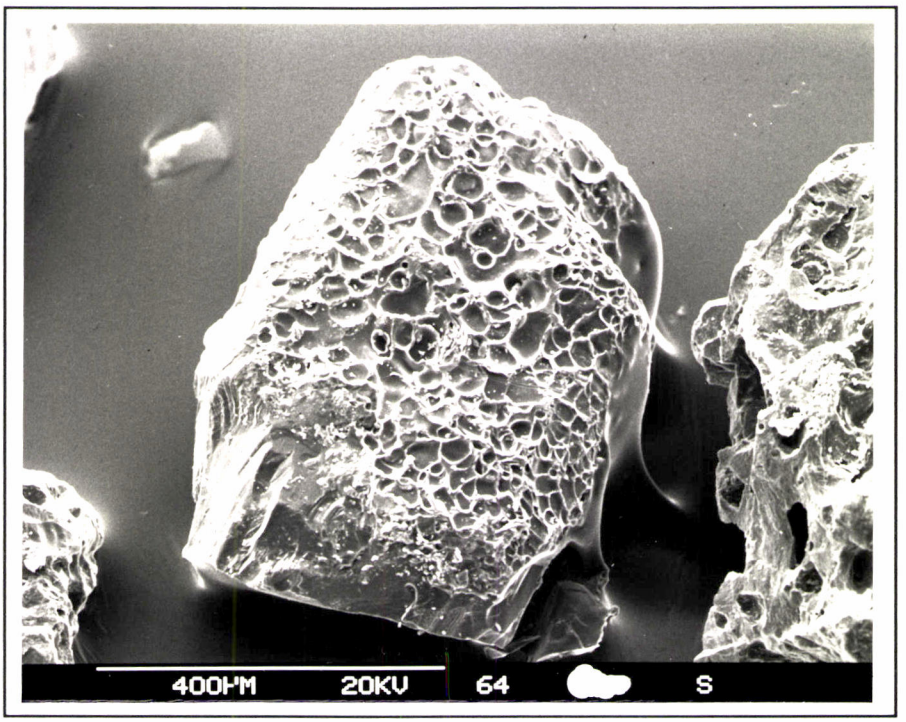


Plate 4.13 FERROMAGNESIAN CRYSTAL MORPHOLOGY
Broken pyroxene crystal with vesiculated glassy coating. Magnification 118x.

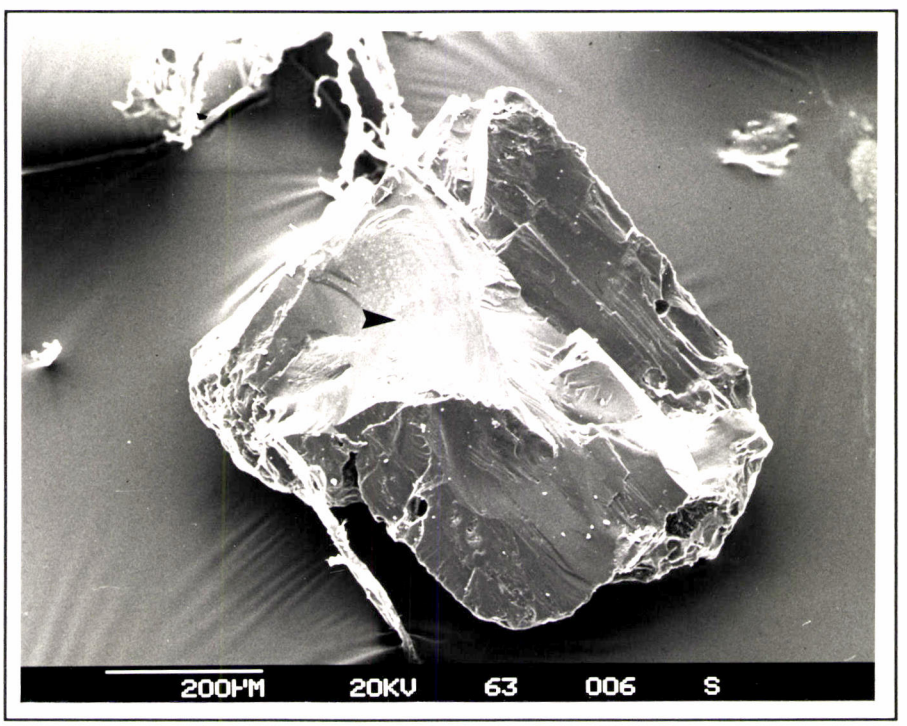


Plate 4.14a Magnification 105x. *(see caption over page)*

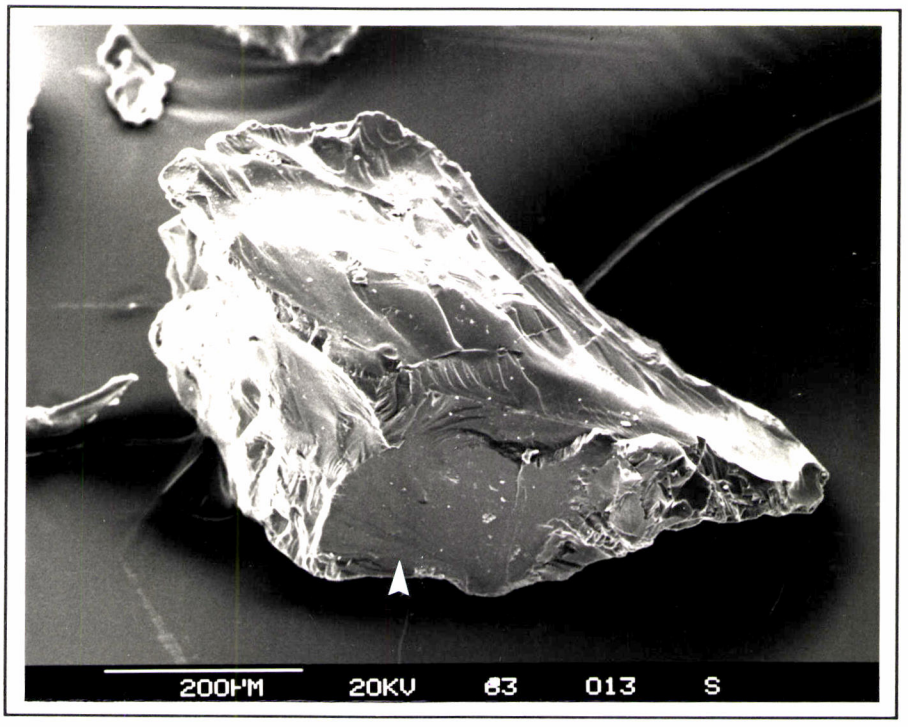


Plate 4.14b Magnification 133x.

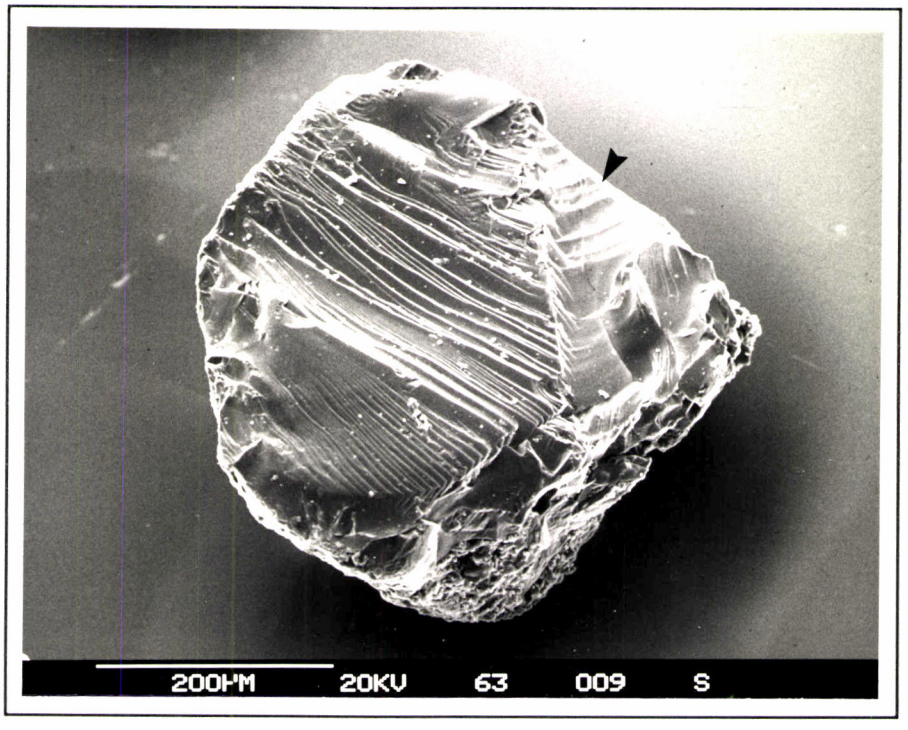


Plate 4.14c Magnification 160x.

Plates 4.14a, 4.14b & 4.14c FERROMAGNESIAN CRYSTAL MORPHOLOGY
Blocky pyroxene crystals showing facial conchoidal fracture [arrows].

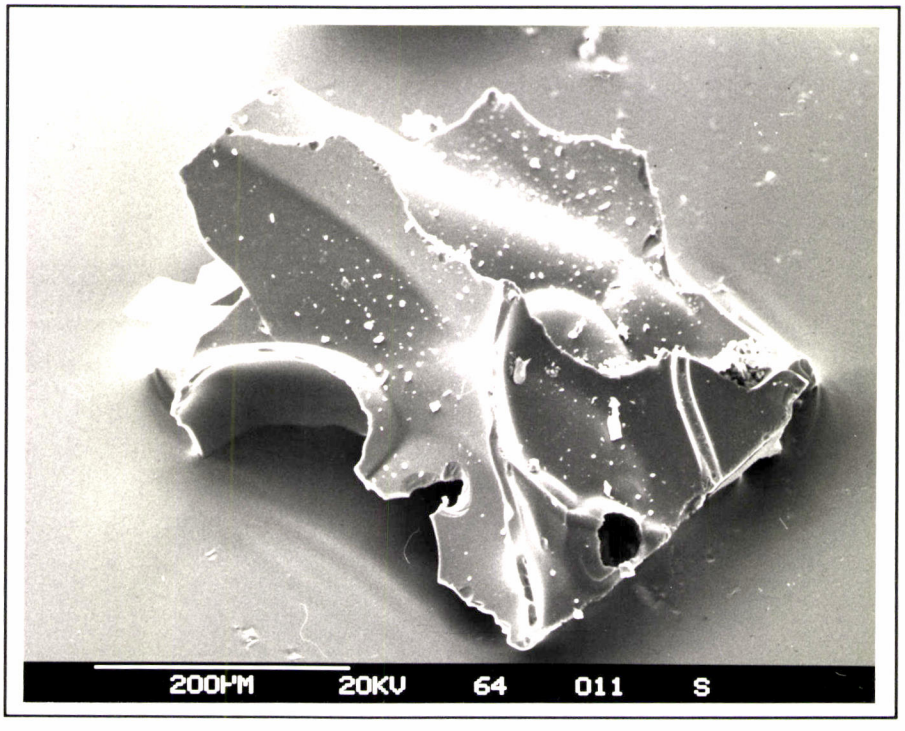


Plate 4.15a Magnification 172x.

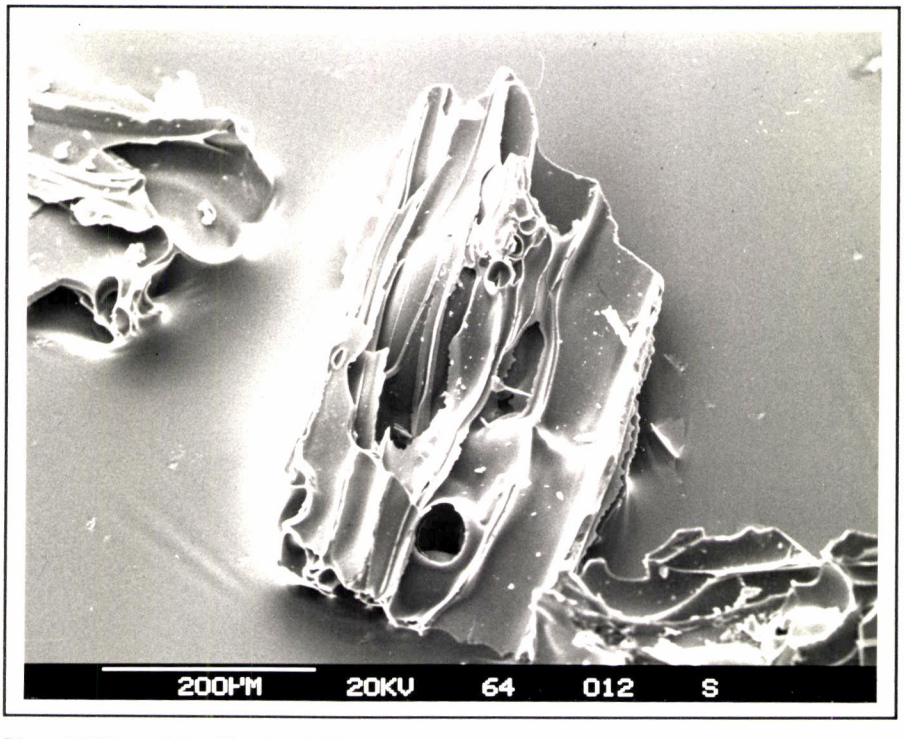


Plate 4.15b Magnification 143x.

Plates 4.15a & 4.15b RHYOLITIC GLASS SHARDS
Rhyolitic glass shards derived from aeolian reworked Taupo Pumice, identified within Tufa Trig Formation tephras.

Plate 5.1 ONETAPU FORMATION TYPE LOCALITY, KARIOI FOREST
Debris flow and hyperconcentrated flood flow deposits of Onetapu Formation exposed in a NW–SE trending drainage channel, immediately west of Whangaehu River.

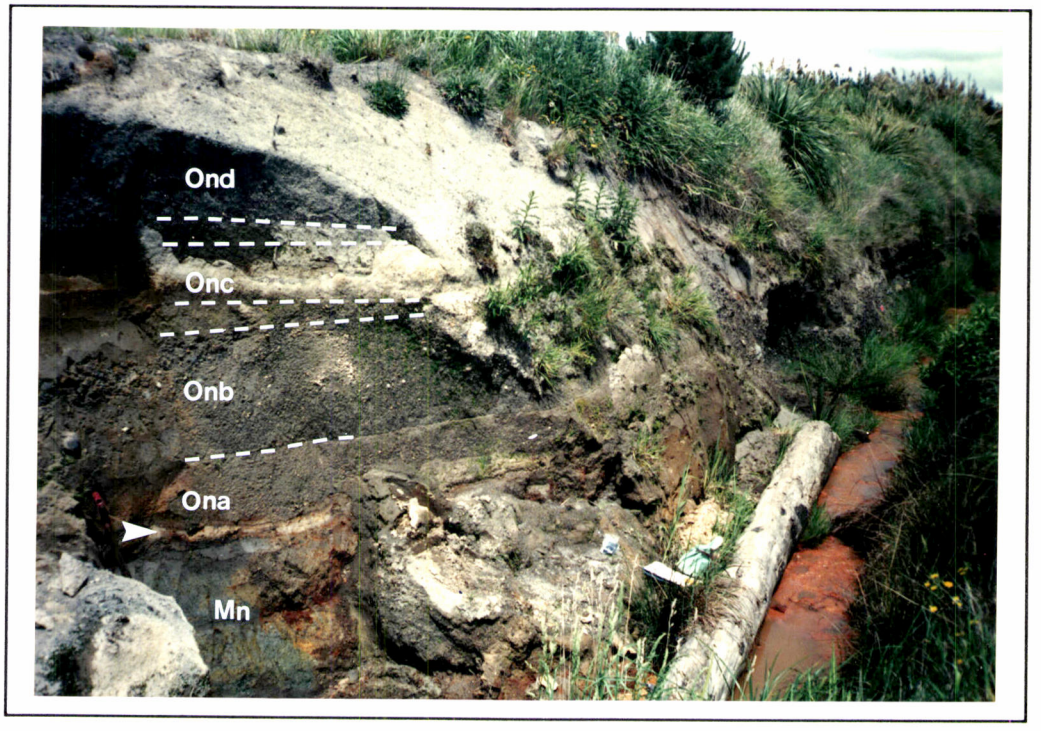


Plate 5.2 ONETAPU FORMATION TYPE SECTION [T20/319906]
Onetapu Formation debris and hyperconcentrated flood flow deposits, exposed at the west side of the type section, overlying Taupo Ignimbrite [arrow] and older deposits of Mangaio Formation [Mn]. Members of Onetapu Formation seen here are Ona, Onb, Onc, and Ond.

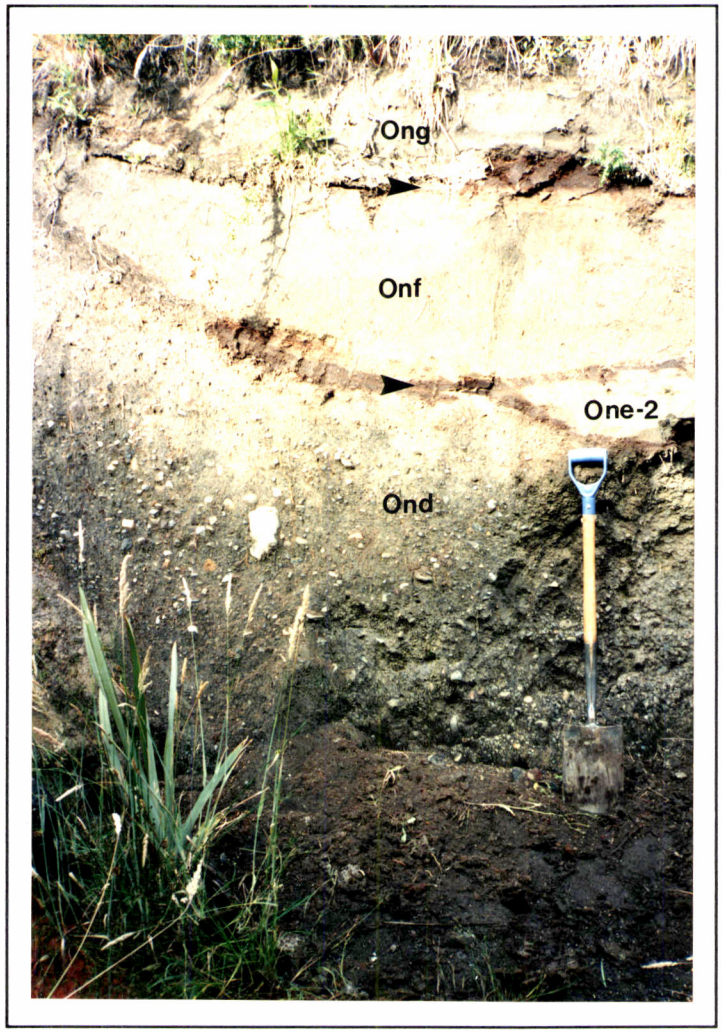


Plate 5.3
ONETAPU FORMATION TYPE SECTION [T20/319906]
Onetapu Formation debris flow and hyperconcentrated flood flow deposits exposed at the east side of the type section. Members shown are Ond, One2, Onf, and Ong. Arrowed are peat deposits radiocarbon dated at *c.* 282 years B.P. [upper] and *c.* 390 years B.P. [lower].

Plate 5.4 TYPE LOCALITY S.2 [T20/320904]
Onetapu Formation deposits exposed proximal to Whangaehu River. Shown are correlatives of members Ond and Onf, and three hyperconcentrated flood flow deposits possibly representing the 1953 [1], 1969 [2] and 1975 [3] events. The positions of pine cones used to estimate-age date these deposits *(see text)* are arrowed.

Plate 5.5
TYPE LOCALITY S.3 [T20/319904]
Stratified hyperconcentrated flood flow, and debris flow deposits of Onetapu Formation [1 – 8] overlying Taupo Pumice [Tp] (Taupo Ignimbrite Member), in an exposure proximal to Whangaehu River. Deposits (obscured) below Taupo Ignimbrite are correlated with the *c.* 4600 years B.P. Mangaio Formation.

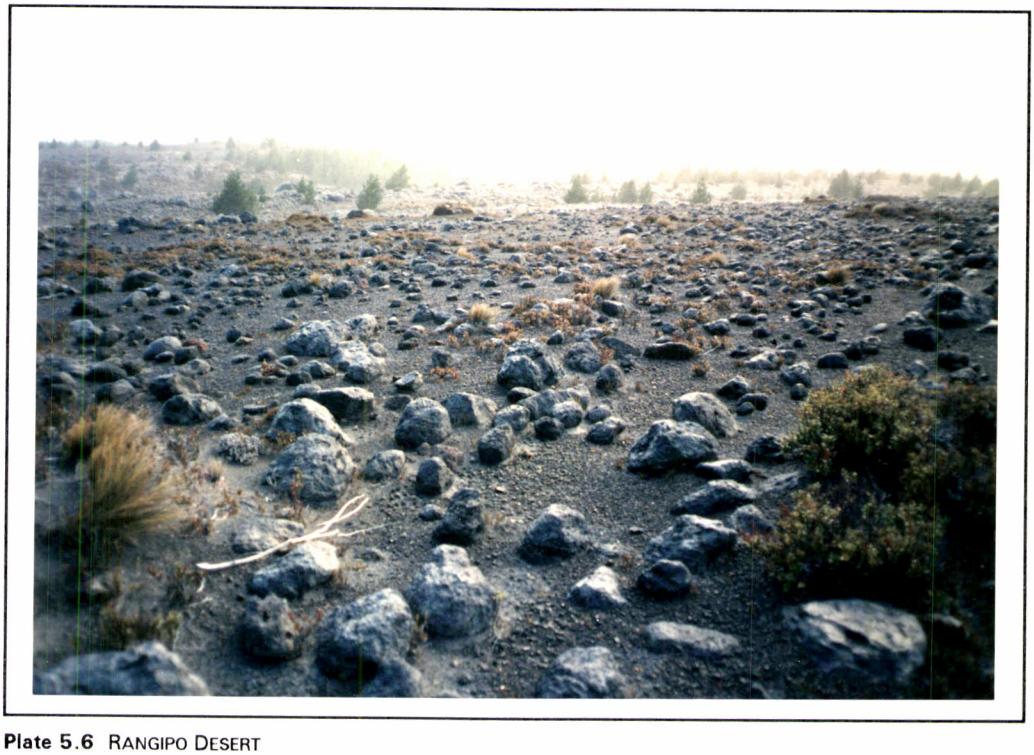


Plate 5.6 RANGIPO DESERT
Boulder strewn laharic surfaces of Onetapu Formation seen within Rangipo Desert. Remnant matrix materials of Onetapu Formation lahar deposits form the coarse sandy 'lag' deposit between the boulders.

Plate 5.7
Debris flow deposits of Onetapu Formation forming bouldery levees alongside Whangaehu River, south of Scorpion Gully. The Whangaehu escarpment is seen to the right of the photograph.

Plate 5.8 NORTHWESTERN RANGIPO DESERT
Coarse channel deposits and boulder banks deposited by debris flows, northwestern Rangipo Desert. Large boulder [arrow] is *c.* 3 m high.

Plate 5.9 SOUTHERN RANGIPO DESERT
Thin pebbly 'lag' deposit (of Onetapu Formation-age), overlying partially eroded white Taupo Ignimbrite in southern Rangipo Desert.

Plate 5.10 SCORPION GULLY REFERENCE LOCALITY
Dark grey Onetapu Formation debris flow deposits unconformably overlie the distinctive orange-coloured Mangaio Formation [Mn] debris flow deposit. Here, upper Papakai Formation, Mangatawai Tephra and Taupo Ignimbrite have been eroded from above Mangaio Formation. Graduations on staff are 100 mm.

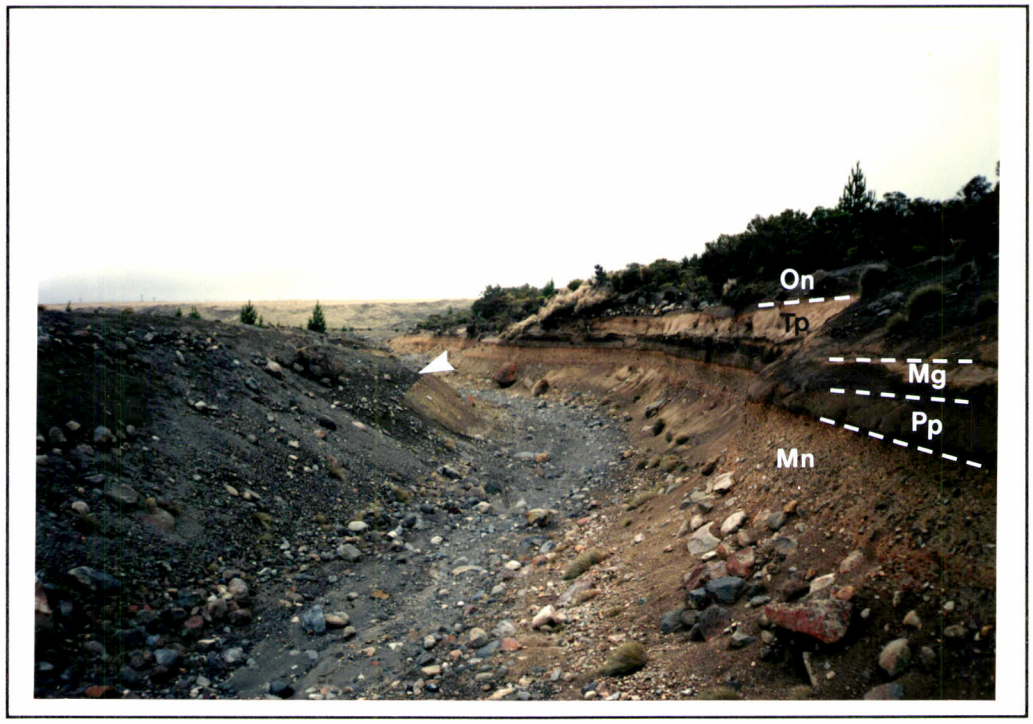


Plate 5.11 SCORPION GULLY REFERENCE LOCALITY
To the right of the photograph, Mangaio Formation [Mn] is overlain by upper Papakai Formation [Pp], Mangatawai Tephra [Mg], Taupo Pumice [Tp] (Taupo Ignimbrite Member), and Onetapu Formation lahar deposits [On]. To the left of the channel, where the tephras have been eroded, Mangaio Formation is unconformably overlain by dark grey Onetapu Formation deposits. The arrow points to the erosional unconformity between these formations.

Plate 5.12 SCORPION GULLY REFERENCE LOCALITY
Photograph shows the three flow units within Mangaio Formation [1,2,3]. Note the distinctive orange matrix and the upward progression from dominantly coarse to fine matrix-supported clasts through these units. Also note the sharp contact of Mangaio Formation with upper Papakai Formation, and the stratigraphic positions of Waimihia Tephra (occurring as white fine ash 'cream cakes' within Papakai Formation [arrow]), Mangatawai Tephra [Mg], Taupo Pumice [Tp] (Taupo Ignimbrite Member), and Onetapu Formation deposits [On] (figure for scale).

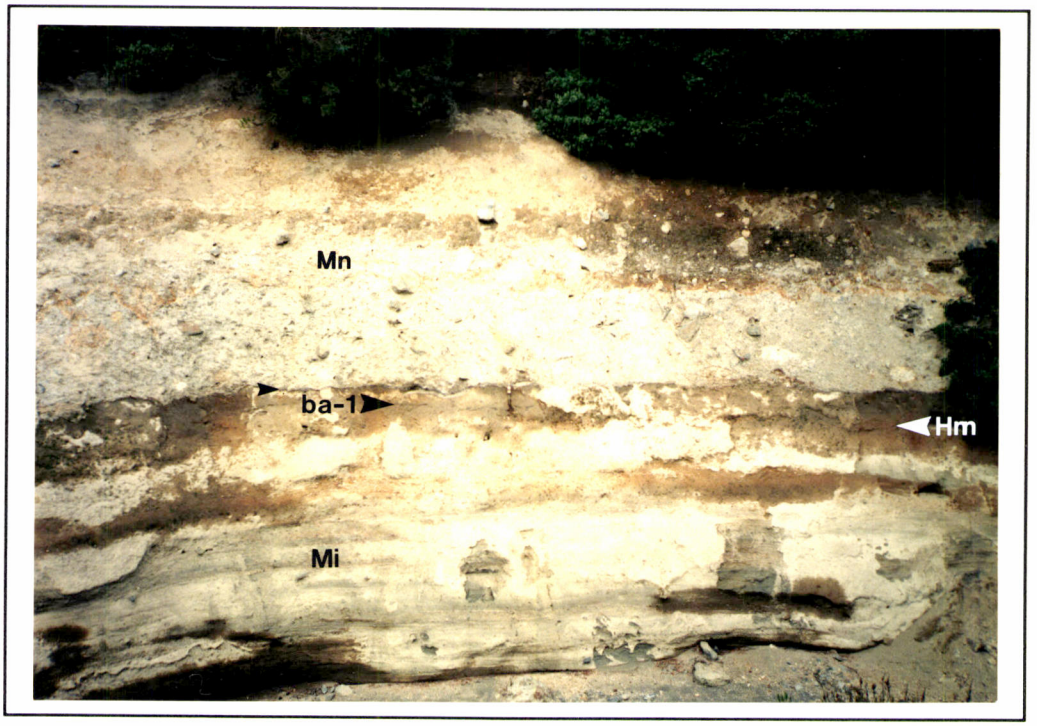


Plate 5.13 MANGAIO FORMATION TYPE SECTION [T20/408047]
Photograph shows Mangaio Formation [Mn] above a thin brown peat [arrow], dated [NZ7532] at 4850 ± 90 years B.P. Wood within the formation is dated at 4600 ± 110 years B.P. Note the positions of the marker beds black ash-1 [ba-1] and Hinemaiaia Tephra [Hm]. Grey sands of Manutahi Formation [Mi] are exposed at the base of the section.

Plate 5.14 MANUTAHI FORMATION TYPE SECTION [T20/410035]
Pale grey bedded pebbly sands and brown silty interbeds of Manutahi Formation overlain by the Mangaio Formation debris flow deposit. Note the stratigraphic position of the interbedded Hinemaiaia Tephra [arrow]. Motutere Tephra occurs at the very base of the exposure just to the right of the photograph.

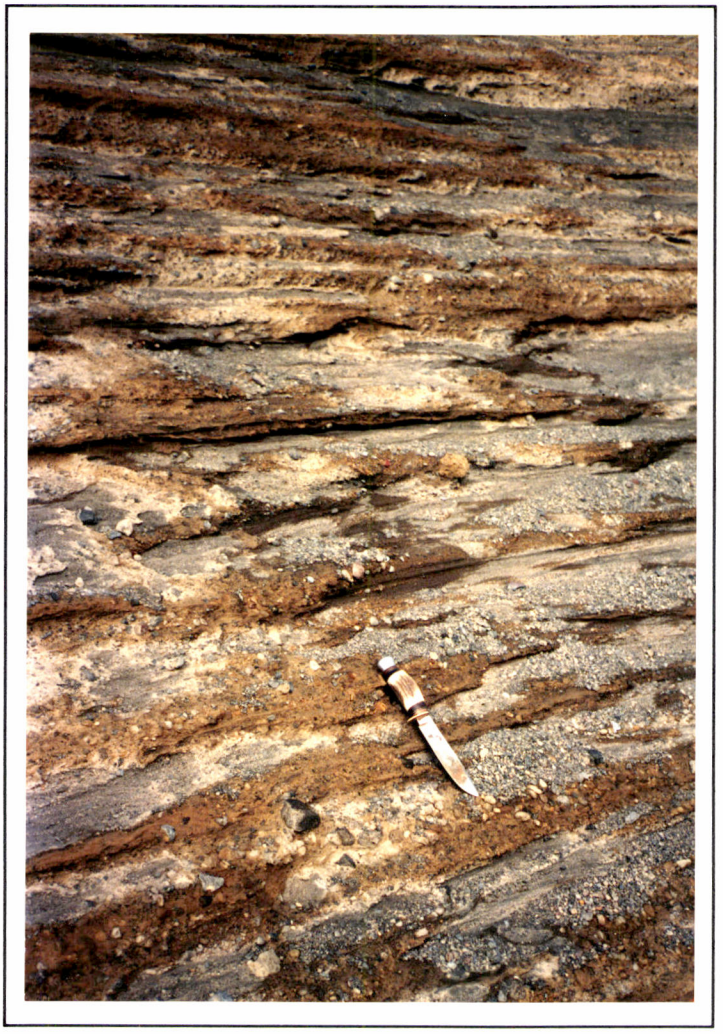
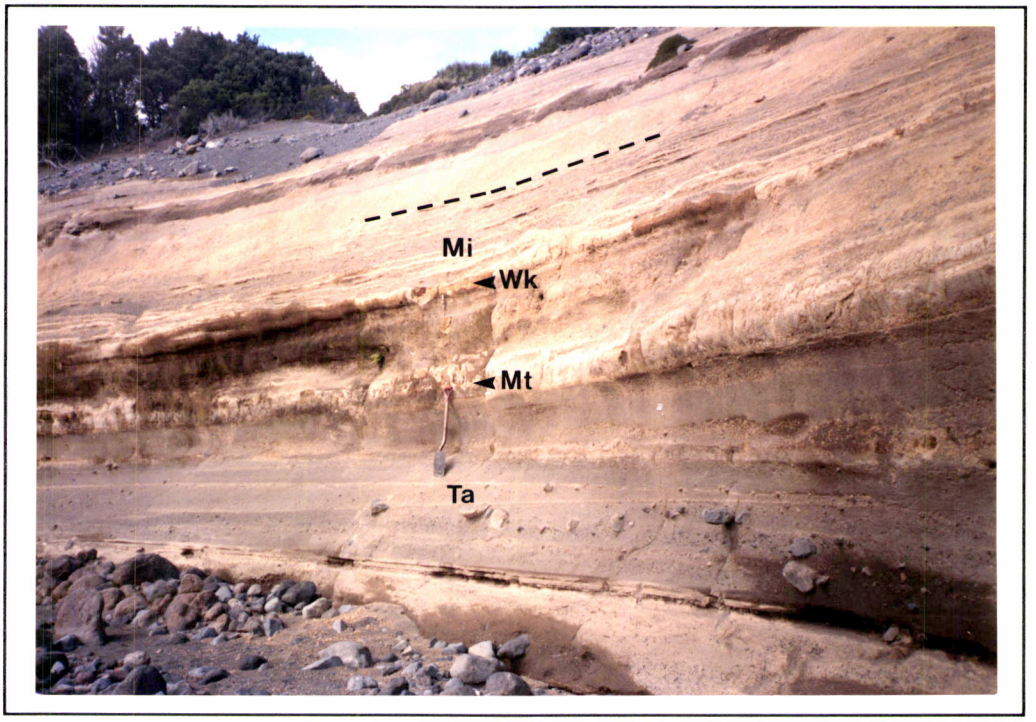


Plate 5.15
MANUTAHI FORMATION TYPE SECTION [T20/410035]
Weakly bedded, poorly sorted pebbly sands and silty interbeds of Manutahi Formation. Note the discontinuity of the beds, the rounded pumice pebbles and cross-bedding in some sand layers.

0.5 m



1 m

Plate 5.16 DEATH VALLEY S.5 [T20/409045]
Bedded SF – HFF deposits of Manutahi Formation [Mi] overlying HFF deposits of Tangatu Formation [Ta]. Whakatane Tephra [Wk] is interbedded within silty clay near the base of Manutahi Formation. The stratigraphic position of Motutere Tephra [Mt] approximates the boundary between Manutahi and Tangatu formations. Dashed line marks the upper boundary of Manutahi Formation with cover bed tephras.

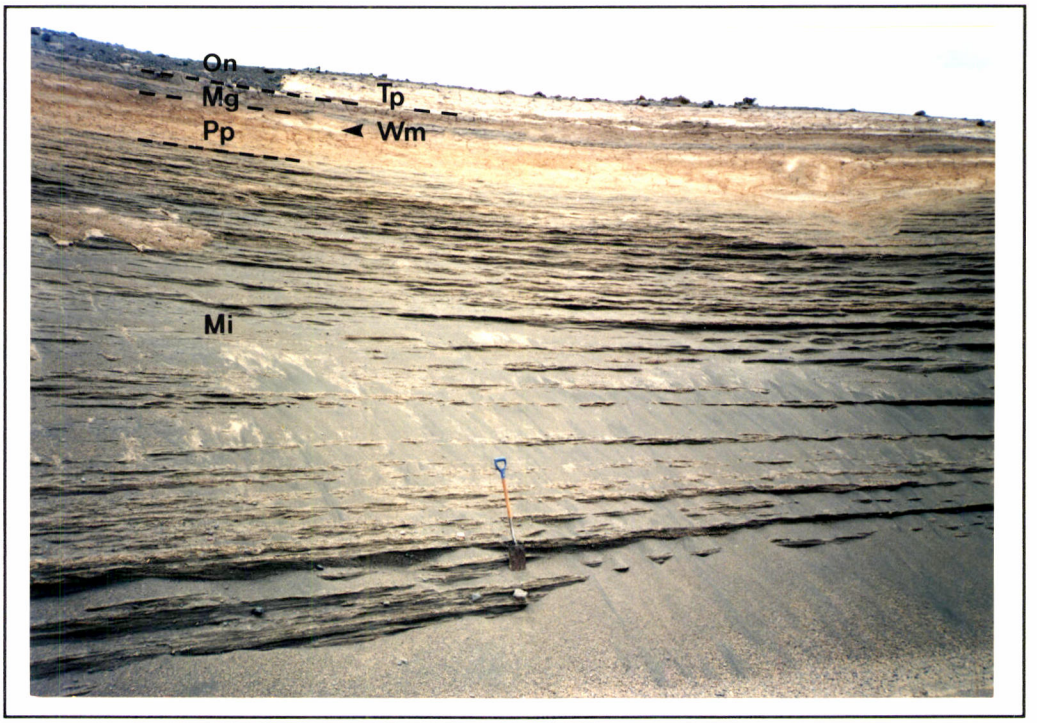


Plate 5.17 BULLOT TRACK S.2 [T20/420110]
Bedded Manutahi Formation pebbly sands [Mi] underlying Papakai Formation [Pp] with interbedded Waimihia Tephra [Wm]. Note also Mangatawai Tephra [Mg], Taupo Pumice [Tp] (Taupo Ignimbrite Member), and dark grey Onetapu Formation deposits [On].

Plate 5.18 TANGATU FORMATION TYPE SECTION [T20/409045]
HFF deposits of Tangatu Formation. Note the reverse grading in these units, the fine clast sizes, and the sharp wavy contacts.

Plate 5.19 THE BADLANDS, RANGIPO DESERT
Eroded surfaces of the Badlands, western Rangipo Desert. Figure stands on surface eroded down to Motutere Tephra.

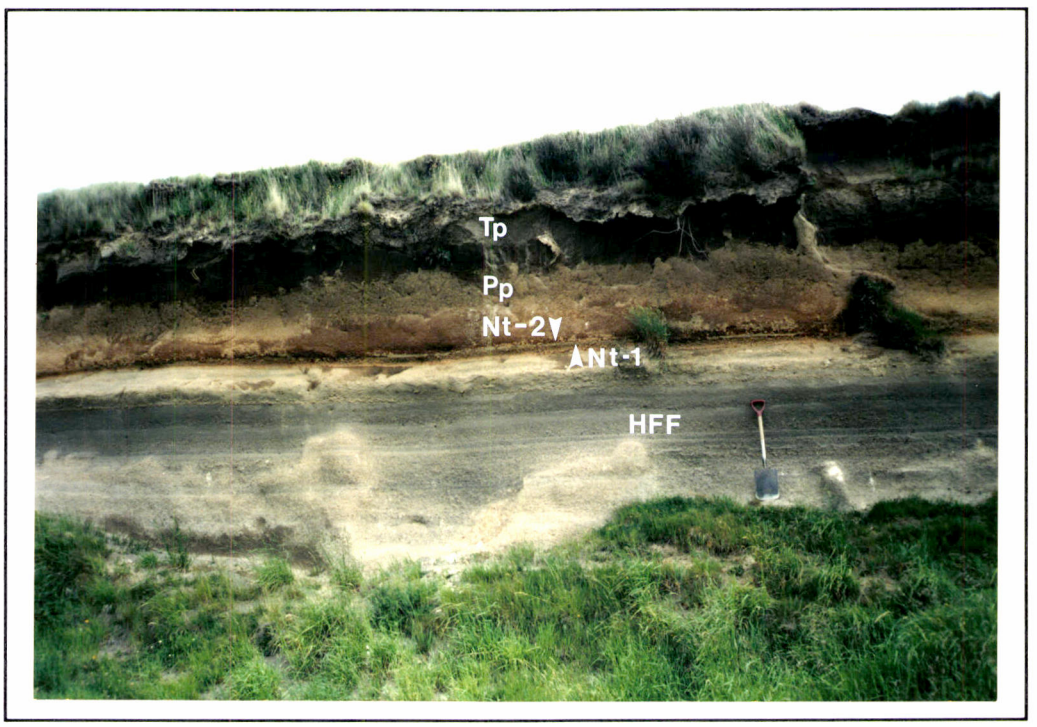


Plate 5.20 HELWAN S.2 [T20/407917]
Horizontally stratified HFF deposit of the Tangatu Formation conformably overlain by Ngamatea lapilli-1 [Nt-1] member of Bullot Formation. Note also Ngamatea lapilli-2 [Nt-2], Papakai Formation [Pp] and Taupo Pumice [Tp] (Taupo Ignimbrite Member).

Plate 5.21 HELWAN QUARRY (NORTH FACE) [T20/408921]
DF and HFF deposits of Tangatu Formation overlain by Waiohau Tephra (position arrowed), Bullot Formation tephras (Shawcroft Tephra [Sh], Helwan lapilli [Hl], Ngamatea lapilli-1 [Nt-1]), Poutu Lapilli [Pt], Papakai Formation [Pp], and Taupo Pumice [Tp] (Taupo Ignimbrite Member).

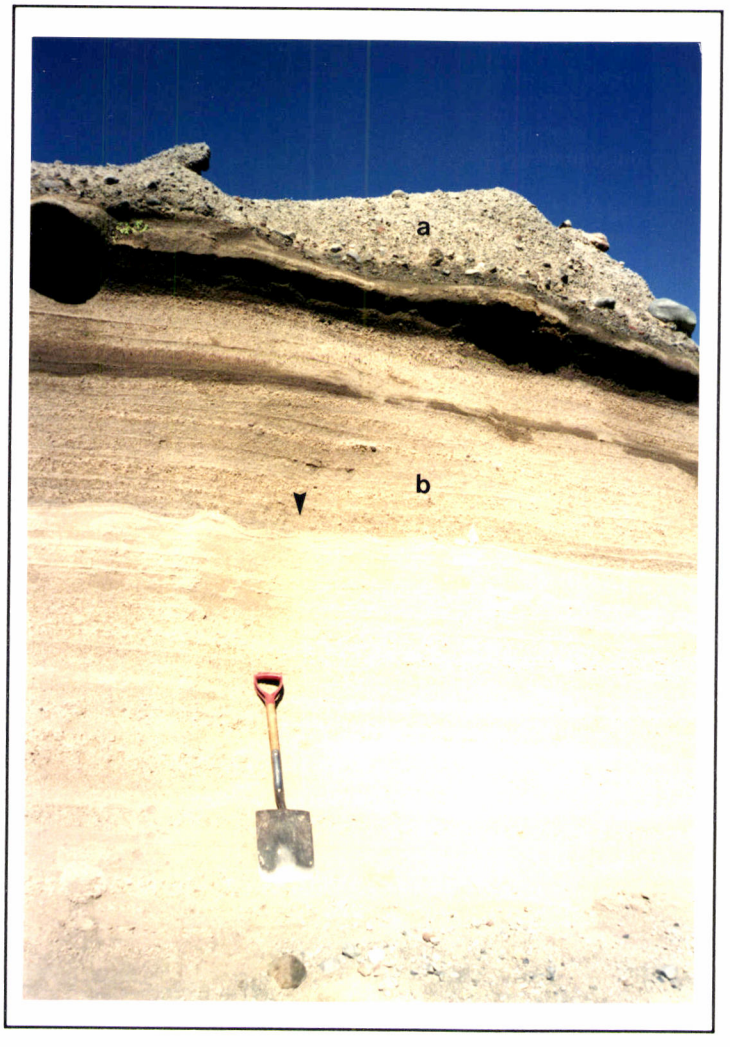


Plate 5.22
HELWAN QUARRY (NORTH FACE) [T20/408921]
HFF deposits of Tangatu Formation showing distinct horizontal stratification (unit b). The deposit comprises alternating pebble-rich and sand-rich beds. Note the presence of water escape structures [arrow]. Here the *c.* 3.5 – 6 m HFF deposit underlies a DF deposit (unit a).

Plate 5.23 HELWAN QUARRY (SOUTH FACE) [T20/408921]
View overlooking Tangatu Formation DF and HFF deposits. Units a and b are correlatives of deposits shown in Plate 5.22. Unit c is a correlative of the HFF deposit exposed at Helwan S.2 (section locality arrowed).

Plate 5.24 HELWAN QUARRY (SOUTH FACE) [T20/408921]
Tangatu Formation unit c conformably overlain by Ngamatea lapilli-1 [Nt-1] and unconformably overlying older Bullot Formation tephras and >11 250 years B.P. Tangatu Formation deposits.

Plate 5.25 WHANGAEHU ESCARPMENT
DF and HFF deposits of Te Heuheu Formation [Hh] exposed along the Whangaehu escarpment. These deposits are overlain by Rerewhakaaitu Tephra (dated *c.* 14 700 years B.P.) and younger Bullot Formation tephras. Arrow indicates course of Whangaehu River. View is to the southeast.

Plate 5.26 SOUTHERN RANGIPO DESERT
Dune sands accumulating on partially eroded Papakai Formation within the southern Rangipo Desert. This incipient dune field is indicative of continuing aeolian erosion within Rangipo Desert.

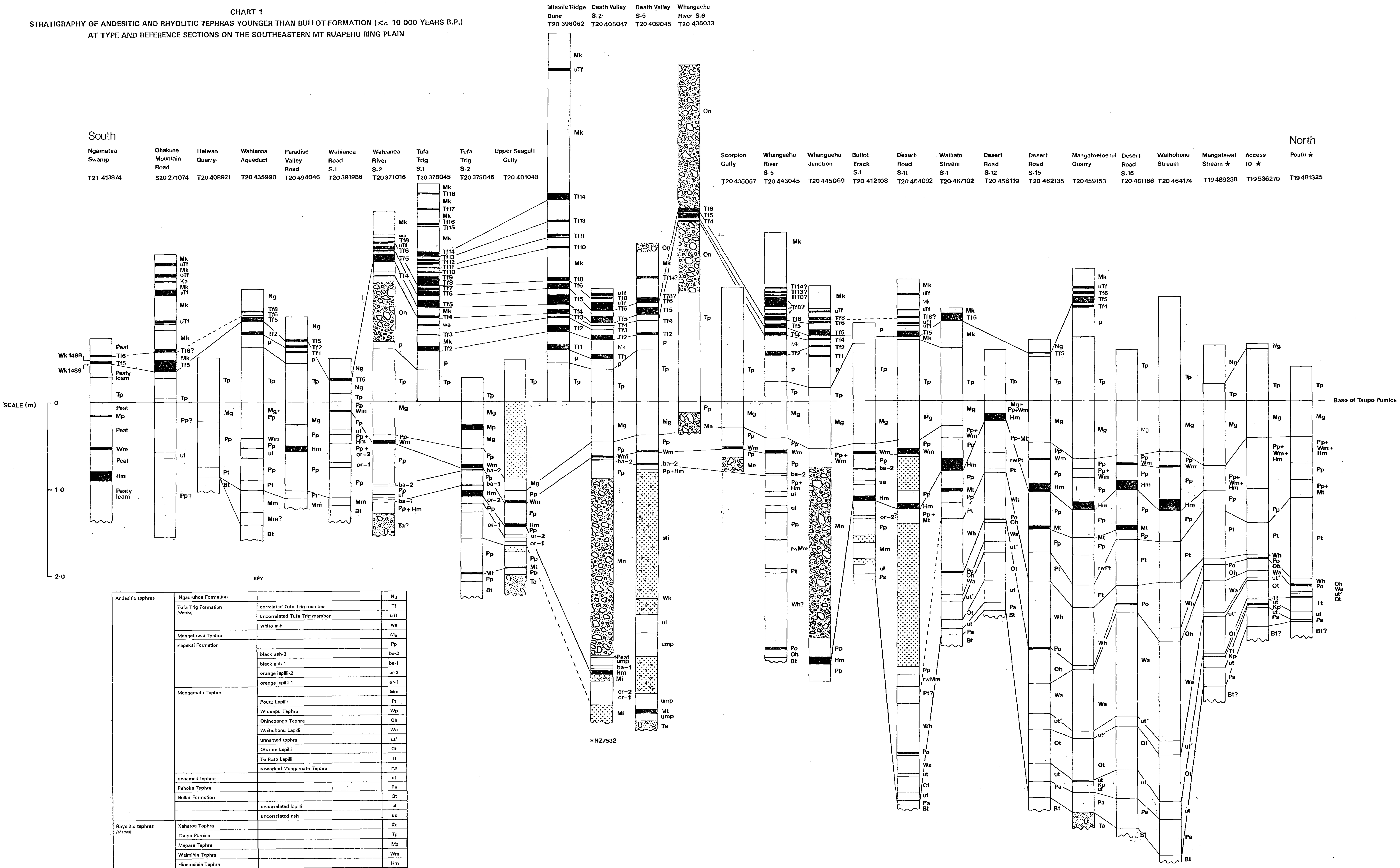
Plate 5.27 BULLOT TRACK
Sparsely vegetated Bullot Formation surfaces are subject to erosion by ephemeral streams and aeolian processes. Frequent dust storms erode and transport much of the finer material.

Plate 5.28 1975 LAHAR
Aerial photograph showing passage of the 1975 lahar down Whangaehu River and across the Whangaehu Fan. During this event The Chute was also an active channel.

Plate courtesy of *D. Lloyd Homer*
NZ Geological Survey
PO Box 30-368
Lower Hutt

CHART 1

STRATIGRAPHY OF ANDESITIC AND RHYOLITIC TEPHRAS YOUNGER THAN BULLOT FORMATION (<c. 10 000 YEARS B.P.) AT TYPE AND REFERENCE SECTIONS ON THE SOUTHEASTERN MT RUAPEHU RING PLAIN



KEY

Andesitic tephras	Ngauruhoe Formation		Ng
	Tufa Trig Formation *(shaded)*	correlated Tufa Trig member	Tf
		uncorrelated Tufa Trig member	uTf
		white ash	wa
	Mangatawai Tephra		Mg
	Papakai Formation		Pp
		black ash-2	ba-2
		black ash-1	ba-1
		orange lapilli-2	or-2
		orange lapilli-1	or-1
	Mangamate Tephra		Mm
		Poutu Lapilli	Pt
		Wharepu Tephra	Wp
		Ohinepango Tephra	Oh
		Waihohonu Lapilli	Wa
		unnamed tephra	ut′
		Oturere Lapilli	Ot
		Te Rato Lapilli	Tt
		reworked Mangamate Tephra	rw
	unnamed tephras		ut
	Pahoka Tephra		Pa
	Bullot Formation		Bt
		uncorrelated lapilli	ul
		uncorrelated ash	ua
Rhyolitic tephras *(shaded)*	Kaharoa Tephra		Ka
	Taupo Pumice		Tp
	Mapara Tephra		Mp
	Waimihia Tephra		Wm
	Hinemaiaia Tephra		Hm
	Whakatane Tephra		Wk
	Motutere Tephra		Mt
	Poronui Tephra		Po
	Karapiti Tephra		Kp
		paleosol	p
		uncorrelated medial unit with paleosol development	ump
	Makahikatoa Sands		Mk
Laharic deposits	Onetapu Formation	Ona – Ong	On
	Manutahi Formation		Mi
	Mangaio Formation		Mn
	Tangatu Formation		Ta

* denotes units radiocarbon dated

Grid references based on 1:50 000 NZMS 260 topographical maps

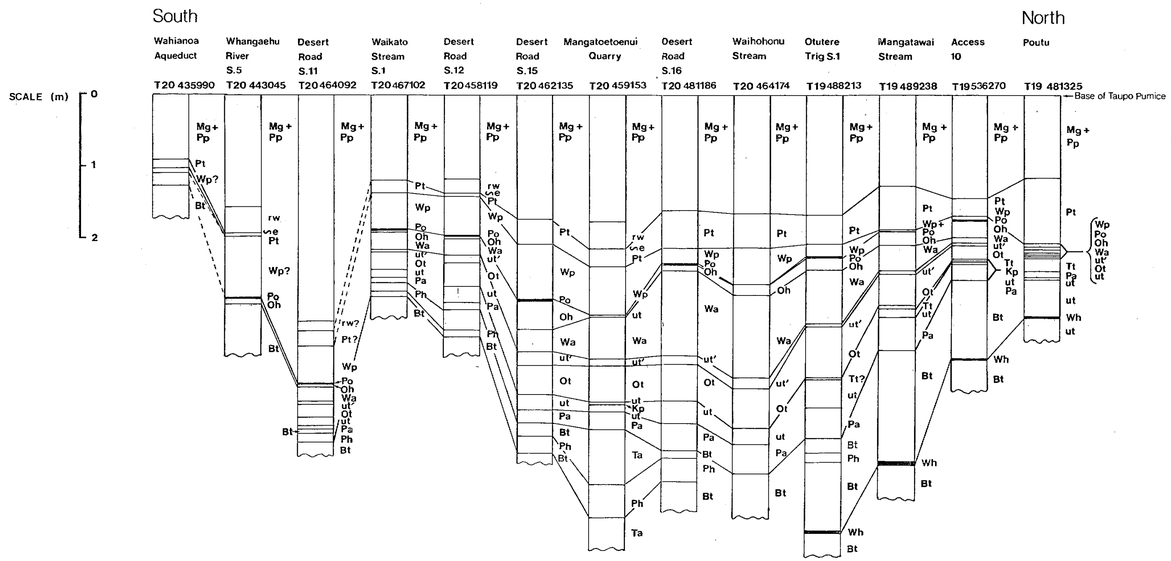
Susan L. Donoghue
Ph.D. thesis 1991
Soil Science
Massey University
Palmerston North
New Zealand

DOMINANT LITHOLOGY

- Debris flow
- Hyperconcentrated flood flow
- Transitional Hyperconcentrated flood flow – Stream flow
- Stream flow

CHART 2

STRATIGRAPHY OF MANGAMATE TEPHRA MEMBERS (*c.* 9700 – *c.* 9780 YEARS B.P.)
AT TYPE AND REFERENCE SECTIONS



KEY

Andesitic tephras	Mangatawai Tephra		Mg
	Papakai Formation		Pp
	Mangamate Tephra	Poutu Lapilli	Pt
		Wharepu Tephra	Wp
		Ohinepango Tephra	Oh
		Waihohonu Lapilli	Wa
		unnamed tephra	ut'
		Oturere Lapilli	Ot
		Te Rato Lapilli	Tt
		reworked Mangamate tephra	rw
	unnamed tephras		ut
	Pahoka Tephra		Pa
	Bullot Formation		Bt
		Pourahu Member	Ph
Rhyolitic tephras *(shaded)*		Peronui Tephra	Po
		Karapiti Tephra	Kp
		Waiohau Tephra	Wh
Lahariic deposits	Tangatu Formation		Ta

~ e denotes erosion break

Grid references based on 1:50 000 NZMS 260 topographical maps

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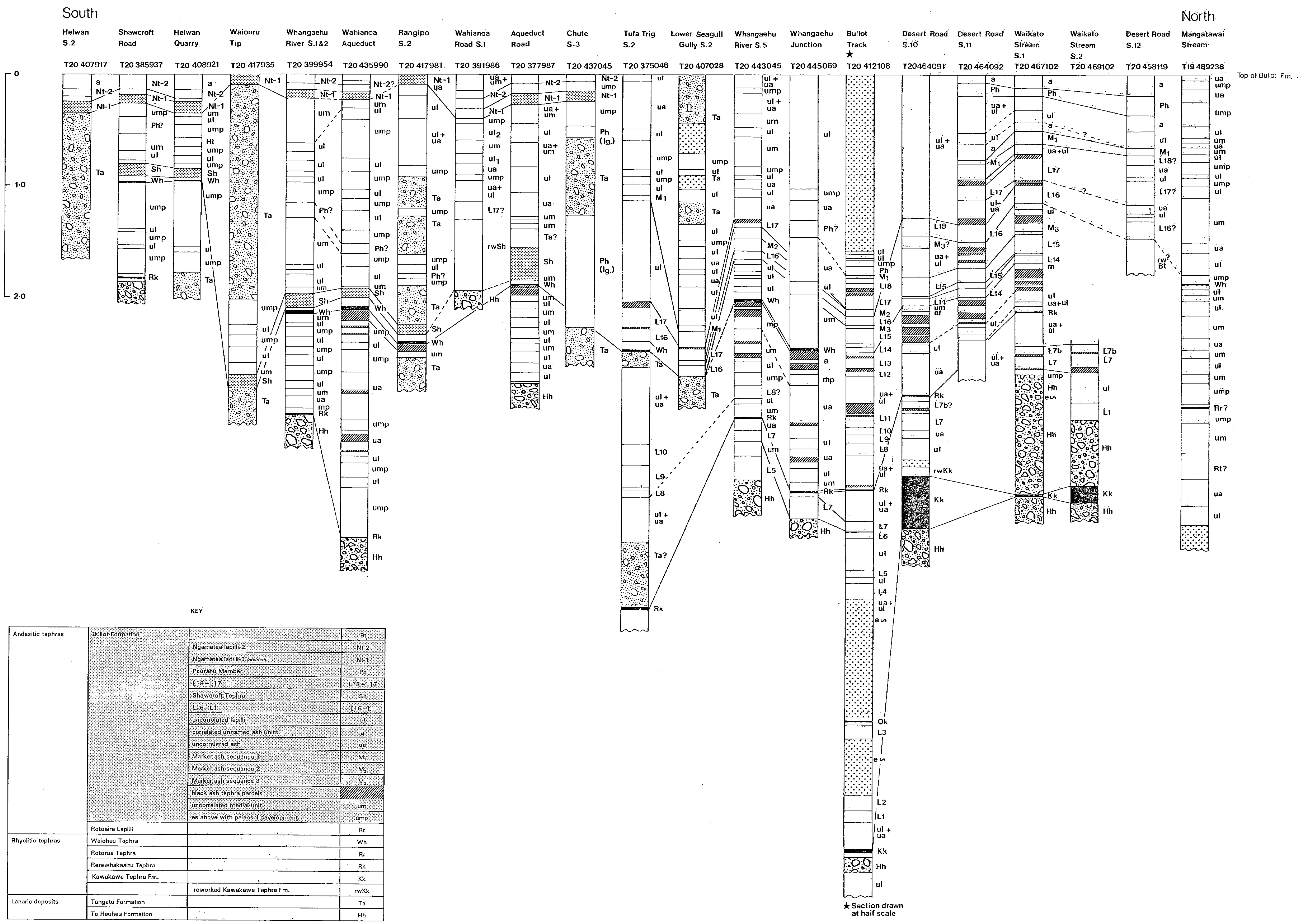
CHART 3

STRATIGRAPHY OF BULLOT FORMATION TEPHRAS AND INTERBEDDED RHYOLITIC TEPHRAS
AT TYPE AND REFERENCE SECTIONS ON THE SOUTHEASTERN MT RUAPEHU RING PLAIN (*c.* 10 000 – 22 500 YEARS B.P.)



KEY

Andesitic tephras	Bullot Formation		Bt
		Ngamatea lapilli-2	Nt-2
		Ngamatea lapilli-1 *(shaded)*	Nt-1
		Pourahu Member	Ph
		L18 – L17	L18 – L17
		Shawcroft Tephra	Sh
		L16 – L1	L16 – L1
		uncorrelated lapilli	ul
		correlated unnamed ash units	a
		uncorrelated ash	ua
		Marker ash sequence 1	M_1
		Marker ash sequence 2	M_2
		Marker ash sequence 3	M_3
		black ash tephra parcels	
		uncorrelated medial unit	um
		as above with paleosol development	ump
	Rotoaira Lapilli		Rt
Rhyolitic tephras	Waiohau Tephra		Wh
	Rotorua Tephra		Rr
	Rerewhakaaitu Tephra		Rk
	Kawakawa Tephra Fm.		Kk
		reworked Kawakawa Tephra Fm.	rwKk
Laharic deposits	Tangatu Formation		Ta
	Te Heuheu Formation		Hh

~ e denotes erosion break
[lg] denotes ignimbrite unit

Grid references based on
1:50 000 NZMS 260 topographical maps

DOMINANT LITHOLOGY

Debris flow

Hyperconcentrated flood flow

Stream flow

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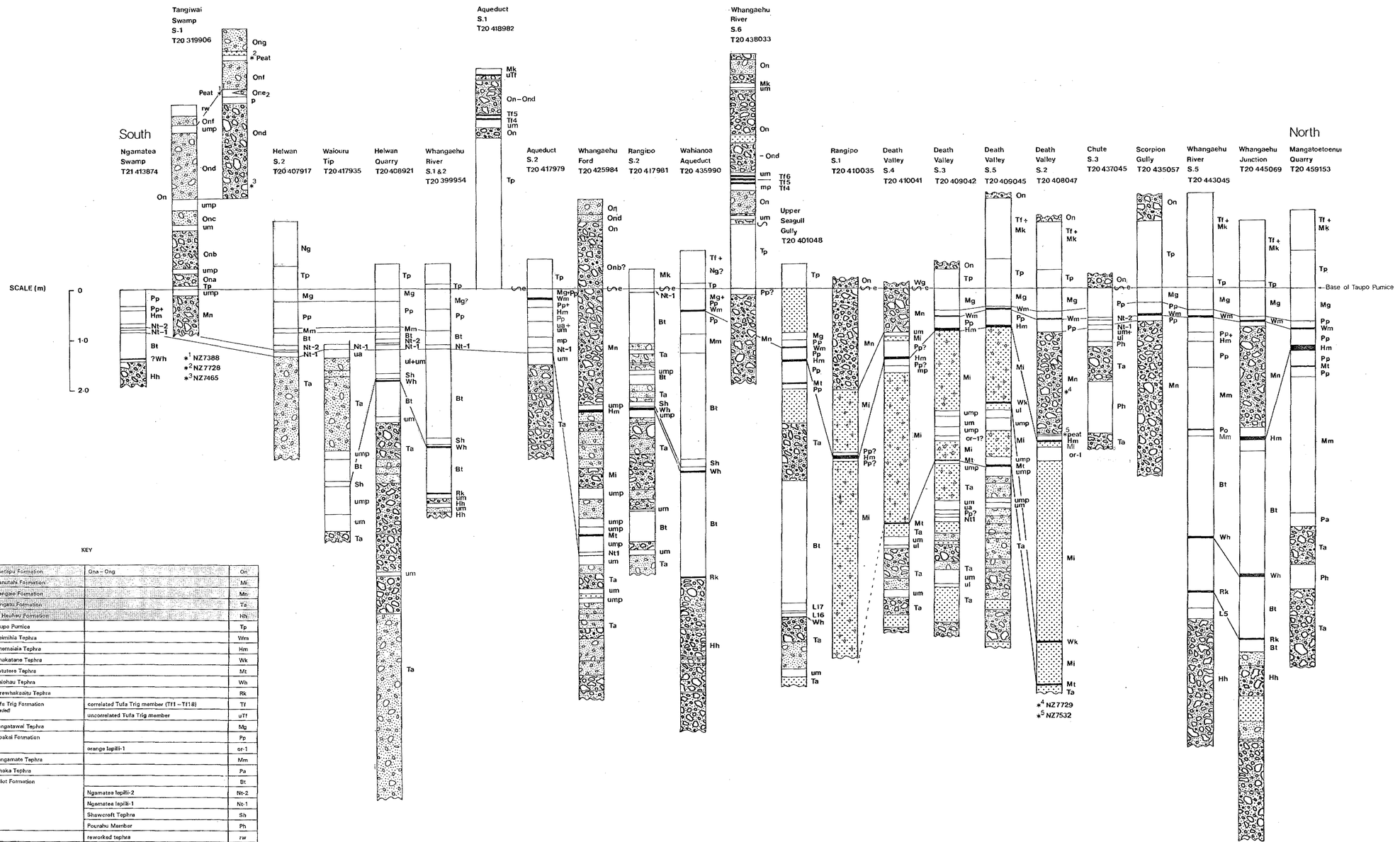
New Zealand

CHART 4

STRATIGRAPHY OF LAHARIC DEPOSITS

AT TYPE AND REFERENCE SECTIONS ON THE SOUTHEASTERN MT RUAPEHU RING PLAIN (0 – 22 500 YEARS B.P.)



KEY

Laharic deposits	Onetapu Formation	Ona – Ong	On
	Manutahi Formation		Mi
	Mangaio Formation		Mn
	Tangatu Formation		Ta
	Te Heuheu Formation		Hh
Rhyolitic tephras	Taupo Pumice		Tp
	Waimihia Tephra		Wm
	Hinemaiaia Tephra		Hm
	Whakatane Tephra		Wk
	Motutere Tephra		Mt
	Waiohau Tephra		Wh
	Rerewhakaaitu Tephra		Rk
Andesitic tephras	Tufa Trig Formation *shaded*	correlated Tufa Trig member (Tf1 – Tf18)	Tf
		uncorrelated Tufa Trig member	uTf
	Mangatawai Tephra		Mg
	Papakai Formation		Pp
		orange lapilli-1	or-1
	Mangamate Tephra		Mm
	Pahoka Tephra		Pa
	Bullot Formation		Bt
		Ngamatea lapilli-2	Nt-2
		Ngamatea lapilli-1	Nt-1
		Shawcroft Tephra	Sh
		Pourahu Member	Ph
		reworked tephra	rw
		uncorrelated medial unit	um
		as above with paleosol development	ump
		uncorrelated lapilli	ul
		uncorrelated ash	ua
	Makahikatoa Sands		Mk

* denotes units radiocarbon dated

~ e denotes erosion break

Grid references based on 1:50 000 NZMS 260 topographical maps

LITHOLOGY

- Debris flow
- Hyperconcentrated flood flow
- Transitional Hyperconpentrated flood flow – Stream flow
- Stream flow

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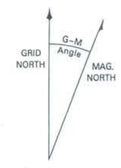
MAGNETIC NORTH on this map is 22° (391 mils) EAST of GRID NORTH during 1983, increasing at the rate of approx. ⅛° (9 mils) over 6 years.



THE VERTICAL INTERVAL BETWEEN THE CONTOURS IS 20 METRES
HEIGHTS ARE IN METRES ABOVE MEAN SEA LEVEL
Contours and spot elevations in forest and snow areas may be less accurate.
Topography by aerial photogrammetry
Date of photography 1977,1979 Date of field check 1981, 1982

This map is drawn on the New Zealand Map Grid Projection, a minimum – error conformal projection. The grid is the New Zealand Map Grid, showing coordinates in metres in terms of the Geodetic Datum 1949, based on the International (Hayford) Spheroid.

WARNING: This map does not show all aerial wires, cable ways and obstructions that could be a hazard to aircraft.

Users noting errors and omissions on this map are urged to mark hereon and forward to the Surveyor General, Private Bag, Wellington. Maps so forwarded will be returned.

Underwater contours represent lake depths in metres.
Data supplied by NZ Oceanographic Institute.

TO GIVE A GRID REFERENCE ON THIS MAP (To nearest 100 metres)			
Disregard the smaller figures of corner grid numbers. They are for finding full coordinates.			
SAMPLE POINT: △ *Mt Ngauruhoe*			
East		**North**	
Locate first VERTICAL grid line to LEFT of point and read figures labelling the line in either the top or bottom margin or across the centre of the map.	37	Locate first HORIZONTAL grid line BELOW point and read figures labelling the line in either the left or right margin or up the centre of the map.	24
Estimate tenths eastward from grid line to point.	7	Estimate tenths northward from grid line to point.	0
	377		240
SAMPLE REFERENCE (Quote sheet number first): T19 377240			

MAP 1
SECTION LOCATIONS

KEY

- Type and reference sections
- Other sections
- Auger sites

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Composite map produced from:
New Zealand Topographical Maps 1:50 000

NZMS 260 Sheet T19	Tongariro
NZMS 260 Sheet T20	Ruapehu
NZMS 260 Sheet S20	Ohakune
NZMS 260 Sheet T21	Taihape

ROADS
Four lanes or more
Two lanes
Narrow road
Vehicle track
Foot track
Road Surface: sealed; metalled; unmetalled
National State Highway
Provincial State Highway
Tunnel
Bridge two lane
Bridge, one lane
Footbridge

WATER FEATURES
Coastal rocks
Sand and mud
Sand
Shingle
Swamp
Dam; waterfall
Cold spring; Hot spring
Drain
Drain beside fence or road
Stream disappears in ground

RELIEF FEATURES
Index contours
Intermediate contours
Supplementary contour
Depression contours
Shallow depressions
Trig station beaconed; unbeaconed
Bench mark
Elevation in metres 130 △1320m
Cliff, terrace
Rock outcrop
Stopbank
Cutting
Embankment
Sandhills
Saddle

RAILWAYS
Double or multiple track
Single track
Station
Railway yard
Level crossing
Road over railway
Railway over road
Tramway

VEGETATION FEATURES
Native forest
Exotic forest
Scrub
Scattered scrub
Shelter belt
Trees
Orchard
Mangroves
Burnt and fallen bush

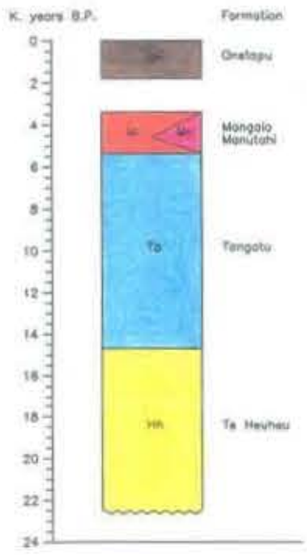
MISCELLANEOUS
Residential area
Large buildings
Building
Homestead Awapuni
Church
Cemetery
Historic Maori Pa
Historic Inscription
Windpump
Lighthouse; beacon
Wreck
Fence (selection only)
Power line on pylons (actual positions)
Power line on poles (away from roads)
Telephone line (away from roads)
Radio mast; T.V. mast
Mine; underground; opencast
Cave
National Park or State Forest Park boundary
Wilderness Area boundary

The representation on this map of a road or track does not necessarily indicate a public right of way

SCALE (km) 0 1 2

MAP 2
DISTRIBUTION OF LAHARIC DEPOSITS ON THE SOUTHEASTERN MT RUAPEHU RING PLAIN

GEOLOGICAL LEGEND



GEOLOGICAL KEY

Approximate boundary

F U / D — Fault trace with direction of movement

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New Zealand Topographical Maps — 1:50 000

NZMS 260 Sheet T20	Ruapehu
NZMS 280 Sheet T21	Taihape