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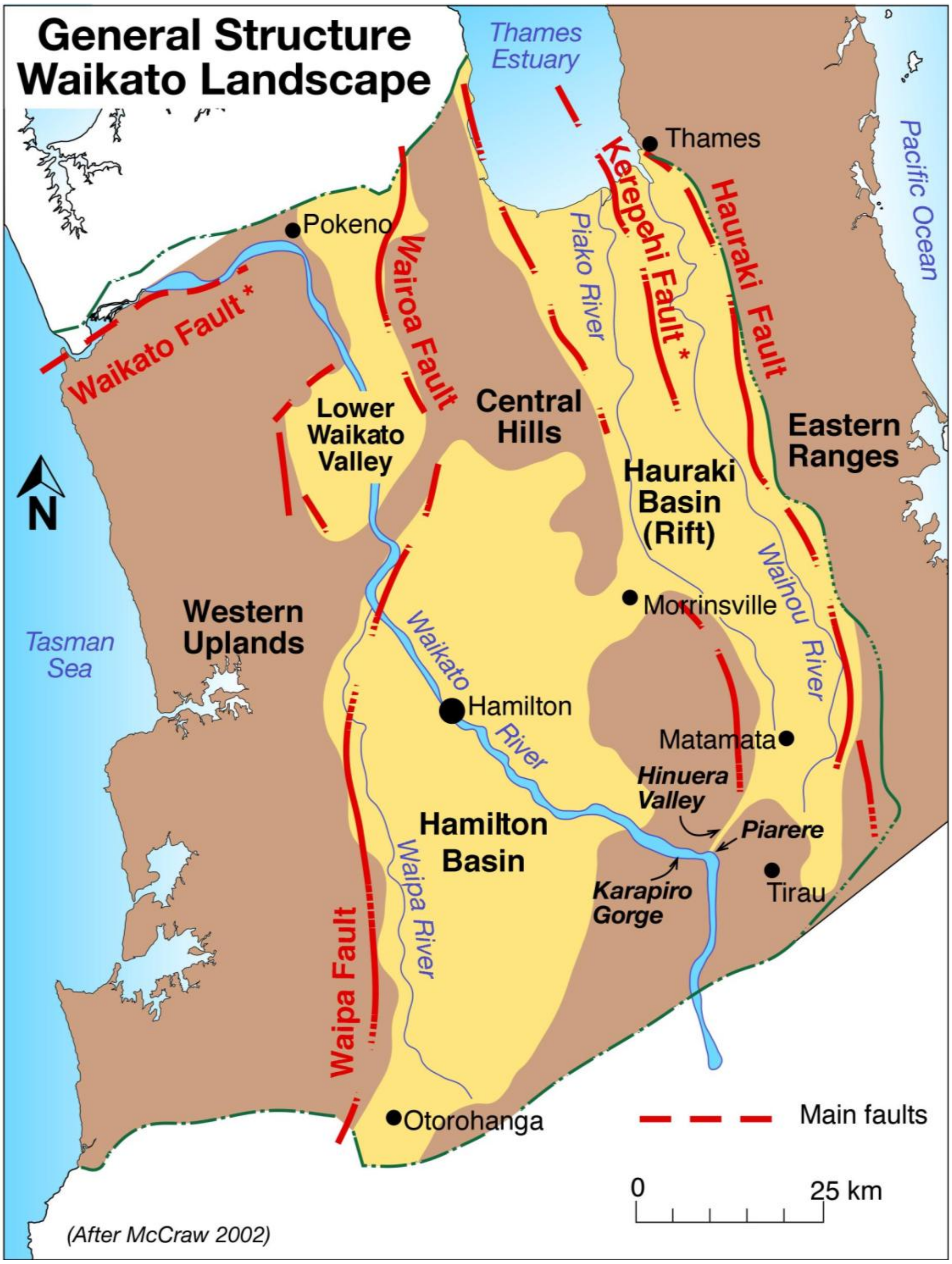
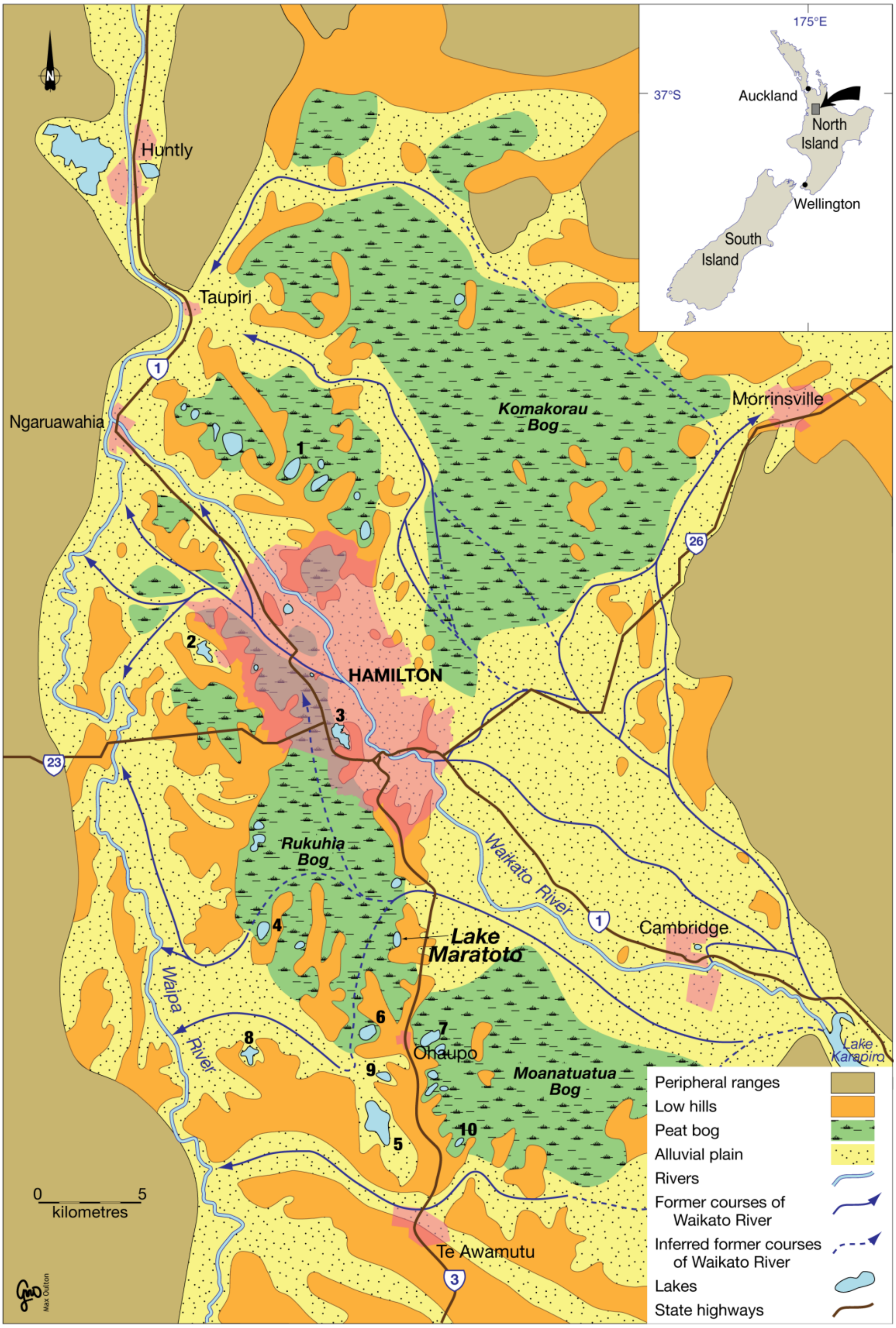
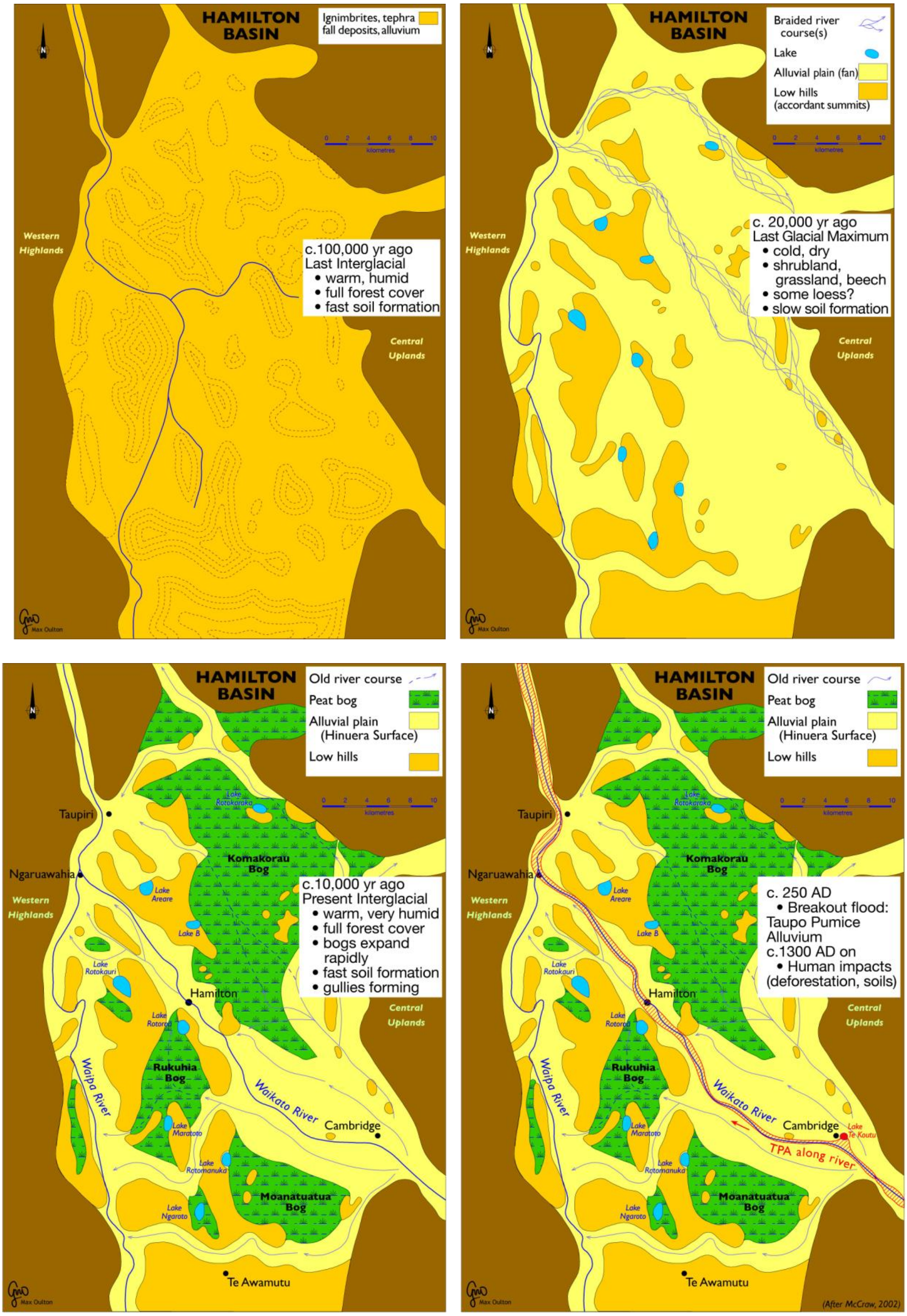
Introduction to the landscapes and soils of the Hamilton Basin



General structure of the Waikato landscape and location of Hamilton Basin (after McCraw, 2002).



Modern landscape features of the Hamilton Basin showing antecedent hills partly buried by volcanogenic alluvium (Hinuera Formation) and post-Hinuera lakes and peat bogs (diagram by D.J. Lowe after McCraw, 2002). Note that the ancestral Waikato River migrated widely in building the low-angle alluvial fans (plain) in the basin; the paleochannels represent just the final stages of river migration and failed downcutting prior to its final incision into the modern channel.



Snapshots at 4 different times since c. 100-125 ka showing the general development of landscape features of the Hamilton Basin. The geology and geomorphic development of the landscape are strongly reflected in the modern soil pattern (diagrams by D.J. Lowe).

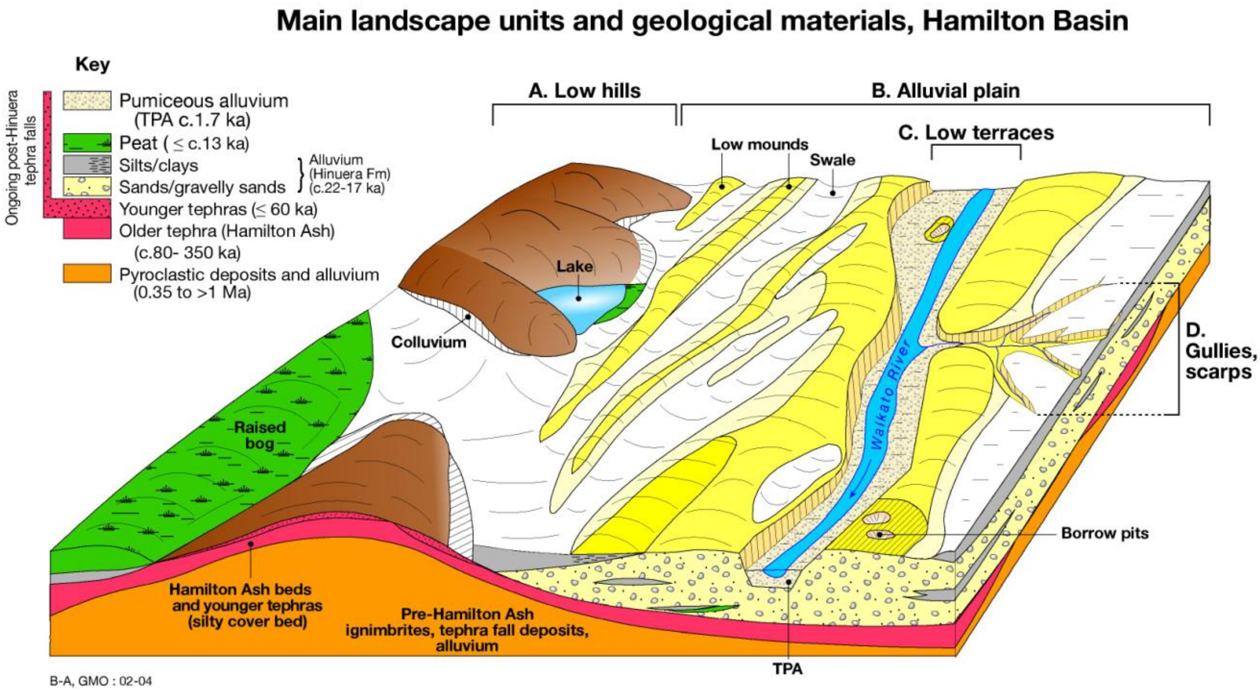
General landscape pattern and soils of the Hamilton Basin

The Hamilton Basin area is characterised by four main landscape units or landforms as depicted in the block diagrams below (McCraw, 1967, 2002; Bruce, 1979; Selby and Lowe, 1992), and these provide a soil-landscape model to predict the soil pattern. The four units are:

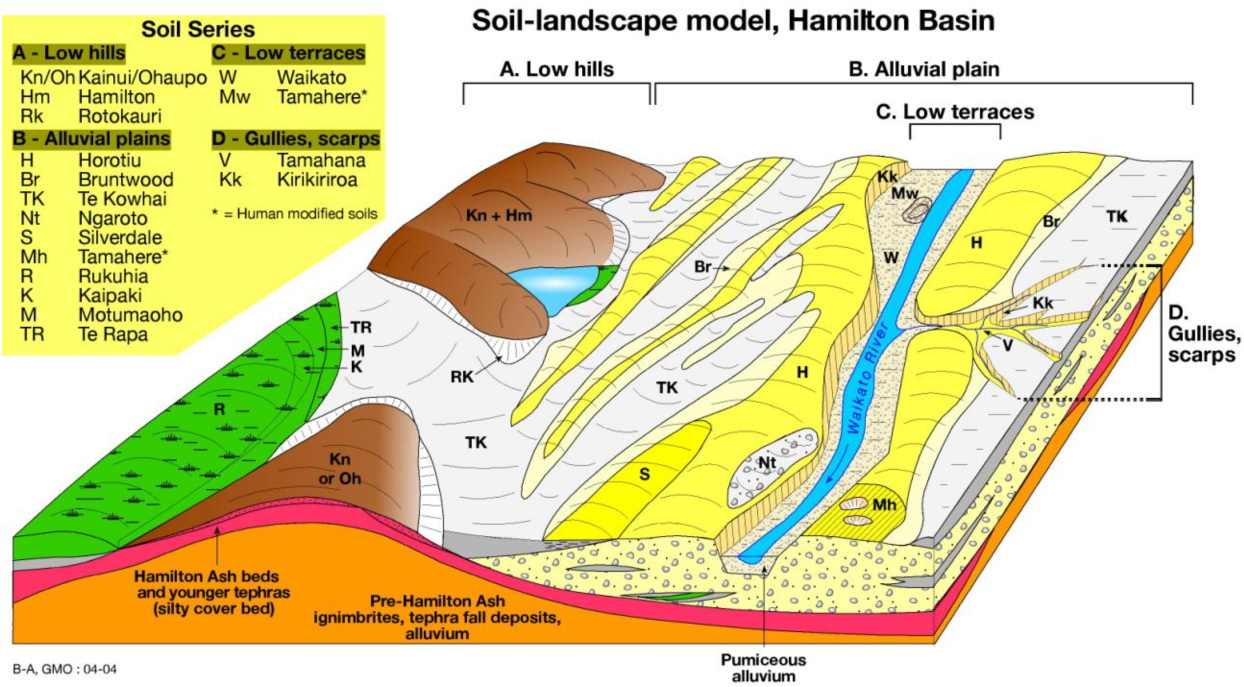
- **Low rolling hills** – the so-called 'Hamilton hills'
- **Flattish alluvial plains** with micro-relief of low mounds (bars) and swales (depressions)
- **Low terraces** adjacent to the modern Waikato River
- **Gullies** cut into the alluvial plain or low terraces and draining to the Waikato River

A. The low rolling hills represent the remnants of a landscape dating back around more than a million years. A drill hole through a hill will typically show the following sequence of deposits (from top down):

- Silty cover bed of post-Hamilton-Ash tephras from multiple sources; ~0.5 m thick; ≤*c*. 60 ka*
- Red-brown, clayey weathered tephra beds (Hamilton Ash); ~1–3 m thick; top bed *c*. 80–125 ka, basal *c*. 350 ka (the dark reddish-brown uppermost buried soil horizon probably represents soil formation during the last interglacial)
- Orange/reddish/cream gravelly alluvial clays (Karapiro Formation); variable thickness (few metres); *c*. 500 ka
- Very dark red-brown, clayey weathered tephra beds (part of Kauroa Ash Formation); patchy; older than *c*. 0.78 Ma (magnetically reversed)
- Cream-coloured ignimbrite (deposit from pyroclastic flows); up to 10–20 m thick. Three main units: Ongatiti Ig., Rocky Hill Ig., Kidnappers Ig., aged from *c*. 1.2 to c. 1.0 Ma, respectively.



* *Note*: ka = thousands of years ago; Ma = millions of years ago



(Previous page) Main landscape units A-D and geological materials and ages in the Hamilton Basin and (above) associated soil series (constructed by D.J. Lowe after McCraw, 1967; Bruce, 1979; Singleton, 1991). The regional geology was described by Kear and Schofield (1978) and Edbrooke (2005); the geomorphology was described by Selby and Lowe (1992).

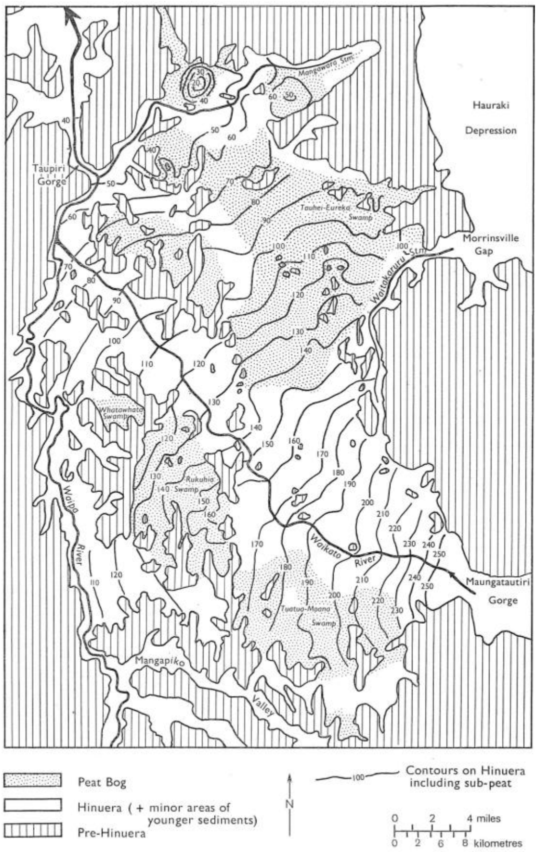
B. The plains represent alluvium derived ultimately from the mainly volcanic catchments of the central North Island and deposited by the ancestral Waipa River and then the ancestral Waikato River system in a series of depositional episodes over the past *c*. 100 ka or so (see maps above). These deposits swept around and over the pre-exisiting hilly landscape in the Waikato, partly burying it so that today we find just remnants of the accordant hills protruding through the essentially flat-lying alluvial surface. The alluvial surface comprises a series of low ridges/bars and swales or depressions; it also slopes very gently in a fan form, the apex at Maungatautari and the toe at Taupiri, ~1 m vertically for every 1 km horizontally (Manville and Wilson, 2004). The ancestral Waikato River was predominantly a high energy, braided system that until c. 22,000 cal. years ago flowed through the Hauraki Basin via the Hinuera Valley to the Thames Estuary/Firth of Thames. It then switched (avulsed) at Piarere near Karapiro to flow into the Hamilton Basin (Manville and Wilson, 2004).

The name of the volcanogenic alluvium deposited by the ancient Waipa and Waikato rivers is the Hinuera Formation, and the surface of the plains is called the Hinuera Surface (Kear and Schofield, 1978; Edbrooke, 2005). The deposits of the Hinuera Formation are up to 60 m thick. The latest depositional episode in the Hamilton Basin was between *c*. 22,000 and 17,000 cal. years ago (Manville and Wilson, 2004). Some time after, the ancestral Waikato River began to entrench, forming terraces, into its modern channel after a series of 'failed' downcutting episodes manifest today as shallow paleochannels in the Hinuera Formation (see map above). Thin but numerous tephra layers (each a few millimetres to a few centimetres in thickness) have blanketed much of the Hinuera Surface in the Hamilton Basin since the surface was abandoned *c*. 17,000 cal. years ago by the entrenching Waikato River. The tephra layers are well preserved in lake sediments (e.g. cores from lakes contain numerous tephra layers: Lowe, 1988) and peat bogs that developed on or alongside the Hinuera deposits (see below).

Slightly undulating surface of the Hinuera Formation – the low gravelly ridge (levee) in foreground (Horotiu soils) drops away to a flat swale towards the right (Te Kowhai soils) and background (note effluent sprayers). Despite being mantled with numerous thin tephras since c. 18 cal ka (~0.4 to ~0.6 m thick in total, see photo below), the subtle ridge-and-swale features derived from braided river channels of the ancestral Waikato River are clearly evident today. Site at Hautapu near Cambridge. Photo: David Lowe

Cross stratified fluvial gravelly sands of c. 18 cal. ka Hinuera Formation overlain by ~0.6 m of thin, intermixed tephras near Hautapu (associated landscape shown in photo above). Sediments comprise mainly quartzo-feldspathic assemblages with rhyolitic rock fragments and subordinate pumice and heavy minerals. Modern soil is Horotiu sandy loam. Cutting tool ~0.3 m in length. Photo: D.J. Lowe.

The soil pattern on the tephra-draped Hinuera Surface mimicks the alluvial depositional environments: well drained soils occur on the slightly raised channel/bar deposits (Horotiu soils comprise tephra fallout cover on coarse alluvium) and poorly drained soils occur on lower-lying 'swales' containing volcanogenic overbank flood deposits (Te Kowhai, Ngaroto, and Matangi soils). Of these, the silt-rich Te Kowhai soils are most common. In between are the Bruntwood soils (well drained upper, poorly drained lower horizons) and Silverdale soils (moderately well drained upper and poorly drained lower horizons). We aim to see examples of the Horotiu-Bruntwood-Te Kowhai soils at Stop 2 that mark a low-elevation toposequence across raised channel/bar deposits through to a swale.



Contours in feet on the Hinuera Surface in the Hamilton Basin showing fan form (from Kear and Schofield, 1978). Slope of fan surface is ~1 m per km.
(1 foot = 0.305 m hence 250 ft = 76 m, 100 ft = 31 m, 50 ft = 15 m).

To the north and south of Hamilton, large raised bogs have developed on the Hinuera Surface. Initially low-lying wet areas, including near lakes, the peats spread and thickened and coalesced into raised bogs when net precipitation in the region increased at c. 13,000 cal years ago (Green and Lowe, 1985). Soils on the deepest parts of the bogs, entirely formed in deep peat, are the Rukuhia soils; those towards the margins are the Kaipaki soils (peat ~1 m thick), and those on the margins are the Motumaoho or Te Rapa soils (~30-40 cm of peat on volcanogenic alluvium). Te Rapa soils are present on Scott Farm at Stop 2.

Along the Waikato and Waipa rivers are numerous examples of human-modified soils (Tamahere series) adapted for growing tropical sweet potato (kumara) by early Maori (Gumbley et al., 2004). These soils typically have overthickened, charcoal-bearing topsoils to which gravels and sands have been added, these being excavated from adjacent small quarries or 'borrow pits' in the Hinuera Formation. The soils were mounded into small hillocks called *puke* to provide perfect drainage conditions, increase soil temperatures, and provide an interface for better tuber development. The growing conditions were adapted from yam-growing practises in the Pacific islands. *Puke* means 'yam-growing mound' in proto-Polynesian. The kumara was imported to temperate New Zealand by early Polynesian sailors.

C. The lowermost terraces adjacent to the modern Waikato River mark deposition from a dramatic break-out flood event about 250 AD ago following the latest eruption of Taupo Volcano (in 232 ± 5 AD). Huge quantities of pumiceous deposits were swept down the Waikato River, which rose several metres to tens of metres, and then left stranded as terrace deposits adjacent to the main river channel and up tributary valleys or gullies that drained into it (Manville et al., 1999, 2007; Manville, 2001, 2002). The deposits are known as the Taupo Pumice Alluvium and are up to ~30 m thick. Soils developed on these materials (Waikato series) are weakly formed because of their young age. On SH 1, the Cambridge Golf Course boasts that it was 'sculptured by the Waikato River 15,000 years ago'. This is untrue: the course is dominated by deposits and paleochannels of the Taupo Pumice Alluvium of *c*. 250 AD, only *c*. 1750 cal. years ago (the earlier Hinuera Formation materials are well buried underneath or were cannibalized during the Taupo break-out flood event).

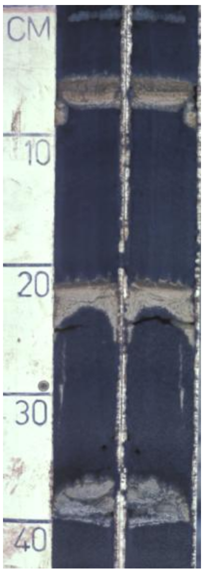
D. Gullies are occasionally cut into the Hinuera Surface, usually draining towards the modern Waikato River. Soils of the gully sides, and terrace scarps, are Kirkiriroa series and soils on the recent alluvium in gully bottoms are Tamahana series. Many gullies in the Hamilton area, some previously used as rubbish dumps, are being restored with native forest as an important and distinctive part of the landscape and to increase native bird life.

(Above)
Lake Maratoto, south of Hamilton, was formed c. 20 cal ka. It is a world reference locality for the Pleistocene-Holocene boundary (marked by Konini Tephra c. 11,700 cal BP).

(Above right)
The first core of 33 eventually taken from the lake (April 1979). Grey layer near base is alluvium overlying dark proto-lake lake sediment (near tape head) and pre-lake soil (Green and Lowe, 1985). Photo: Rex Julian

(Right)
Close up of tephras in core from Lake Rotongata (SW of Putaruru). VC = volcanic centre.

Photos: David Lowe



Tuhua c. 7 cal ka
(Mayor Is./Tuhua VC)

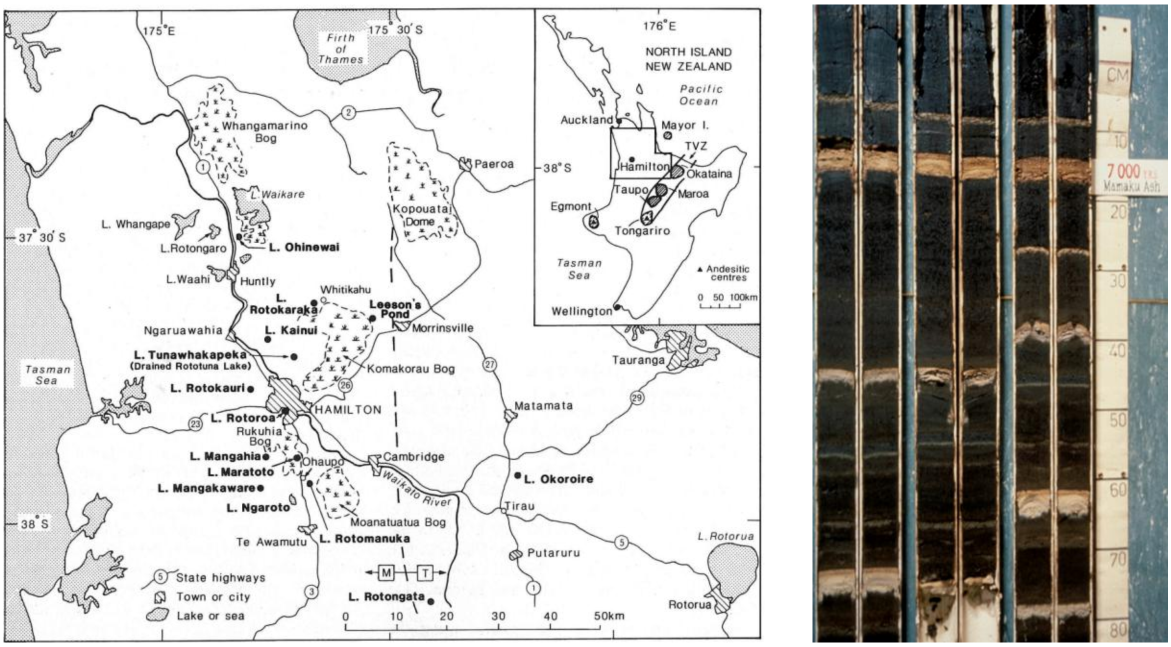
Mamaku c. 8 cal ka
(Okataina VC)

Rotoma c. 9.5 cal ka
(Okataina VC)

Opepe (E) c. 10.1 cal ka
(Taupo VC)

Lakes and peat bogs as tephra archives

Numerous lakes were formed as a result of deposition of sediments (Hinuera Formation) by the ancestral Waikato River system c. 20,000 to 17,000 cal. years ago. Where sediment was deposited alongside an embayment in the antecedent hills, a small basin was able to form and drainage from the hills eventually resulted in it being filled with a lake. Examples include Lake Maratoto (see photo above), Lake Rotoroa (Hamilton Lake), Lake Ngaroto, Lake Rotokauri, Lake Kainui (D), and Lake Rotomanuka. Most of the lakes in the Hamilton Basin date to this time (Lowe and Green, 1992). All contain about 2–4 m of lake sediment within which are preserved >40 multiple, thin, visible tephra layers within their sediments (e.g. Green and Lowe, 1985; Lowe, 1988). These tephras, derived from six volcanic centres, each range in thickness from a few millimetres to several centimetres and in this area amount to an estimated ~40 cm in total thickness (Lowe, 1988). The average rate of tephra accumulation in the Hamilton Basin since c. 18 cal. ka is ~4 mm per century. Numerous cryptotephras (glass-shard or crystal concentrations preserved in sediments but not visible as a layer to the naked eye) (Alloway et al., 2007a) are also present. From recent work on lake cores and peat bogs, such cryptotephras are confirmed in the Waikato region (Gehrels et al., 2006, 2008) and thus probably were assimilated into modern soils as ‘dustings’ from small-scale eruption plumes.

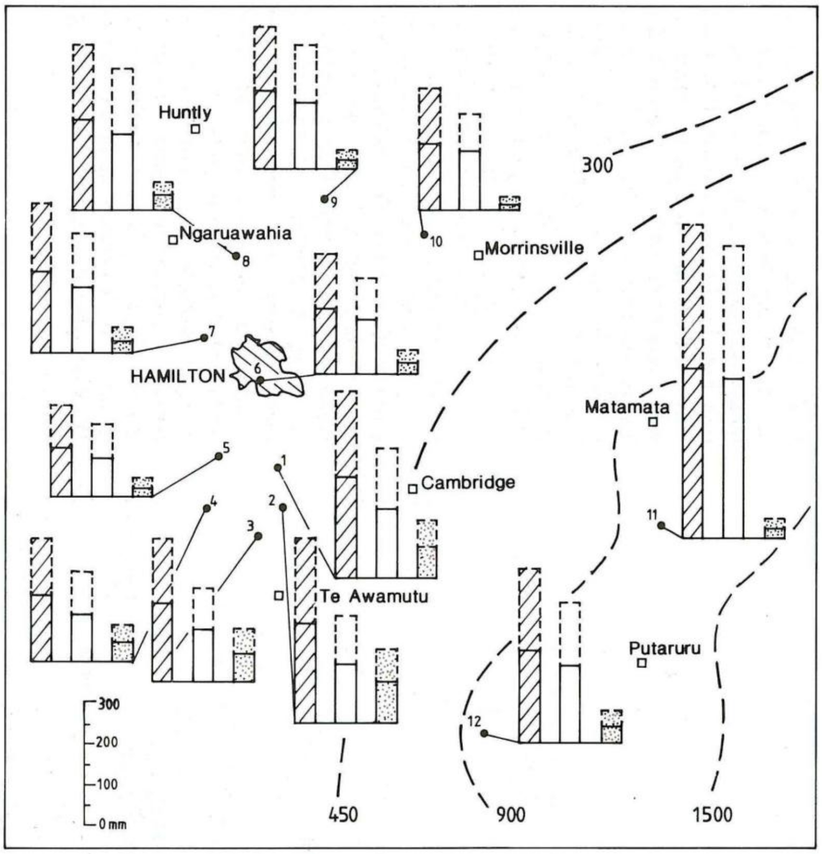


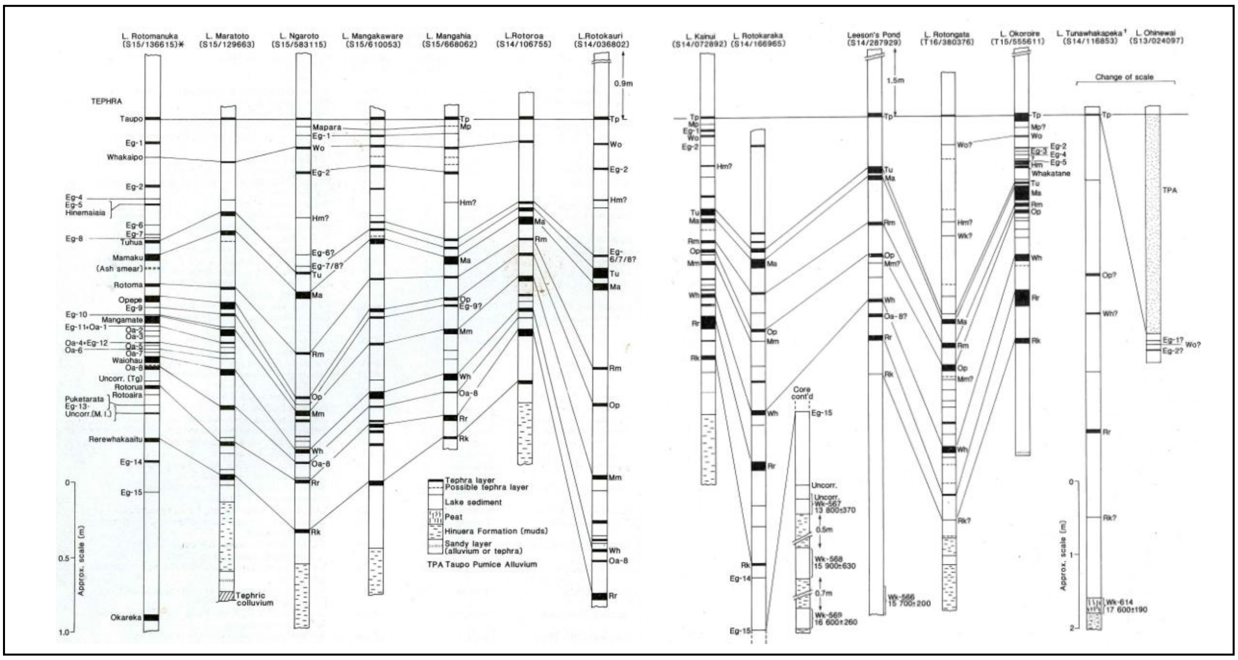
(Left) Waikato area showing locations of lakes cored to obtain detailed post-c. 20 cal ka tephra record. Scott Farm site is just above the word 'HAMILTON' by SH 26. (Right) Cores from Lake Rotomanuka opened to show tephra layers preserved in dark lake sediments (from Lowe, 1988).

Many lakes, including L. Rotoroa, were deepened by the growth of peat on top of the Hinuera Formation from *c.* 13,000 cal. yes ago, which formed a second ‘storey’ to the dam impounding the lake waters. Lake Maratoto has been identifed recently as the Australasian reference site (parastratotype) marking the boundary between the Pleistocene and the Holocene in this part of the world, dated at 11,700 cal. yrs BP (the global reference site, called the global stratotype section and point, for this boundary is the Greenland ice core NGRIP) (Walker et al., 2009). Vegetation studies using lakes and peats as archives show that prior to c. 17.5 cal ka the region was dominated by shrubland-grassland with patches of beech and rare podocarps. Full broadleaf-podocarp forest became re-established at c. 17.5 cal ka (Newnham et al., 1989, 1999, 2003; see also Alloway et al., 2007b).

Lake sites are: 1, L. Maratoto; 2, L. Rotomanuka; 3, L. Ngaroto; 4, L. Mangakaware; 5, L. Mangahia; 6, L. Rotoroa; 7, L. Rotokauri (thickness measurements do not include Rerewhakaaitu Ash); 8, L. Kainui; 9, L. Rotokaraka; 10, Leeson's Pond; 11, L. Okoroire; 12, L. Rotongata.

Thickness and compositional relationships based on measurements of tephras in lake cores. Bars with hatching = total thickness of all tephras ≤ c. 20 cal ka; blank bars = rhyolitic tephras; stippled bars = andesitic tephra. Solid bars = actual measurements, dashed bars = thicknesses corrected for compaction and dissemination in sediment cores. Dashed lines = isopachs (in mm) of sum of tephras at subaerial sites deposited since c. 20 cal ka (from Lowe, 1988).





Stratigraphy and correlation of post- c. 20 cal ka visible tephras in cores from 14 Waikato lakes (from Lowe, 1988). It is likely that numerous cryptotephras are also present in the sequences.

Total thicknesses of visible tephras < c. 20 cal ka in central Waikato area based on lake core measurements and estimated 'dry-land' (subaerial) thicknesses (values in cm) (from Lowe, 1988)

Area	Total visible thickness in cores (average)	Compaction - corrected thickness (visible x1.75)	Estimated dissemination thickness (visible x0.1)	Total equivalent dry-land thickness (approx.)
Hamilton–Ohaupo	25	44	2.5	47
Whitikahu–Morrinsville	20	35	2.0	37
Okoroire–Tirau	42	74	4.2	78

*Assumed to represent airfall material only, with no modification to thickness by postdepositional reworking or catchment erosion.

Deposition of the break-out flood deposits of the Taupo Pumice Alluvium at *c*. 250 AD resulted in the formation of several young lakes, including Lake Hakanoa at Huntly and Lake Te Koutu at Cambridge.

Peat bogs are extensive in the Hamilton Basin, as noted earlier. They began as sparse, isolated, scattered swampy hollows on top of the Hinuera Surface in low-lying spots and adjacent to lakes, but massive peat bog formation and coalescence began as regional water tables rose when net rainfall began increasing from about *c*. 13,000 cal. years ago. Especially fast rates of growth occurred because of warm and wet conditions until *c*. 8000 cal. yrs ago when they slowed (Green and Lowe, 1985).

References

Alloway, B.V., Larsen, G., Lowe, D.J., Shane, P.A.R., Westgate, J.A. 2007a. Tephrochronology. *In*: Elias, S.A. (editor-in-chief) *Encyclopaedia of Quaternary Science*. Elsevier, London, pp. 2869-2898.

Alloway, B.V., Lowe, D.J., Barrell, D.J.A., Newnham, R.M., Almond, P.C., Augustinus, P.C., Bertler, N.A., Carter, L., Litchfield, N.J., McGlone, M.S., Shulmeister, J., Vandergoes, M.J., Williams, P.W. and NZ-INTIMATE members 2007b. Towards a climate event stratigraphy for New Zealand over the past 30,000 years (NZ-INTIMATE project). *Journal of Quaternary Science* 22, 9-35.

Bakker, L., Lowe, D.J., Jongmans, A.G. 1996. A micromorphological study of pedogenic processes in an evolutionary soil sequence formed on Late Quaternary rhyolitic tephra deposits, North Island, New Zealand. *Quaternary International* 34-36, 249-261.

Bruce, J.G. 1979. Soils of Hamilton City, North Island, New Zealand. *New Zealand Soil Survey Report* 31. 65p + 1 sheet 1:20,000.

Edbrooke, S.W. (compiler) 2005. Geology of the Waikato area. *Institute of Geological and Nuclear Sciences 1:250,000 Geological Map* 4. 1 sheet + 68p. IGNS, Lower Hutt.

Gehrels, M.J., Lowe, D.J., Hazell, Z.J.; Newnham, R.M. 2006. A continuous 5300-yr Holocene cryptotephrostratigraphic record from northern New Zealand and implications for tephrochronology and volcanic-hazard assessment. *The Holocene* 16, 173-187.

Gehrels, M.J., Newnham, R.M., Lowe, D.J., Wynne, S., Hazell, Z.J., Caseldine, C. 2008. Towards rapid assay of cryptotephra in peat cores: Review and evaluation of selected methods. *Quaternary International* 178, 68-84.

Green, J.D., Lowe, D.J. 1985. Stratigraphy and development of c. 17 000 year old Lake Maratoto, North Island, New Zealand, with some inferences about postglacial climatic change. *New Zealand Journal of Geology and Geophysics* 28, 675-699.

Gumbley, W., Higham, T.F.G., Lowe, D.J. 2004. Prehistoric horticultural adaptation of soils in the middle Waikato Basin: review and evidence from S14/201 and S14/185, Hamilton. *New Zealand Journal of Archaeology* 25, 5-30.

Kear, D.S., Schofield, J.C. 1978. Geology of the Ngaruawahia Subdivision. *New Zealand Geological Survey Bulletin* 88.

Lowe, D.J. 1986. Controls on the rates of weathering and clay mineral genesis in airfall tephras: a review and New Zealand case study. *In:* Colman, S.M., Dethier, D.P. (eds) *Rates of Chemical Weathering of Rocks and Minerals.* Academic Press, Orlando, 265-330.

Lowe, D.J. 1988. Stratigraphy, age, composition, and correlation of late Quaternary tephras interbedded with organic sediments in Waikato lakes, North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 31, 125-165.

Lowe, D.J. 1995. Teaching clays: from ashes to allophane. *In*: Churchman, G.J., Fitzpatrick, R.W., Eggleton, R.A. (eds) *Clays: Controlling the Environment.* Proceedings 10th International Clay Conference, Adelaide, Australia (1993). CSIRO Publishing, Melbourne, 19-23.

Lowe, D.J., Percival, H.J. 1993. Clay mineralogy of tephras and associated paleosols and soils, and hydrothermal deposits, North Island [New Zealand]. *Review and Guide F1 Field Tour – New Zealand*. Tenth International Clay Conference, Adelaide, Australia, 1-110.

Lowe, D.J., Tippett, J.M., Kamp, P.J.J., Liddell, I.J., Briggs, R.M., Horrocks, J.L. 2001. Ages on weathered Plio-Pleistocene tephra sequences, western North Is., New Zealand. *Les Dossiers de l'Archeo-Logis* 1, 45-60.

Manville, V. 2001. Environmental impacts of large-scale explosive rhyolitic eruptions in the central North Island. *In*: Smith, R.T. (ed), Fieldtrip Guides, Geol. Soc. of NZ Annual Conference, University of Waikato, Hamilton. *Geological Society of New Zealand Miscellaneous Publication* 110B, 19pp.

Manville, V. 2002. Sedimentary and geomorphic responses to ignimbrite emplacement: readjustment of the Waikato River after the A.D. 181 Taupo eruption, New Zealand. *The Journal of Geology* 110, 519-541.

Manville, V., Wilson, C.J.N. 2004. The 26.5 ka Oruanui eruption, New Zealand: a review of the roles of volcanism and climate in the post-eruptive sedimentary response. *New Zealand Journal of Geology and Geophysics* 47, 525-547.

Manville, V., White, J.D.L., Houghton, B.F., Wilson, C.J.N. 1999. Paleohydrology and sedimentology of a post-1.8 ka breakout flood from intracaldera Lake Taupo, North Island, New Zealand. *Geological Society of America Bulletin* 111, 1435-1447.

Manville, V., Hodgson, K.A., Nairn, I.A. 2007. A review of break-out floods from volcanogenic lakes in New Zealand. *New Zealand Journal of Geology and Geophysics* 50, 131-150.

McCraw, J.D. 1967. The surface features and soil pattern of the Hamilton Basin. *Earth Science Journal* 1, 59-74.

McCraw, J.D. 2002. Physical environment. In: Clarkson, B., Merrett, M., Downs, T. (eds) *Botany of the Waikato*. Waikato Botanical Society, pp. 13-22.McLeod, M. 1984. Soils of the Waikato lowlands. *NZ Soil Bureau District Office Report* HN 11. 32p + 2 sheets 1: 31,680

Newnham, R.M., Lowe, D.J., Green, J.D. 1989. Palynology, vegetation, and climate of the Waikato lowlands, North Island, New Zealand, since c. 18 000 years ago. *Journal of the Royal Society of New Zealand* 19, 127-150.

Newnham, R.M., Lowe, D.J., Williams, P.W. 1999. Quaternary environmental change in New Zealand: a review. *Progress in Physical Geography* 23, 567-610.

Newnham, R.M., Eden, D.N., Lowe, D.J., Hendy, C.H. 2003. Rerewhakaaitu Tephra, a land-sea marker for the Last Termination in New Zealand, with implications for global climate change. *Quaternary Science Reviews* 22, 289-308.

Parfitt, R.L., Russell, M., Orbell, G.E. 1983. Weathering sequence of soils from volcanic ash involving allophane and halloysite. *Geoderma* 29, 41-57.

Parfitt, R.L., Saigusa, M., Cowie, J.D. 1984. Allophane and halloysite formation in a volcanic ash bed under different moisture conditions. Soil Science 138, 360-364.

Selby, M.J., Lowe, D.J. 1992. The middle Waikato Basin and hills. *In:* Soons, J.M., Selby, M.J. (eds) *Landforms of New Zealand: Second Edition.* Longman Paul, Auckland, 233-255.

Singleton, P.L. 1991. Soils of Ruakura – a window on the Waikato. *DSIR Land Resources Scientific Report* 5. 127 pp. + 1 sheet 1: 5000.

Singleton, P.L., McLeod, M., Percival, H.J. 1989. Allophane and halloysite content and soil solution silicon in soils from rhyolitic volcanic material, New Zealand. *Australian Journal of Soil Research* 27, 67-77.

Walker, M., Johnsen, S., Rasmussen, S.O., Popp, T., Steffensen, J.-P., Gibbard, P., Hoek, W., Lowe, J.J., Andrews, J., Björck, S., Cwynar, L., Hughen, K., Kershaw, P., Kromer, B., Litt, T., Lowe, D.J., Nakagawa, T., Newnham, R.M., Schwander, J. 2009. Formal definition and dating of the GSSP (Global Stratotype Section and Point) for the base of the Holocene using the Greenland NGRIP ice core, and selected auxiliary records. *Journal of Quaternary Science* 24, 3-17.

Wilson, A.D. 1980. Soils of Piako County, North Island, New Zealand. *New Zealand Soil Survey Report* 39. 171 p. + 5 sheets 1: 63,360.

1.5 Stop 2 – DairyNZ Scott Farm Research Centre
Prototype farmlets, Horotiu-Bruntwood-Te Kowhai soils

Location S14 ~186785, elevation 45 m asl, rainfall 1200 mm pa

A 120 ha dairy farm milking 350 cows on a mixture of Allophanic, Gley, and Organic/peaty Gley soils, which vary markedly in their drainage characteristics from well drained to poorly drained. Research programmes are focussed on reducing the environmental impact of intensive dairying.

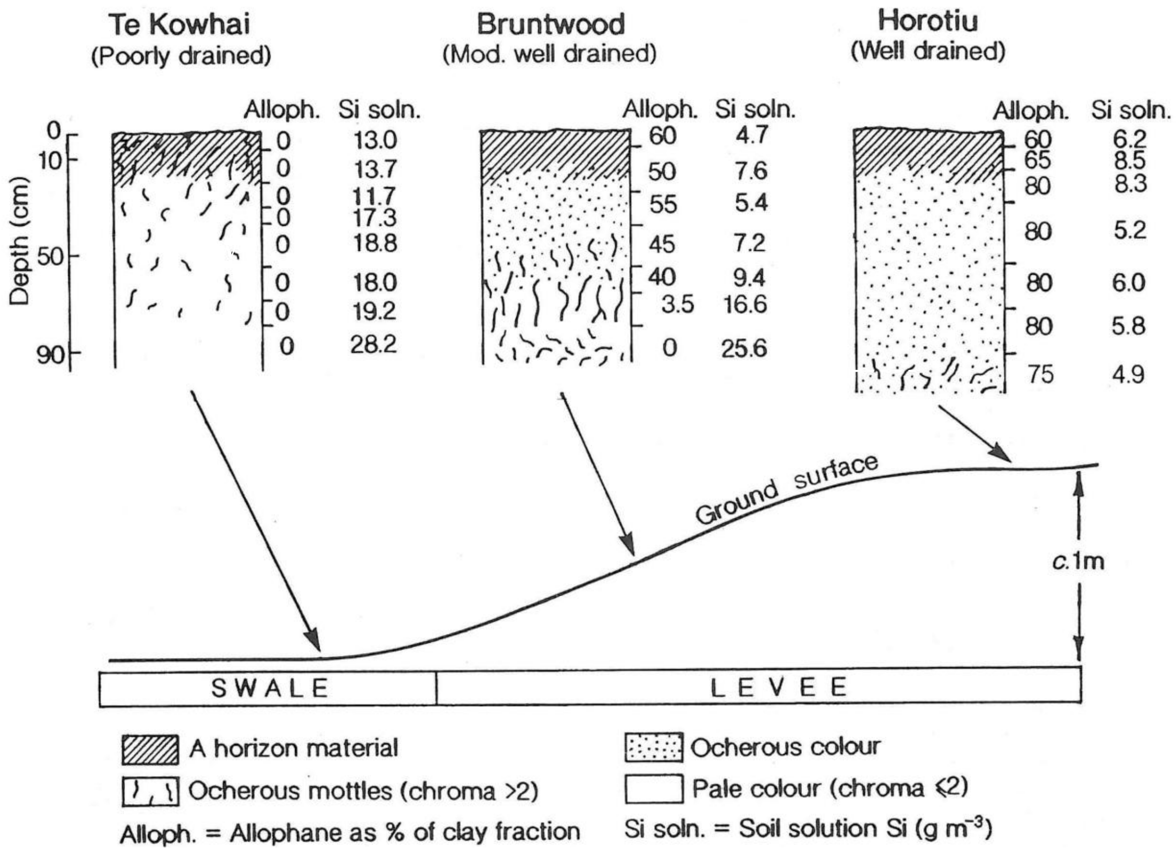
Soils

Soils on Scott Farm include mineral soils in both well-drained to poorly-drained landscape positions on the ash-mantled Hinuera Surface, as well as organic-rich soils developed on shallow peat (~30 cm or more thick) over alluvium. Although the farm soil map indicates that soils on the peaty materials, mapped as Te Rapa series, are Podzol Soils (Spodosols), in my opinion (DJL) they are much more likely to be either Organic Soils or Gley Soils in NZSC depending on the thickness of peat and its organic carbon content. The Te Rapa soils do not have podzolic-B (spodic) horizons. Instead, they are probably either Acid/Mellow Humic Organic Soils (Haplohemists?) or Peaty Acid Gley Soils (Humaquepts?).

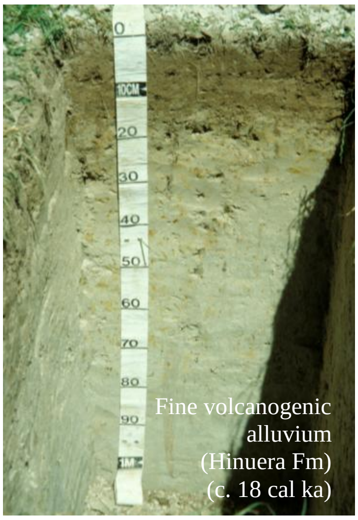
Horotiu soils (Vitric or Typic Hapludands) occur in slightly elevated levees or channel bar positions, manifest as low ridges or mounds, over coarse textured volcanogenic alluvium. They are free-draining and hence have lost silicon in soil solution by leaching and have predominantly allophanic properties. Measurements of Si in soil solution in this soil show concentrations <10 g/m^3 (ppm), therefore favouring the formation of Al-rich allophane (Singleton et al., 1989). **Te Kowahi soils** (Typic Humaquepts) in contrast occur in adjacent depressions or swales where overbank alluvial deposits have finer textures, the soils are less free draining with fluctuating and often high water tables. These soils are non-allophanic because silicon is retained and thus halloysite is the dominant clay. In Te Kowhai soils, measurements of Si in soil solution show concentrations >10 g/m^3 (ppm), therefore favouring the formation of halloysite (Singleton et al., 1989).

In the intermediate landscape positions are the **Bruntwood soils** (Aquic Hapludands) which have allophane in upper horizons and halloysite in lower horizons. Low [Si] levels in soil solution are found in the leached upper horizons and high [Si] levels occur in the poorly drained lower horizons. Thermodynamically, imogolite (and by implication allophane) is more stable than halloysite over a wide range of silicon concentrations (see stability diagram below). Halloysite is more stable than imogolite/allophane only at high silicon activity, with the threshold/cross-over point being about 10-15 ppm Si in soil solution (Singleton et al., 1989; Lowe, 1995; Churchman and Lowe, 2010).

Mineralogically, sand fractions of all three soils are dominated by very abundant volcanic glass and very common plagioclase, with quartz and cristobalite common in Te Kowhai soils (see data sheets below). The alluvium in each soil is identical in age (c. 18 cal ka). Thin intermixed tephras mantle the alluvium for Horotiu and Bruntwood soils, but for Te Kowhai soils the ash mantle seems to have been removed (or blended into upper alluvial materials).

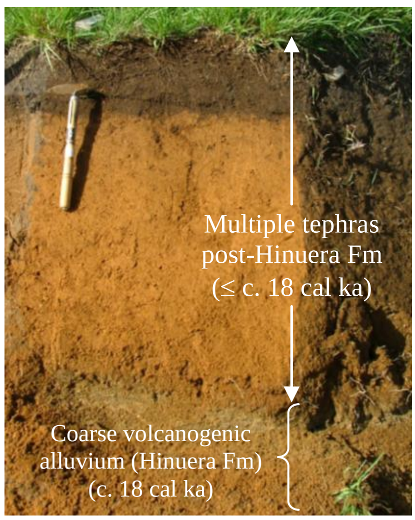


Horotiu–Bruntwoood–Te Kowhai soil drainage leaching sequence and associated mineralogical and soil-solution analyses at Ruakura (after Singleton et al., 1989) (from Lowe and Percival, 1993). The soil solution studies confirmed the general leaching model proposed by Parfitt et al. (1983, 1984) and Lowe (1986). The threshold value of about 10 to 15 ppm of silicon in soil solution matches closely thermodynamic stability diagrams (see diagram below; Lowe, 1995; Churchman and Lowe, 2010). Cutting tool is ~30 cm long.



Te Kowhai

Bruntwood



Horotiu

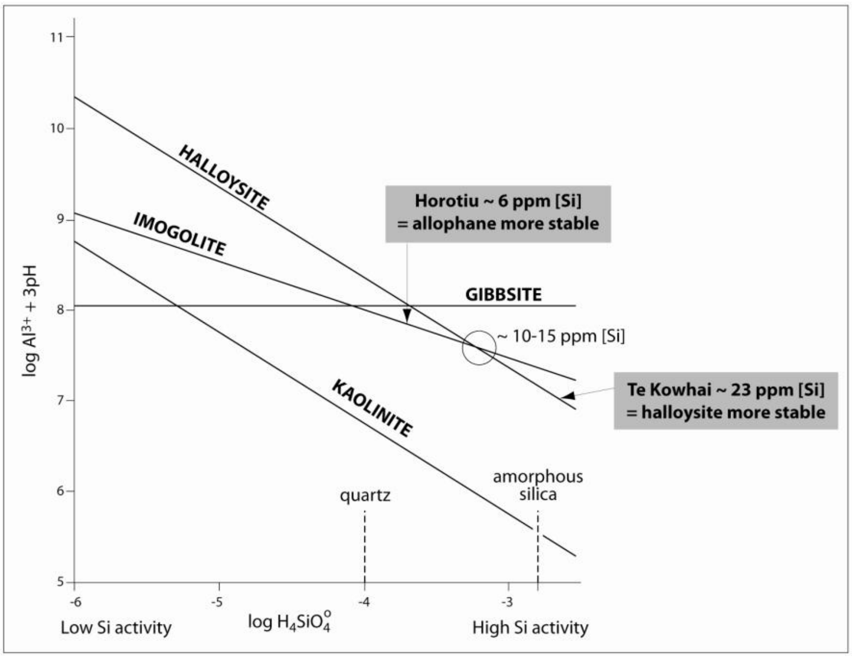
Allophane and halloysite contents, and measurements of silicon in soil solution, in Horotiu, Bruntwood, and Te Kowhai soils near Scott Farm (from Lowe and Percival, 1993, after Singleton et al., 1989)

A, allophane; H, halloysite

Depth (cm)	Horizon	Fe_{py} (%)	Al_{py} (%)	Fe_{ox} (%)	Al_{ox} (%)	Si_{ox} (%)	Soil soln Si (g m^{-3})	Atomic ratio[A]	A (% of clay)	H (% of clay)
Horotiu silt loam, well drained (Sample No. SB 9944)										
0–6	Aw1	0·20	0·56	0·80	3·1	1·1	6·2	2·4	60	35
6–17	Aw2	0·18	0·53	0·79	3·3	1·3	8·5	2·2	65	30
17–31	B/A	0·08	0·34	0·83	3·7	1·6	8·3	2·2	80	15
31–55	Bw1	0·02	0·19	0·79	3·3	1·6	5·2	2·0	80	15
55–73	Bw2	0·02	0·18	0·76	3·7	1·9	6·0	1·9	80	15
73–91	Bw3	0·01	0·12	0·77	3·4	1·6	5·8	2·1	80	15
91–107	2C	0·01	0·12	0·46	2·3	0·97	4·9	2·3	75	20
Bruntwood silt loam, moderately well drained (SB 9952)										
0–7	Aw1	0·24	0·69	1·1	4·0	1·7	4·7	2·0	60	25
7–24	Aw2	0·25	0·76	1·1	4·2	1·6	7·6	2·2	50	25
24–38	Bw	0·02	0·27	1·0	4·5	2·5	5·4	1·6	55	20
38–57	Bg1	0·01	0·16	0·67	3·9	1·6	7·2	2·4	45	25
57–67	Bg2	0·01	0·10	0·66	1·6	0·98	9·4	1·6	40	35
67–79	Bg3	0·02	0·03	0·24	0·23	0·09	16·6	2·3	3·5	60
79–105	2Cr	0·01	0·02	0·10	0·10	0·02	25·6	—[B]	0	75
Te Kowhai silt loam, poorly drained (SB 9945)										
0–9	Aw	0·20	0·06	0·33	0·33	0·05	13·0	—	0	35
9–22	A/B	0·11	0·06	0·34	0·35	0·05	13·7	—	0	35
22–32	B/A	0·09	0·04	0·44	0·44	0·06	11·7	—	0	40
32–39	Br1	0·08	0·02	0·28	0·28	0·05	17·3	—	0	40
39–57	Br2	0·08	0·02	0·32	0·11	0·06	18·8	—	0	40
57–70	2Br1	0·09	0·04	0·30	0·13	0·06	18·0	—	0	45
70–80	2Br2	0·06	0·07	0·11	0·19	0·07	19·2	—	0	40
80–93	3Cr	0·01	0·05	0·03	0·11	0·04	28·2	—	0	55

[A] $(Al_{ox}-Al_{py})/Si_{ox}$

[B] Insufficient allophane present.



Stability of kaolinite (Al: Si = 1: 1), halloysite (Al: Si = 1: 1), and imogolite (Al: Si = 2: 1) compared with that of gibbsite (after Lowe and Percival, 1993, after Percival, 1985). An Al-rich allophane line is likely to parallel the imogolite line and to be in a similar position, i.e., have similar or possibly slightly greater stability (Lowe and Percival, 1993). Generally, stability increases downwards in the figure (solubility decreases). Soil solution data from Singleton et al. (1989).

Clay skins in an Andisol

Note that Bakker et al. (1996) reported micro-laminated, anisotropic, clay coatings bridging rounded grains of fluvial origin in BCt and 2bBCt horizons of the Horotiu soil at Pony Club pit (Gordonton Rd) in Hamilton. The undisturbed character of the delicate coatings indicated that illuviation took place after deposition of the sediment. Such illuviation had not previously been reported in soils of the Horotiu series, nor, possibly, in Andisols (McDaniel et al., 2011).

References

Bakker, L., Lowe, D.J., Jongmans, A.G. 1996. A micromorphological study of pedogenic processes in an evolutionary soil sequence formed on Late Quaternary rhyolitic tephra deposits, North Island, New Zealand. *Quaternary International* 34-36, 249-261.

Churchman, G.J., Lowe, D.J. 2010. Alteration, formation, and occurrence of minerals in soils. *In*: Sumner, M.E. (ed) *Handbook of Soil Science, 2nd edition*. CRC Press (Taylor and Francis), London (in press)

Gumbley, W., Higham, T.F.G., Lowe, D.J. 2004. Prehistoric horticultural adaptation of soils in the middle Waikato Basin: review and evidence from S14/201 and S14/185, Hamilton. *New Zealand Journal of Archaeology* 25, 5-30.

Lowe, D.J. 1986. Controls on the rates of weathering and clay mineral genesis in airfall tephras: a review and New Zealand case study. *In:* Colman, S.M., Dethier, D.P. (eds) *Rates of Chemical Weathering of Rocks and Minerals.* Academic Press, Orlando, 265-330.

Lowe, D.J. 1988. Stratigraphy, age, composition, and correlation of late Quaternary tephras interbedded with organic sediments in Waikato lakes, North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 31, 125-165

Lowe, D.J. 1995. Teaching clays: from ashes to allophane. *In*: Churchman, G.J., Fitzpatrick, R.W., Eggleton, R.A. (eds) *Clays: Controlling the Environment.* Proceedings 10th International Clay Conference, Adelaide, Australia (1993). CSIRO Publishing, Melbourne, 19-23.

Lowe, D.J., Percival, H.J. 1993. Clay mineralogy of tephras and associated paleosols and soils, and hydrothermal deposits, North Island [New Zealand]. *Review and Guide F1 Field Tour – New Zealand*. Tenth International Clay Conference, Adelaide, Australia, 1-110.

McCraw, J.D. 2002. Physical environment. In: Clarkson, B., Merrett, M., Downs, T. (eds) *Botany of the Waikato*. Waikato Botanical Society, pp. 13-22.

McDaniel, P.A.; Lowe, D.J.; Arnalds, O.; Ping, C.-L. 2011. Andisols. *In*: Sumner, M.E. (ed) *Handbook of Soil Science, 2nd edition.* CRC Press (Taylor and Francis), London (in press).

Parfitt, R.L., Russell, M., Orbell, G.E. 1983. Weathering sequence of soils from volcanic ash involving allophane and halloysite. *Geoderma* 29, 41-57.

Parfitt, R.L., Saigusa, M., Cowie, J.D. 1984. Allophane and hallloysite formation in a volcanic ash bed under different moisture conditions. Soil Science 138, 360-364.

Parfitt, R.L., Pollok, J., Furkert, R.J. 1981. Guide book for tour 1, North Island. *International 'Soils With Variable Charge' conference*, Palmerston North, Feb 1981 (pp. 84-90)

Percival, H.J. 1985. Soil solutions, minerals, and equilibria. *New Zealand Soil Bureau Scientific Report* 69. 21p.

Singleton, P.L. 1991. Soils of Ruakura – a window on the Waikato. *DSIR Land Resources Scientific Report* 5. 127 pp. + 1 sheet 1: 5000.

Singleton, P.L., McLeod, M., Percival, H.J. 1989. Allophane and halloysite content and soil solution silicon in soils from rhyolitic volcanic material, New Zealand. *Australian Journal of Soil Research* 27, 67-77.

Description of Horotiu soil at former Hamilton East Pony Club pit, Gordonton Rd (S14 119820), from Parfitt et al. (1981) (see also Bakker et al., 1996)

HOROTIU SILT LOAM

Location: 50 m south side of southeastern corner of old quarry, on crest of levee, 10 m west of power pole

Aspect: - Altitude (m): 30 Rainfall (mm): 1270

Vegetation: Improved pasture species - rye grass, white clover

Land use: Dairying, stud stock (include race horses), orchards, maize, cropping

Grid ref: N56/796526

Slope: Flat to gently undulating Landform: Low angle fan

Drainage class: Well drained

Parent material: Rewashed predominantly rhyolite sands and gravels. (Hinuera Formation). Possibly some airfall tephra on surface.

PROFILE DESCRIPTION

Horizon	Depth (cm)	
Ap	0-18	dark brown (10YR 3/8) silt loam; friable; moderately developed medium and fine nut structure breaking to moderately developed medium crumb structure; many fine roots; distinct smooth boundary,
Bw1	18-34	dark yellowish brown (10YR 4/6) greasy silt loam; very friable; very weakly developed coarse block structure breaking to medium fine crumb structure; many fine roots; few prominent coarse humus lined worm channels; distinct wavy boundary,
Bw2	34-43	yellowish brown (10YR 5/6) greasy silt loam; slightly firm; moderately developed fine block structure breaking to moderately developed fine crumb structure; some fine roots; diffuse wavy boundary,
BC	43-72	yellowish brown (10YR 5/8) greasy gritty silt loam; slightly firm; weakly developed coarse block structure breaking to moderately developed medium crumb structure; few fine roots; diffuse smooth boundary,
Cs	72-75	dark reddish brown (5YR 3/4) and strong brown (7.5YR 5/8) gravelly sand; hard; massive breaking to single grain; distinct smooth boundary,
2C	75-100	rounded gravels and coarse sand (Hinuera Formation).

CHEMISTRY HOROTIU SILT LOAM

Sample No. SB	Depth (cm)	Hor.	pH H_2O	pH KCl	pH ΔpH	pH NaF	Exchangeable cations (meq/100 g) Ca	Mg	K	Na	H (KCl)	Al (KCl)	Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	ECEC	CEC (meq/100 g) NH_4OAc (pH 7)	Σ Cations (pH 8.2)	Base saturation (%) Σ bases / CEC NH_4OAc	Σ bases / Σ Cations
9434 A	0-18	Ap	4.8	4.3	-0.5	10.2	2.9	0.29	0.44	0.16		1.07	51.0	49.9	4.9	25.1	54.8	15	7
B	18-34	Bw1	5.7	5.3	-0.4	10.2	3.4	0.24	0.33	0.12		0.02	36.5	36.5	4.1	17.0	40.6	24	10
C	34-43	Bw2	6.4	5.7	-0.7	10.1	5.1	0.33	0.25	0.27		0.02	25.8	25.8	6.0	12.7	31.8	47	19
D	43-55	BC1	6.8	5.7	-1.1	9.6	4.9	0.79	0.32	0.45		0.02	13.6	13.6	6.5	10.1	20.1	64	32
E	55-72	BC2	7.0	5.4	-1.6	8.7	3.7	0.69	0.36	0.37		0.02	5.6	5.6	5.1	6.9	10.7	74	48
F	72-75 75-100	Cs 2C	6.6	5.1	-1.5	7.9	1.2	0.22	0.17	0.18		0.00	3.3	3.3	1.8	2.7	5.1	67	35

Sample No. SB	Depth (cm)	Hor.	Total C (%)	Total N (%)	P (mg/100 g) H_2SO_4 (0.5 M)	Inorg.	Org.	P Retention (%)	Dithion. cit. (%) Fe	Al	Tamm ox. (%) Fe	Al	Si	Pyrophos. (%) Fe	Al	Reserves (meq/100 g) K_c	Mg_r	Extractable S (ppm)
9434 A	0-18	Ap	8.2	0.67	51	63	72	98	1.43	1.08	0.96	3.4	1.15	0.34	0.84	0.18	1.3	124
B	18-34	Bw1	3.3	0.27	15	20	29	99	2.0	1.20	1.34	4.5	1.98	0.14	0.48	0.18	1.3	225
C	34-43	Bw2	1.5	0.11	9	13	12	98	1.70	0.76	1.09	3.2	1.60	0.03	0.29			205
D	43-55	BC1	0.6	0.04	5	10	7	81	1.25	0.44	0.60	1.21	0.62	0.03	0.16			80
E	55-72	BC2	0.3	0.02	4	7	6	36	1.13	0.15	0.27	0.21	0.11	0.03	0.06			1
F	72-75 75-100	Cs 2C	0.1	0.01	16	23	6	16	0.54	0.08	0.13	0.09	0.05	0.00	0.02			0

PHYSICS

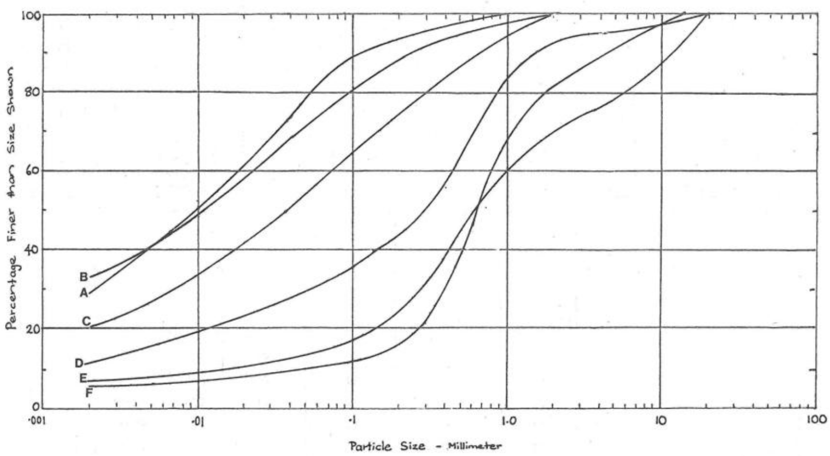
Hor. Depth (cm)	Hor.	15 bar water Field moist (%)	Air Dry (%)
0-18	Ap	25.6	22.3
18-34	Bw1	43.9	20.5
34-43	Bw2	37.5	18.3
43-55	BC1	23.4	14.8
55-72	BC2	13.5	10.5
75-100	2C	3.7	3.3

Core Depth (cm)	Dry bulk density (T/m^3)	Total porosity (%)	Large pores (%)	Field Cap. (at 0.2 bar) (% v/v)	Wilting Pt. (at 15 bar) (% v/v)	Available water (% v/v)
2-9	0.80					
20-27	0.62					
35-42	0.72					
49-56	0.96					

PARTICLE SIZE DISTRIBUTION (<2 mm) Horotiu Silt Loam

Sample No. SB	Depth (cm)	Hor.	Sand 2-0.1 mm (%)	Sand 0.1-0.05 mm (%)	Silt 0.05-0.002 mm (%)	Clay <0.002 mm (%)	Fine clay <0.0002 mm (%)	Fine clay / Total clay	Stones (%)
9434A	0-18	Ap	12	12	56	20			
B	18-34	Bw1	8	12	67	13			
C	34-43	Bw2	9	14	63	14			
D	43-55	BC1	11	17	50	22			
E	55-72	BC2	30	15	35	20			
F	75-100	2C	83	5	7	5			

SB 9434 Horotiu Silt Loam



Mineralogy HOROTIU

Sample No. SB	Depth (cm)	Hor.	Mica-Smectite	Mica-Vermiculite	Smectite	Vermiculite	Interlayered Hydrous Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Cristobalite	Allophane	Feldspar	Anatase	Volcanic glass
			Clay Fraction (%)														
9434A	0-18								12	18	2		2	50			16
B	18-34								9	18	1		2	62			8
C	34-43								9	21	tr		6	55			9
D	43-55								8	42	tr		4	20			26
E	55-72									67	tr		5	8			20
F	75-100									72			tr	8			20

Classification: Horotiu sandy loam [Pony Club site]

NZSC: Typic Orthic Allophanic Soils; tephric, mixed rhyolitic and andesitic; silty/sandy; moderate/rapid

Soil Taxonomy: Medial/sandy-skeletal, thermic Vitric Hapludands

Description of Te Kowhai soil near former Hamilton East Pony Club pit, Gordonton Rd (S14 118820), from Parfitt et al. (1981)

TE KOWHAI SILT LOAM

Location: 20 m south of southeast corner of old sand quarry
Grid ref: N56/795526
Aspect: - **Altitude (m):** 30 **Rainfall (mm):** 1270
Slope: Flat to gently undulating **Landform:** Low angle fan
Vegetation: Improved pasture species - rye grass, white clover, paspalum, flat weeds
Drainage class: Poorly drained
Land use: Dairying, stud stock, maize cropping
Parent material: "Pumice" clays and silts, rarely sands (Hinuera Formation)

PROFILE DESCRIPTION

Horizon	Depth (cm)	
Ap	0-18	very dark grey (7.5YR 3/1) silt loam; slightly firm; strongly developed coarse and medium nut structure breaking to moderately developed medium crumb structure; many fine roots; few fine Mn concretions; few fine inclusions of underlying horizon; distinct irregular boundary,
Bg1	18-38	light grey (2.5YR 7/2) silt loam; firm; weakly developed coarse prismatic structure to massive; many dark reddish brown (5YR 3/2) prominent fine and medium soft Mn concretions; few roots down prism faces; few vertical tongues and infillings of Ap horizon material; few very coarse worm channels lined with organic material; diffuse irregular boundary,
Bg2	38-53	light grey (7.5YR 7/2) silt loam; firm; weakly developed coarse prismatic structure to massive; few dark reddish brown (5YR 3/2) prominent fine soft Mn concretions; few fine roots; very few thin humus coatings on ped faces; few very coarse worm channels; diffuse wavy boundary,
2Cg1	53-90	light grey (5YR 7/2) fine loamy sand; firm; massive; very few roots; distinct smooth boundary,
2Cg2	90-100	light grey (5YR 7/2) fine sand; loose; massive breaking to single grain.

CHEMISTRY TE KOWHAI SILT LOAM

Sample No. SB	Depth (cm)	Hor.	pH H_2O	pH KCl	pH ΔpH	pH NaF	Exchangeable cations (meq/100 g) Ca	Mg	K	Na	H (KCl)	Al (KCl)	Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	ECEC	CEC (meq/100 g) NH_4OAc (pH 7)	CEC Σ Cations (pH 8.2)	Base saturation (%) Σ bases / CEC NH_4OAc	Σ bases / Σ Cations
9433 A	0-18	Ap	4.5	3.9	-0.6	8.0	4.3	0.60	0.77	0.21		1.23	19.8	18.5	7.1	14.4	25.7	41	23
B	18-38	Bg1	4.6	3.8	-0.8	8.0	2.7	0.33	0.27	0.21		1.02	8.4	7.4	4.5	7.6	11.9	46	29
C	38-53	Bg2	5.2	3.9	-1.3	8.1	4.1	1.23	0.11	0.33		0.79	9.3	8.5	6.6	10.4	15.1	56	38
D	53-70	2Cg1	5.6	4.1	-1.5	8.0	3.2	1.73	0.11	0.45		0.20	7.2	7.0	5.7	8.1	12.7	68	43
E	70-90	2Cg1	6.0	4.3	-1.7	7.9	2.0	1.58	0.16	0.35		0.03	3.3	3.3	4.1	5.4	7.4	76	55
F	90-100	2Cg2	6.0	4.4	-1.6	7.8	1.7	0.73	0.17	0.21		0.03	2.8	2.8	2.8	3.6	5.6	78	50

Sample No. SB	Depth (cm)	Hor.	Total C (%)	Total N (%)	P (mg/100 g) H_2SO_4 (0.5 M)	P Inorg.	P Org.	P Retention (%)	Dithion. cit. (%) Fe	Dithion. cit. Al	Tamm ox. (%) Fe	Tamm ox. Al	Tamm ox. Si	Pyrophos. (%) Fe	Pyrophos. Al	Reserves (meq/100 g) K_c	Reserves Mg_r	Extractable S (ppm)
9433 A	0-18	Ap	3.8	0.33	16	23	49	28	0.26	0.08	0.18	0.21	0.04	0.13	0.15	0.40	1.2	41
B	18-38	Bg1	0.4	0.05	2	6	7	21	0.26	0.03	0.13	0.11	0.03	0.00	0.02	0.29	0.7	16
C	38-53	Bg2	0.3	0.03	2	6	5	25	0.21	0.05	0.05	0.12	0.02	0.00	0.03			9
D	53-70	2Cg1	0.2	0.01	2	6	3	15	0.08	0.03	0.02	0.10	0.02	0.00	0.02			1
E	70-90	2Cg1	0.1	0.01	3	6	2	11	0.10	0.03	0.02	0.05	0.00	0.00	0.02			0
F	90-100	2Cg2	0.1	0.01	3	7	2	9	0.10	0.03	0.02	0.04	0.01	0.00	0.02			0

PHYSICS

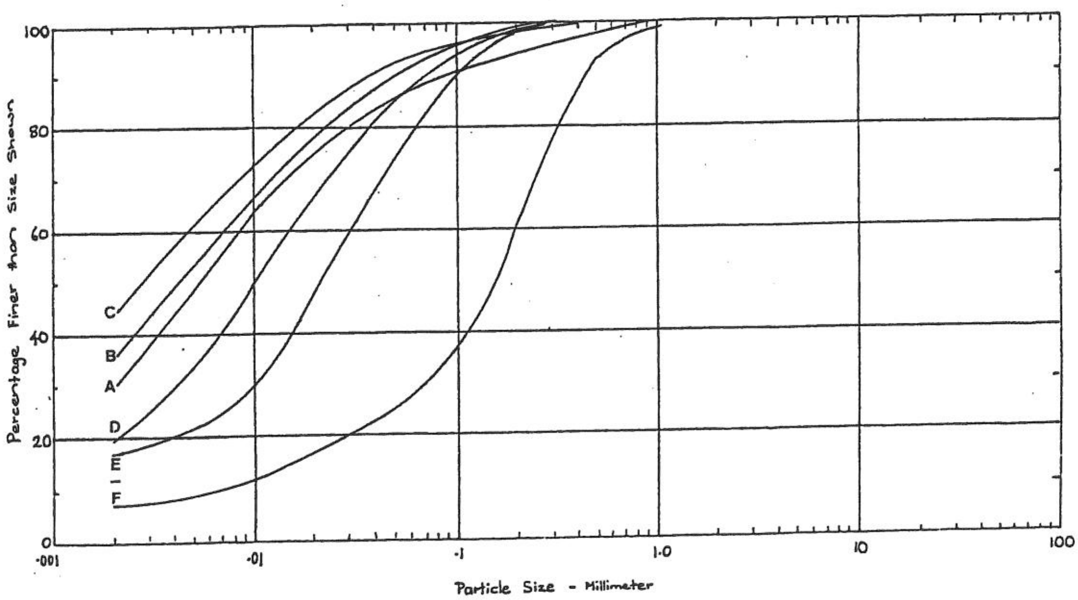
Hor. Depth (cm)	Hor.	15 bar water Field moist (%)	15 bar water Air Dry (%)
0-18	Ap	17.9	15.1
18-38	Bg1	16.6	13.0
38-53	Bg2	25.9	19.4
53-70	2Cg1	18.0	12.6
70-90	2Cg2	12.2	7.9
90-100	2Cg2	5.7	4.4

Core Depth (cm)	Dry bulk density (T/m^3)	Total porosity (%)	Large pores (%)	Field Cap. (at 0.2 bar) (% v/v)	Wilting Pt. (at 15 bar) (% v/v)	Available water (% v/v)
3-10	1.02					
25-32	1.26					
41-48	1.17					
57-64	1.09					
73-80	1.16					
91-98	1.17					

PARTICLE SIZE DISTRIBUTION (<2 mm) Te Kowhai Silt Loam

Sample No. SB	Depth (cm)	Hor.	Sand 2-0.1 mm (%)	Sand 0.1-0.05 mm (%)	Silt 0.05-0.002 mm (%)	Clay <0.002 mm (%)	Fine clay <0.0002 mm (%)	Fine clay / Total clay	Stones (%)
9433A	0-18	Ap	9	6	55	30			
B	18-38	Bg1	5	6	53	36			
C	38-53	Bg2	4	4	47	45			
D	53-70	2Cg1	5	10	66	19			
E	70-90	2Cg1	8	19	56	17			
F	90-100	2Cg2	64	11	18	7			

SB 9433 Te Kowhai Silt Loam



Mineralogy TE KOWHAI

Sample No. SB	Depth (cm)	Hor.	Clay Fraction (%): Mica-Smectite	Mica-Vermiculite	Smectite	Vermiculite	Interlayered Hydrous Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Cristobalite	Allophane	Feldspar	Anatase	Volcanic glass
9433A	0-18								27	33			6	8			26
B	18-38								24	36			4	8			28
C	38-53								20	50			2	8			20
D	53-70								13	52			1	8			26
E	70-90									63			tr	10			26
F	90-100									62			tr	8			30

Sample No. SB	Sand Fraction (%): Quartz	Feldspar (acid)	Andesine	Glass	Muscovite	Biotite	Horneblende	Augite	Hypersthene	Epidote	Zoisite	Apatite	Magnetite	Plant opal
9433A														
B														
C														
D														
E														
F														

Classification: Te Kowhai silt loam [Pony Club site]
NZSC: Acidic Orthic Gley Soils; tephric, rhyolitic; silty; slow
Soil Taxonomy: Fine/fine silty, mixed, thermic Typic Humaquepts

Classification: Bruntwood silt loam [Pony Club site, no data available]
NZSC: Mottled Orthic Allophanic Soils; tephric, mixed rhyolitic and andesitic; silty; moderate/slow
Soil Taxonomy: Medial/fine-silty, thermic Aquic Hapludands

Summmary of possible nutrient deficiencies under pastoral farming (from W.M.H. Saunders in Singleton, 1991)

Soil name	Possible nutrient deficiencies Pasture	Stock	Stocking rates (stock units/ha) Present[1]	Potential(?)
Horotiu	N P K S Mg	Co Se	30	32
Bruntwood	N P K S Mg	Se	30	32
Te Kowhai	N P K S Mg	Se	30	32
Te Rapa	N P K S Mg Cu Mo?	Se Cu	28	30
Motumaoho	N P K S Mg Cu Mo?	Se Cu	28	30
Kaipaki	N P K S Mg Cu Mo?	Se Cu	28	30
Hamilton	N P K S Mg	–	30	32

[1] These are stocking rates which are current on Ruakura Agricultural Centre. The averages on commercial farms are about 80% of these. There are, however, commercial farms with equally high stocking rates.

Classification of soils according to their actual or potential value for food production (from Singleton, 1991)

Class 1:	Soils of high actual or potential value for food production.
1A	*Soils of high actual value for food production.*
	Horotiu soils Bruntwood silt loam Hamilton clay loam Hamilton clay loam, easy rolling phase Hamilton clay loam, brown subsoil variant Te Rapa humic silt loam and peaty silt loam Te Rapa brown and shallow brown variants Silverdale silt loam and clay loam.
1B	*Soils of high potential value for food production.*
	Bruntwood silt loam, pale subsoil variant Te Kowhai soils Te Rapa pale subsoil variant Motumaoho silty peat drained phase Motumaoho shallow silty peat, drained phase Rotokauri clay loam.
Class 2:	Soils of moderate actual or potential value for food production.
	Hamilton clay loam, strongly rolling phase Hamilton clay loam, brown subsoil variant, strongly rolling phase Horsham clay loam Kaipaki peat.
Class 3:	Soils of low actual or potential value for food production.
	Not represented in this survey.

Land-use suitability classifications of Waikato soils for various uses are given by Singleton (1990); one example is shown above. The Horotiu soils are highly versatile soils (classed as 1s1 ***in LUC) that are able to successfully grow most horticultural (and other) crops provided they are climatically suited to the Waikato region (the main limiting factor can be water availability, and irrigation is desirable and essential for some permanent crops). Horotiu soils are especially good for the production of asparagus (which requires a free root run and good drainage), and stone and pip fruit, cereals, vegetables and berry fruit (S.J. Franklin in Singleton, 1991).***

1.6 Transit from Scott Farm (Stop 2) to Mokai (Stop 3), Taupo

After leaving Scott Farm at Newstead near Hamilton, the road to Cambridge gradually climbs (rising about 1 metre every kilometre travelled) up the very low-angle alluvial fans of the (composite tephra-draped) Hinuera Surface towards the eastern margins of the Hamilton Basin. We briefly descend onto the younger Taupo Pumice Alluvium (c. 250 AD) past the Cambridge Golf Course (with the false advertising) before returning to the Hinuera Surface. Andesite-dacite Maungatautari stratovolcano (797 m, age 1.8 Ma) features near Lake Karapiro. The forested upper slopes of Mt Maungatautari have been totally enclosed with a predator-proof fence as part of a new project to restore animal life to New Zealand forests using the concept of 'ecological islands' of which the Maungatautari Trust project is the leading example. An enclosure within the main fenceline on the southern slopes (off Tari Rd) is being stocked with kiwi in an attempt to halt their rapidly declining numbers.

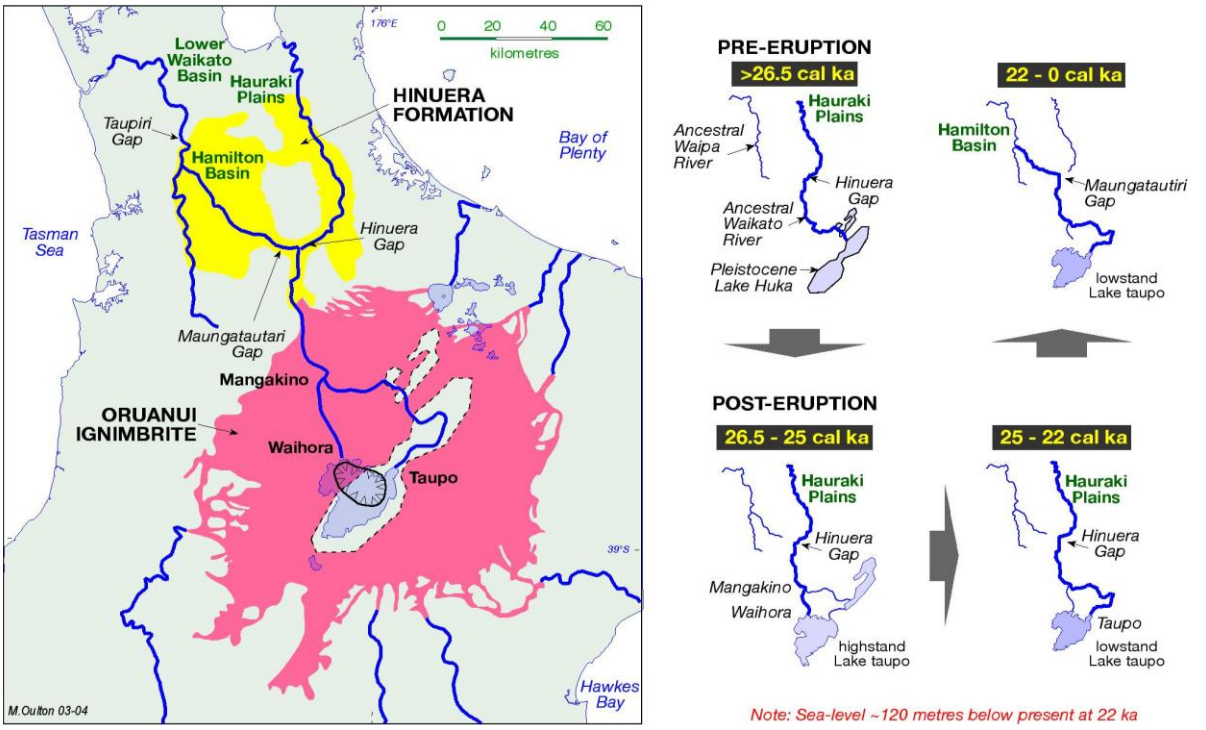


Diagram depicting the impacts of the Oruanui/Kawakawa eruption of Taupo caldera volcano (c. 27,100 cal. yrs BP) on the ancestral Waikato River (after Manville, 2001). Note distribution of Hinuera Formation (volcanogenic sediments) in both Hauraki and Hamilton basins. Hinuera Formation sediments in the Hauraki Plains extend well beyond the marked area into the Firth of Thames and are more voluminous than those in the Hamilton Basin (Manville and Wilson, 2004).

Gradually the landscape becomes steeper and hillier as the underlying ignimbrites become thicker. Tephra layers amounting to several metres or more in thickness drape most of the landscape and become thicker as we get closer to their source volcanoes in central TVZ. The impacts of mass movement, especially slumping and soil creep, become evident in the hillsides. Such slumping (on pasture) can be triggered by high intensity storms every c. 20-30 years on average (under native forest slumping occurs every c. 100 yrs) (Selby, 1974, 1976).

At Piarere the geological framework of the hills becomes obvious as a three-tiered landscape repesenting three welded ignimbrite units all derived from Mangakino caldera volcano in

TVZ: Ongatiti (1.23 Ma), Ahuroa (~1.1 Ma), and Rocky Hill (~1.0 Ma). The Ongatiti Ignimbrite is quarried nearby (Hinuera) and sold as brick used for cladding: 'Hinuera Stone'. The cliffs of Ongatiti Ignimbrite marking the Hinuera Valley margins featured in the first of the *Lord of the Rings* film series. Tirau soils (Typic Hapludands) drape the landscape and an example will be seen at Stop 5 on Day 4. Note that the famous hypothetical **nine-unit landscape model** was developed in this area by Dalrymple et al. (1968).

Triple-tier landscape at Piarere relating to three welded ignimbrite sheets aged c. 1.2 to 1.0 Ma. Photo: D.J. Lowe

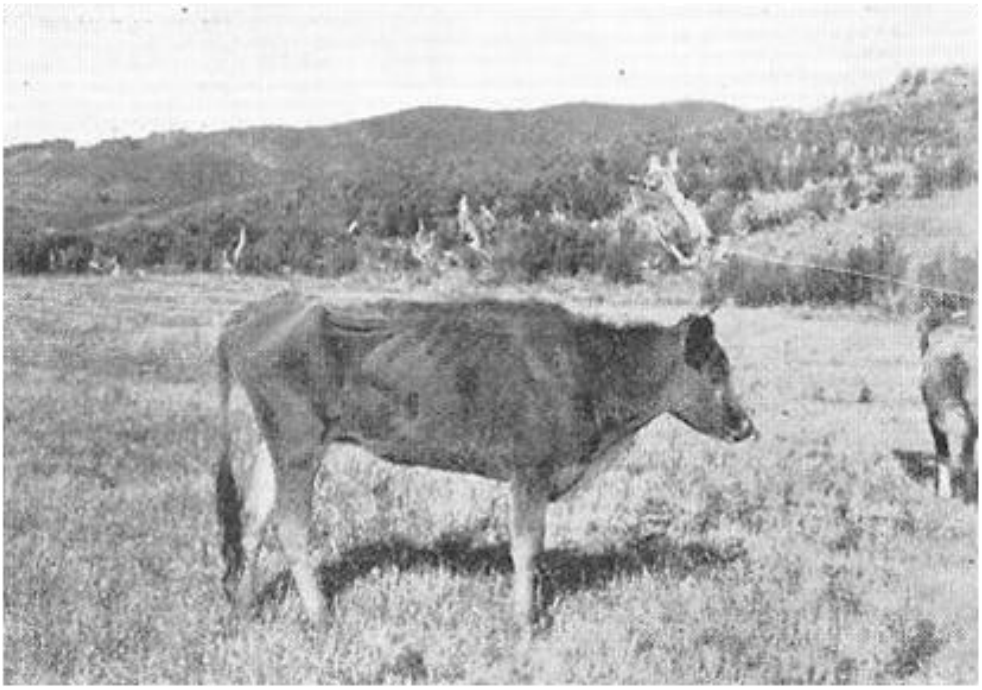
From Tirau southward the road climbs gradually onto more sheets of ignimbrites derived from a number of sources. The soils in this region are the result of upbuilding pedogenesis, mainly developmental but occasionally retardant when thicker tephras are emplaced (see diagram and photo below). At Litchfield, just south of Putaruru, the distal feather edge of the nonwelded Taupo Ignimbrite (c. 232 AD) forms the uppermost soil-forming parent material in many places from here until we reach Lake Taupo. The low Co content of soils developed on Taupo Tephra led to a vitamin-B12 related stock wasting disease of ruminants (especially sheep and cattle) in the early part of the 20^{th} Century ("bush sickness") in this and other parts of central North Island (see Day 4) and the remedy, discovered in the mid 1930s by Australian and New Zealand scientists, was first employed in this area on K.S. Cox's farm. Cobalt is an essential requirement for red blood cell production.

First studies on possible causes publ. 1911, became incr. urgent in late 1920s ⇒ many farms on Pumice Soils abandoned

In 1934 Grimmett and Shorland (DSIR) discovered trace cobalt in iron → effective as 'licks'→ made connection

Co identified as cause in 1935 (Underwood & Filmer 1935 *Austr. Vet. Jl* 11, 84-92)

Landscape at Litchfield underlain by Taupo soils and associated Co-deficiency. The deficiency is remedied by topdressing with cobaltalised superphosphate (100-200 g per ha), spraying pastures, oral dosing or drinking-water additives, salt licks, or long-lasting injections. Photo: David Lowe



'Bush–sick' cow on Taupo soil at Ngaroma, South Waikato (from Grange & Taylor 1932)

Partly as a result of these agricultural problems, a forestry industry became established, the mainstay tree being *Pinus radiata* from California (known as Monterey pine). *P. radiata* has been very successful, it matures rapidly in about 27 years on average, and can grow on 'clapped out' soils with little problem. Its roots can easily punch through surficial pumice deposits to reach nutrients and water in buried soil horizons. The soils to the east of SH1 between Putaruru and Tokoroa are now growing their 4th crop (rotation) of *P. radiata*. The importance of this tree to New Zealand will become very evident as we head to Tokoroa and on to Taupo! Palmer et al. (2005) used a P-based nutrient model to establish that *P. radiata* was growing sustainably after two rotations on Spodosols developed on Taupo Ignimbrite in elevated areas on the southern Mamaku Plateau to the east of Tokoroa. Models to predict *Pinus radiata* productivity throughout New Zealand have recently been developed by Watt et al. (2010). Various spatial prediction techniques for developing *Pinus radiata* productivity surfaces across New Zealand were compared by Palmer et al. (2010).

As we head towards Mokai north of Taupo, the landscape steepens with numerous rhyolite lava domes evident within this central part of the TVZ.

Young pines growing in raw pumice (from Molloy and Christie, 1998)

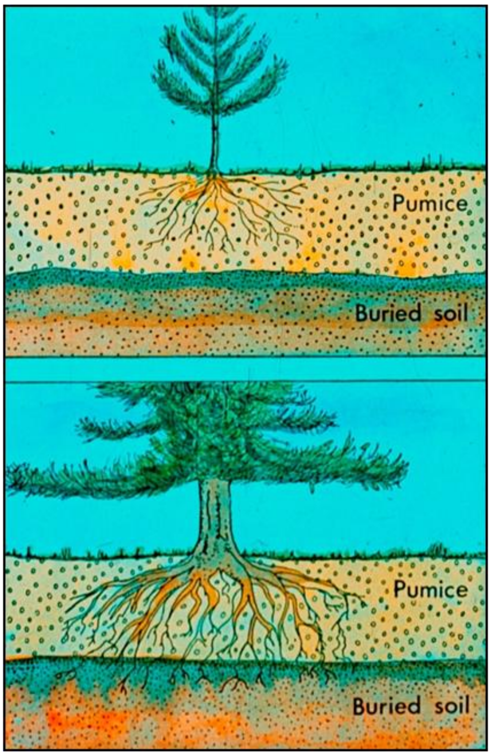


Diagram showing how* P. radiata *can exploit buried soils (courtesy of J.D. McCraw)

Eucalyptus *spp. are also planted in central North Island for the paper industry.*

Dalrymple, J.B., Blong, R.J., Conacher, A.J. 1968. An hypothetical nine unit landsurface model. *Zeitschrift für Geomorphologie* 12, 61-76.

Grange, L. I., and Taylor, N. H., 1932. The distribution and field characteristics of bush-sick soils. Part 2A. In: Bush Sickness. *N.Z. Department of Scientific and Industrial Research Bulletin* 32, pp. 21-35.

Lowe, D.J. 2000. Upbuilding pedogenesis in multisequal tephra-derived soils in the Waikato region. *In:* Adams, J.A.; Metherell, A.K. (eds), Proceedings, Australian & New Zealand 2nd Joint Soils Conference, Lincoln University. N.Z. Society of Soil Science 2, 183-184

Lowe, D.J., Tonkin, P.J., Palmer, A.S., Palmer, J. 2008. Dusty horizons. *In*: Graham, I.J. (chief editor) "A Continent on the Move: New Zealand Geoscience into the 21st Century". *Geological Society of New Zealand Miscellaneous Publication* 124**,** 270-273.

Manville, V. 2001. Environmental impacts of large-scale explosive rhyolitic eruptions in the central North Island. *In*: Smith, R.T. (ed), Fieldtrip Guides, Geol. Soc. of NZ Annual Conference, University of Waikato, Hamilton. *Geological Society of New Zealand Miscellaneous Publication* 110B, 19pp.

Manville, V. 2002. Sedimentary and geomorphic responses to ignimbrite emplacement: readjustment of the Waikato River after the A.D. 181 Taupo eruption, New Zealand. *The Journal of Geology* 110, 519-541.

Manville, V., Wilson, C.J.N. 2004. The 26.5 ka Oruanui eruption, New Zealand: a review of the roles of volcanism and climate in the post-eruptive sedimentary response. *New Zealand Journal of Geology and Geophysics* 47, 525-547.

Manville, V., White, J.D.L., Houghton, B.F., Wilson, C.J.N. 1999. Paleohydrology and sedimentology of a post-1.8 ka breakout flood from intracaldera Lake Taupo, North Island, New Zealand. *Geological Society of America Bulletin* 111, 1435-1447.

Molloy, L., Christie, Q. 1998. *Soils in the New Zealand Landscape*, 2nd edition. NZ Society of Soil Science.

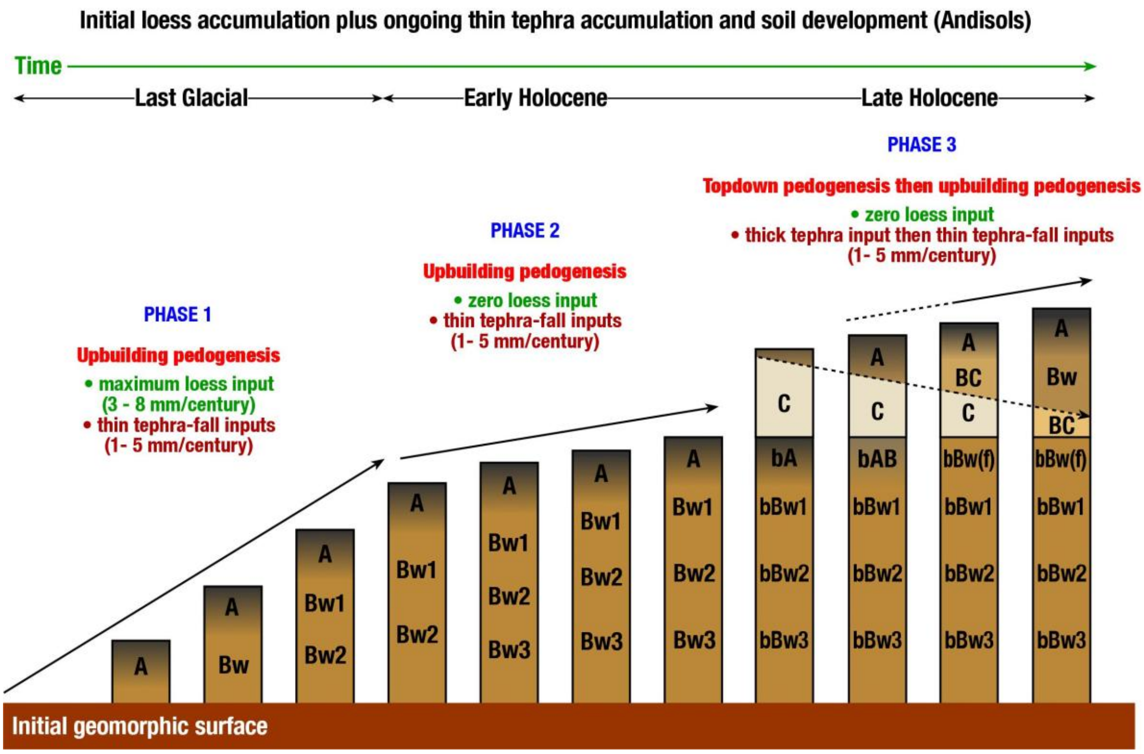
Palmer, D.J., Lowe, D.J., Payn, T.W., Höck, B.K., McLay, C.D.A., Kimberley, M.O. 2005. Soil and foliar phosphorus as indicators of sustainability for *Pinus radiata* plantation forestry in New Zealand. *Forest Ecology and Management* 220, 140-154.

Palmer, D.J., Höck, B.K., Kimberley, M.O., Lowe, D.J., Payn, T.W. 2009. Comparison of spatial prediction techniques for developing *Pinus radiata* productivity surfaces across New Zealand. *Forest Ecology and Management* 258, 2046-2055.

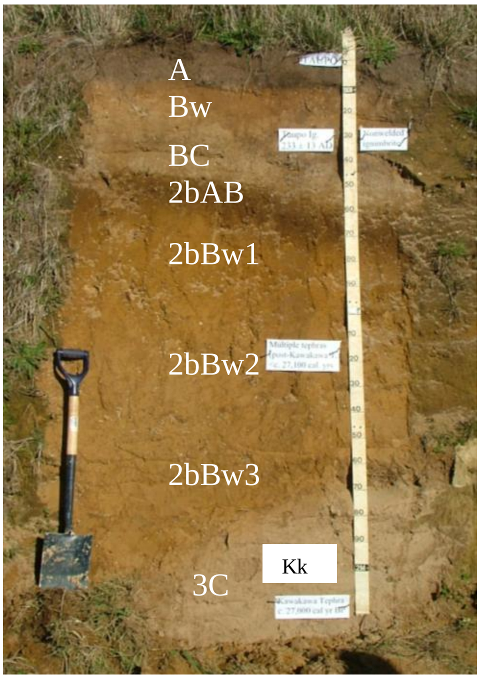
Selby, M.J. 1974. Dominant geomorphic events in landform evolution. *Bulletin of Engineering Geology and the Environment* 9, 85-89.

Selby, M.J. 1976. Slope erosion due to extreme rainfall: a case study from New Zealand. *Geografiska Annaler* 58A, 131-138.

Watt, M.J., Palmer, D.J., Kimberley, M.O., Höck, B.K., Payn, T., Lowe, D.J. 2010. Development of models to predict *Pinus radiata* productivity throughout New Zealand. *Canadian Journal of Forest Research* 40, 488-499.



Model of soil development in the eastern Waikato area near Tirau-Putaruru via upbuilding pedogenesis (after Lowe, 2000; Lowe et al., 2008). Most parts of the soil columns have at some time been 'temporary' A horizons. Rates of tephra and tephric loess accumulation in the Putaruru-Tapapa area since c. 27 cal ka average about 7 mm per century (cf. ~4 mm per century for the Horotiu soil since c. 18 cal. ka). Most of the time the upbuilding is developmental as the rates of addition are sufficiently slow to allow topdown pedogenesis to continue as the land surface gently rises, but occasionally a thicker deposit, such as Taupo ignimbrite as depicted above in phase 3, effectively seals off the antecedent soil and soil formation begins anew on the fresh parent materials (i.e. retardant upbuilding). To what extent the properties of the buried soil horizons change subsequently depends on a range of factors including the depth of burial and whether the horizons are effectively isolated or within range of various soil-forming process, and diagenesis.



Soil profile at Kokako Rd near Litchfield showing results of upbuilding pedogenesis. Photo: D.J. Lowe

Taupo Ignimbrite c. 232 AD

Multiple thin intermixed tephra layers deposited after Kawakawa Tephra & before Taupo Ignimbrite (i.e. between c. 27 cal ka and 1.8 cal ka)

Kawakawa Tephra c. 27,100 cal yr BP