

Introduction to the landscapes and soils of the Hamilton Basin and South Waikato: field notes

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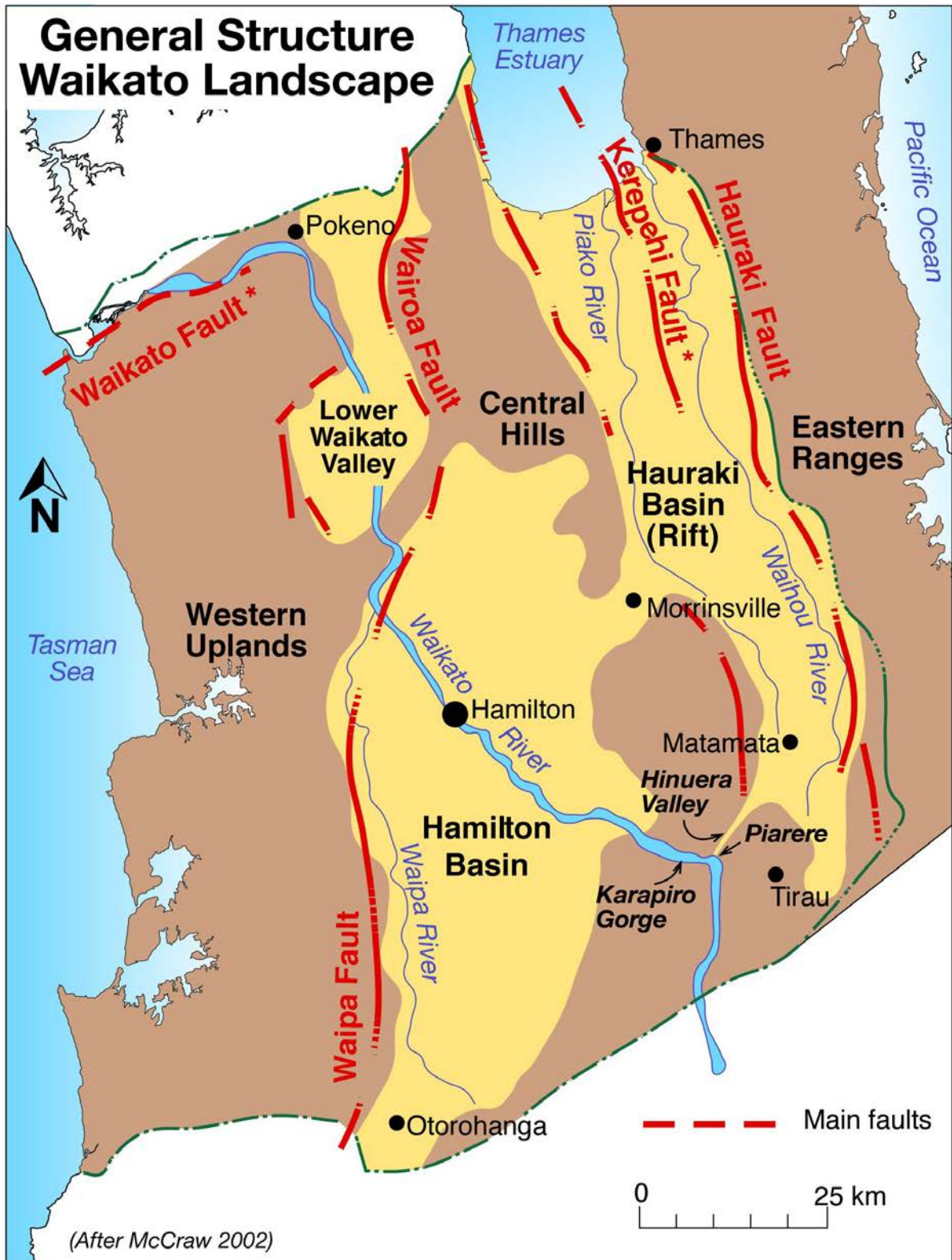
View over part of Hamilton Basin landscape looking south (from Sanatorium Hill) towards Kakepuku (far right) and Te Kawa (far left) volcanoes. Cambridge, on the ash-mantled Hinuera Formation, is in the middle part of the photo. Photo: David Lowe.

Citation:

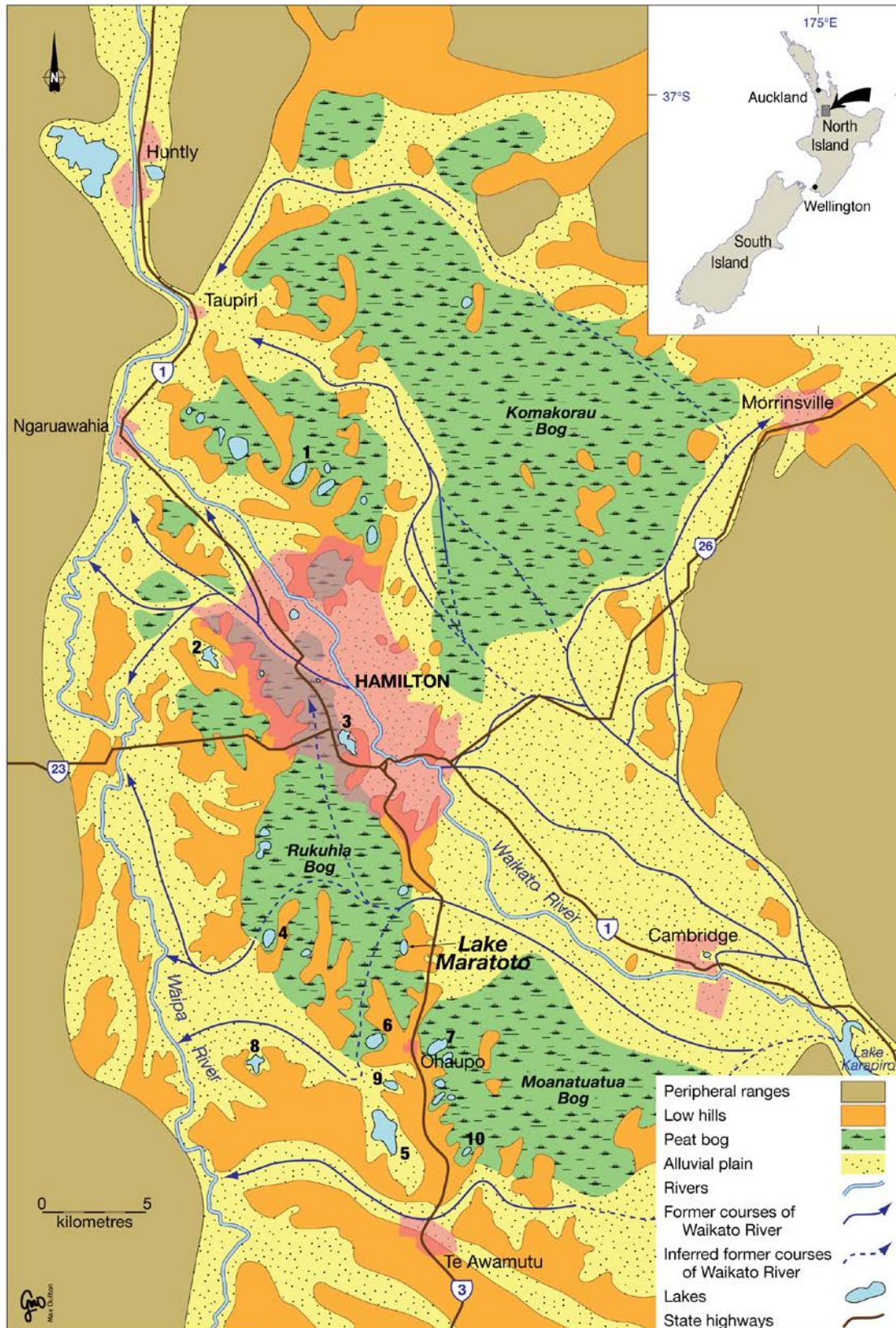
Lowe, D.J. 2021. Introduction to the landscapes and soils of the Hamilton Basin and South Waikato. *Field notes*, School of Science, University of Waikato, Hamilton. 36 pp. DOI: 10.13140/RG.2.2.36071.39845

These notes are an updated version (revised 25 Jan 2021) of those prepared for a field trip held in conjunction with the World Soils Congress in Brisbane in 2010:

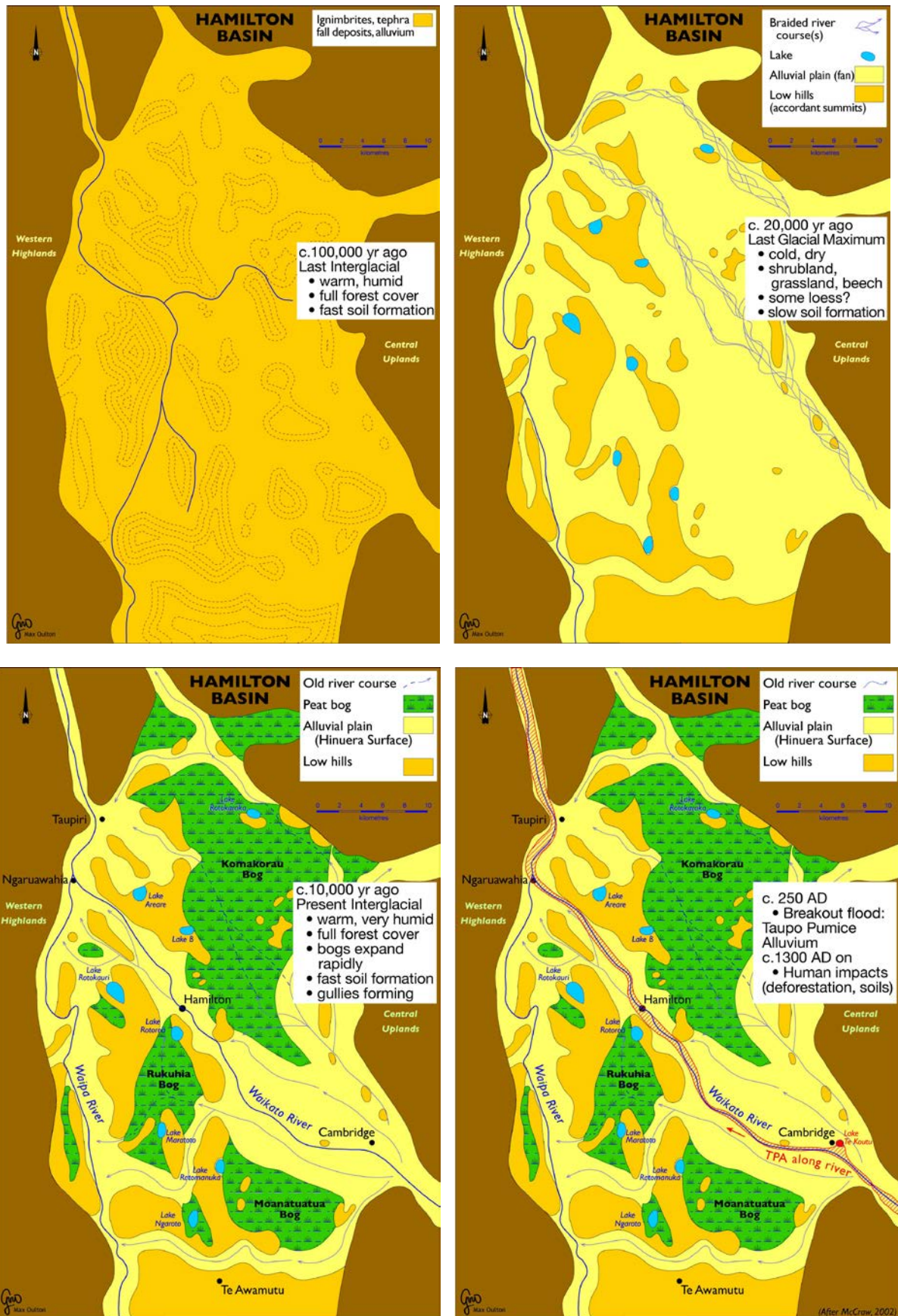
Lowe, D.J. 2010. Introduction to the landscapes and soils of the Hamilton Basin. *In*: Lowe, D.J., Neall, V.E., Hedley, M., Clothier, B., Mackay, A. 2010. Guidebook for Pre-conference North Island, New Zealand “Volcanoes to Oceans” field tour (27-30 July). 19th World Soils Congress, International Union of Soil Sciences, Brisbane. *Soil and Earth Sciences Occasional Publication No. 3*, Massey University, Palmerston North, pp. 1.24-1.61.



General simplified structure of the Waikato landscape and location of Hamilton Basin (after McCraw, 2002). Note that new faults have been discovered in the Hamilton Basin (not shown) (Moon and de Lange, 2017; Moon and Spinardi, 2019). 'South Waikato' is the district from Tirau southwards that also includes Putaruru and Tokoroa. Karapiro Gorge also known as Maungatautari Gorge or Gap (see p. 30).



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, 2011). 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

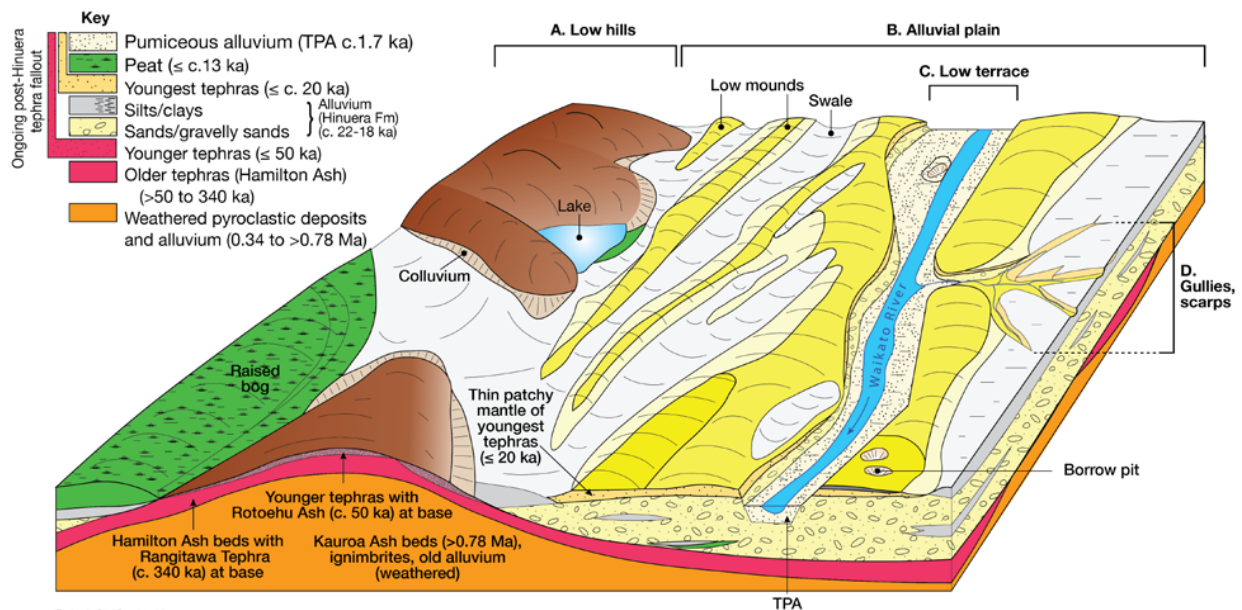
The Hamilton Basin area is characterised by four main landscape units or landforms as depicted in the block diagrams below (McCraw, 1967, 2002, 2011; Bruce, 1979; Selby and Lowe, 1992), and these provide a soil-landscape model to enable the soil pattern to be predicted. The four units are:

- **Low rolling hills** – the so-called ‘Hamilton hills’
- **Flattish alluvial plain** with micro-relief of low mounds (bars) and swales (depressions)
- **Low terrace** 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. The hilly morphology pre-dates c. 340 ka*. A drill hole through a hill will typically show the following sequence of deposits (from top down):

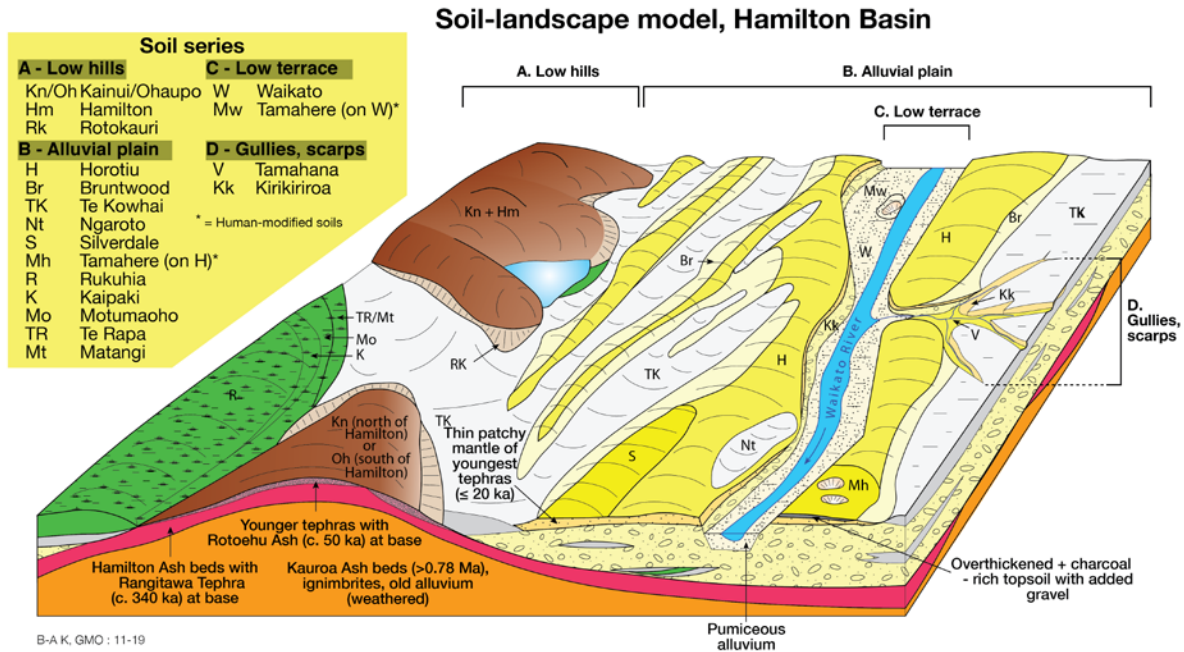
- Silty cover bed of post-Hamilton-Ash tephra from multiple sources; ~0.5 m thick; ≤c. 50 ka
- Red-brown, clayey weathered tephra beds (Hamilton Ash); ~1–3 m thick; top bed c. >>50 ka, basal c. 340 ka (the dark reddish-brown uppermost buried soil horizon likely represents developmental upbuilding soil formation during the last interglacial) (see Lowe, 2019, for a review)
- 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: see Hopkins et al., 2021)
- 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. 1.3 to c. 1.0 Ma, respectively.

Main landscape units (landforms) and geological materials, Hamilton Basin



(Caption is on next page)

* Note: ka = thousands of years ago; Ma = millions of years ago; cal =calibrated or calendar



(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; Lowe, 2019). The regional geology was described by Kear and Schofield (1978) and Edbrooke (2005); the geomorphology was described by Selby and Lowe (1992).

B. The plain represents 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-existing 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. 23,500 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 c. 23,500 cal years ago (Hogg et al., 1987; Manville and Wilson, 2004; Williams, 2017; Peti et al., 2021).

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. 23,500 and 17,000 cal. years ago (Manville and Wilson, 2004; Peti et al., 2021). Soon after, as the landscape stabilised as climate ameliorated and forest cover returned from c. 17,500 cal. years ago (Newnham et al., 2003), 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 soils were formed by developmental upbuilding pedogenesis (Lowe and Tonkin, 2010; Lowe et al., 2015a; Hewitt et al., 2021).

The tephra layers are well preserved in lake sediments (e.g. cores from lakes contain numerous tephra layers: Lowe, 1988, 2019) and peat bogs that developed on or alongside the Hinuera deposits (see below).

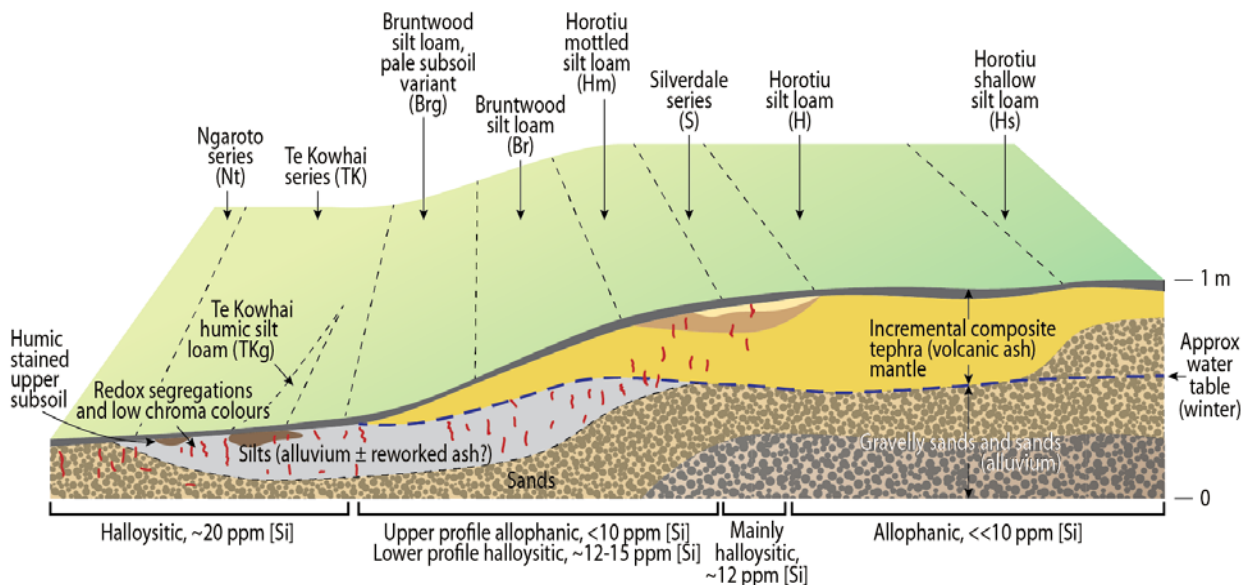


Slightly undulating surface of the Hinuera Formation – the low gravelly ridge (levee) in foreground (Horotiu soils) drops away to a flat swale towards the right (Te Kowhai soils) and background (note effluent sprayers). Despite being mantled with numerous thin tephras since c. 18 cal ka (~0.4 to ~0.6 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.

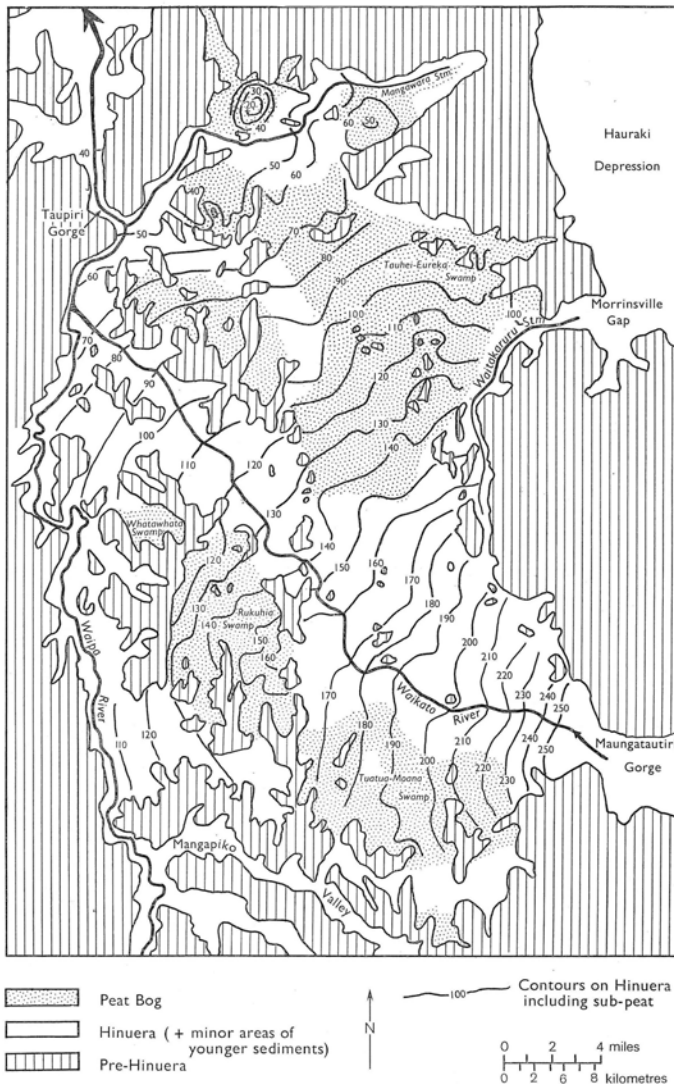
The soil pattern on the patchy tephra-draped Hinuera Surface mimicks the alluvial depositional environments: well drained soils occur on the slightly raised channel/bar deposits (Horotiu soils comprise tephra fallout cover on coarse alluvium) and poorly drained soils occur on lower-lying ‘swales’ (shallow depressions) 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 association that mark a low-elevation toposequence across raised channel/bar deposits through to a swale.



Detailed soil-landscape model on the plains showing parent materials and drainage of the soils together with generalized measurements of silicon in soil solution associated with them (redrawn by D.J. Lowe after Singleton et al., 1989; Singleton, 1991; Lowe, 1988).

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) (Hewitt et al., 2021). Te Rapa soils are present on Scott Farm.

Along the Waikato and Waipa rivers are numerous examples of human-modified soils (Tamahere series) adapted for growing tropical sweet potato (kūmara) by early Maori (Gumbley et al., 2004; Hewitt et al., 2021). 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 (Puke, 2021). The growing conditions were adapted from yam-growing practises in the Pacific islands. *Puke* means ‘yam-growing mound’ in proto-Polynesian. The kūmara was imported to temperate New Zealand by early Polynesian sailors (ultimately from South America). It may have taken some time before it was grown at inland sites (Anderson and Petchey, 2020).



Contours in feet on the Hinuera Surface in the Hamilton Basin showing fan form despite a partial thin ash mantle (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).

C. The lowermost terrace 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 ± 10 AD: Hogg et al., 2012, 2018). 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 records 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) (Lowe and Pittari, 2021).

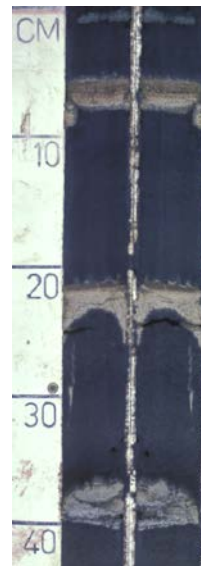
D. Gullies are occasionally cut into the Hinuera Surface, usually draining towards the modern Waikato River. Soils of the gully sides, and terrace scarps, are Kirikiriroa series and soils on the recent alluvium in gully bottoms are Tamahana series. Many gullies in the Hamilton area, some previously used 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 (parastratotype) for the Pleistocene-Holocene boundary (marked by Konini tephra-b 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) (see also Lowe, 2019).
 Photo: Rex Julian

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



Tuhua c. 7.6 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)

Ages of soils

In some cases, the age of the deposition of parent material provides the age of a soil, for example the soil developed on Taupo Tephra is the same age as the tephra, which was deposited rapidly about 1800 years ago in AD 232 ± 10 years (Hogg et al. 2012, 2019). Similarly, the volcanogenic alluvium that partly infills the Hamilton Basin (Hinuera Formation) forming the plains was deposited between about 23,500 years ago and 18,000 years ago (the modern Waikato River beginning to entrench itself from soon after ~17,500 years ago), albeit much less precisely than the previous example. But in other cases, the age of a parent material may be far greater than the age of the soil formed on it. For example, soils formed on greywacke (the rock itself may be ~180 million years old) on a steep slope may be very young and weakly developed because of constant erosion of any soil horizons formed on the rock as a result of slope instability so that the soil never develops much beyond an A-C profile before it is sloughed off during an intense storm event or an earthquake, for example (Hewitt et al., 2021).

In other cases, the soil age is not a single age but an age range where upbuilding pedogenesis has occurred over time, and such composite ages are common in tephra terrains. In the Hamilton Basin, the ages of the soils (defined here as the uppermost 1 m of the land surface) vary across the landscape. There are three ways of ascertaining the likely age:

- (1) ***Radiometrically-dated geological record and law of superposition***: we have radiometric ages on the geological deposits making up the hills, plains, and low terraces in the soil-landscape model. The model also shows the stratigraphic (layered) arrangements of these deposits: the Hinuera Formation overlies the antecedent hilly terrain it partly buries; it is clear that the youngest soils (apart from actively eroding steep-sided gullies) are located on the low terraces, these soils (Waikato series) being formed on the break-out flood-deposits of the Taupo Pumice Alluvium that dates to around AD 250 (about 1700 years old). The Hinuera Formation is (generalising) c. 20,000 cal. years of age (c. 20 cal ka). In places it has a ~0.5-m-thick patchy mantle of thin tephra deposits that have accumulated incrementally (millimetre by millimetre) from c. 20 cal. ka to the present. Hence the soils with a thin tephra mantle are ‘two-storeyed’, the top storey being <20 cal ka in age, the lower 20 cal. ka.
- (2) ***Concept of geomorphic surfaces and the associated principle of ascendancy and descendancy***: recognition of geomorphic surfaces allows us to estimate relative ages of the soils forming the soil-landscape model. From the hill summits we descend an erosional surface to a depositional surface (top of Hinuera Formation, the Hinuera Surface, tephra-mantled in part), which is younger. Essentially, the hill is an older landform than the alluvial plain which in turn is an older landform than the low terrace (that occurs adjacent to the modern Waikato River).
- (3) ***Soil profile morphology (degree of development)***: soil morphology is the nature of a soil encompassing its physical and other properties – the number and types of soil horizons, their degree of weathering (especially pedogenic clay content), and other features. As a rule of thumb, clay-rich soils are usually older than clay-poor soils (conditions apply). Although we use the dynamic-rate model for pedogenesis, and recognise that soils evolve and that their character can ‘ebb and flow’ (see Johnson & Watson-Stegner, 1987; Johnston et al., 1990; Hewitt et al., 2021), we can still make some assumptions about relative degree of development and hence relative age. Therefore in the Hamilton Basin the soils (defined as upper 1 m profiles) developed on the hills are older than those on the plains (putting aside the complication of both land surfaces receiving the same thin tephra-fall deposits since c. 20,000 cal. years ago) and the profile morphologies show this. Be aware that the textures of a soil may be primary in origin. For example, alluvium making up the Hinuera Formation includes lithofacies ranging from muds and silts (overbank flood deposits) to sands and gravelly sands (high energy braided bar deposits) (Hume et al., 1975) and so the amount of fine material derived by pedogenic weathering may be masked or dominated by the primary textures.

Summary of main soils of the Hamilton region

Arranged according to landscape position (landform) (see block diagrams above) and parent materials plus drainage and main clay type

A. Soils of low rolling hills

- summits, shoulders, backslopes

Hamilton series	<i>Hm</i>	On strongly weathered, reddish-brown, sticky clay-rich tephra (Hamilton Ash Formation, aged >>50 ka), halloysitic clays
Kainui series	<i>Kn</i>	On cover-bed mantle of numerous thin tephra deposits aged ≤50 ka (typically ~0.5 to 0.6 m thick) that are silty and halloysitic <i>overlying</i> reddish-brown clayey Hamilton Ash (soil profile comprises both the upper silty materials and lower clayey tephra materials), halloysitic
Ohaupo series	<i>Oh</i>	On young tephra deposits (≥~0.8 m thick, on hills to the south of Hamilton) with allophanic clays predominant in the upper profile
Horsham series	<i>Hs</i>	On pre-Hamilton Ash deposits on steep backslopes where Hamilton Ash is eroded (yellow-brown subsoils)

- footslopes

Rotokauri series	<i>Rk</i>	On gleyed clayey colluvium on footslopes (with pale grey subsoils)
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B. Soils of the plain

Horotiu series	<i>H</i>	On cover-bed mantle (up to ~0.6 m thick) of numerous thin tephra deposits ≤20 ka, well drained, allophanic, <i>overlying</i> well-drained coarse alluvium (Hinuera Formation c. 20 ka) on low mounds on plains (soil profile comprises both the tephra deposits in the upper profile and alluvium in the lower profile)
Bruntwood series	<i>Br</i>	On cover-bed mantle (up to ~0.6 m thick) of numerous thin tephra deposits ≤ 20 ka, well drained, allophanic, <i>overlying</i> poorly drained alluvium (Hinuera Formation c. 20 ka), halloysitic, on intermediate positions (margins) of low mounds on plains (soil profile comprises both the tephra deposits in the upper profile and alluvium in lower)
Te Kowhai series	<i>TK</i>	On poorly drained fine alluvium (usually silt) over grey sands (both represent the Hinuera Formation c. 20 ka) in shallow swales (low-lying depressions) on plains, halloysitic throughout profile
Ngaroto series	<i>Nt</i>	On poorly drained coarse alluvium (Hinuera Formation c. 20 ka) in shallow swales (low-lying depressions in landscape), halloysitic
Silverdale series	<i>S</i>	On cover-bed mantle (up to ~0.6 m thick) of numerous thin tephra deposits ≤ 20 ka that are halloysitic rather than allophanic <i>overlying</i> clayey alluvium (greyish brown to brown; sometimes pale subsoil colours where gleyed), halloysitic
Rukuhia series	<i>R</i>	On deep peat >1 m thick
Kaipaki series	<i>K</i>	On peat (≤1 m thick) unconformably <i>overlying</i> alluvium (Hinuera Formation c. 20 ka) (both materials form the profile)
Motumaoho series	<i>M</i>	On peat (0.4–1 m thick) unconformably <i>overlying</i> alluvium (Hinuera Formation c. 20 ka) (both materials usually form profile)

Te Rapa series	<i>TR</i>	On shallow peat (≤ 0.4 m thick) unconformably overlying alluvium (Hinuera Formation c. 20 ka) (both materials form profile)
Tamahere series	<i>Mh</i>	Human-modified soil on (originally) a cover-bed mantle of thin tephra ≤ 20 ka <i>overlying</i> typically coarse alluvium (Hinuera Formation c. 20 ka) (originally <i>H</i>), associated with borrow pits

C. Soils of low terrace

Waikato series	<i>W</i>	On mainly pumiceous alluvium (Taupo Pumice Alluvium, TPA, c. 1770 years old), weakly developed soil
Tamahere series	<i>Mw</i>	Human-modified soil on mainly pumiceous alluvium (TPA, c. 1770 years old) (originally <i>W</i>), associated with borrow pits

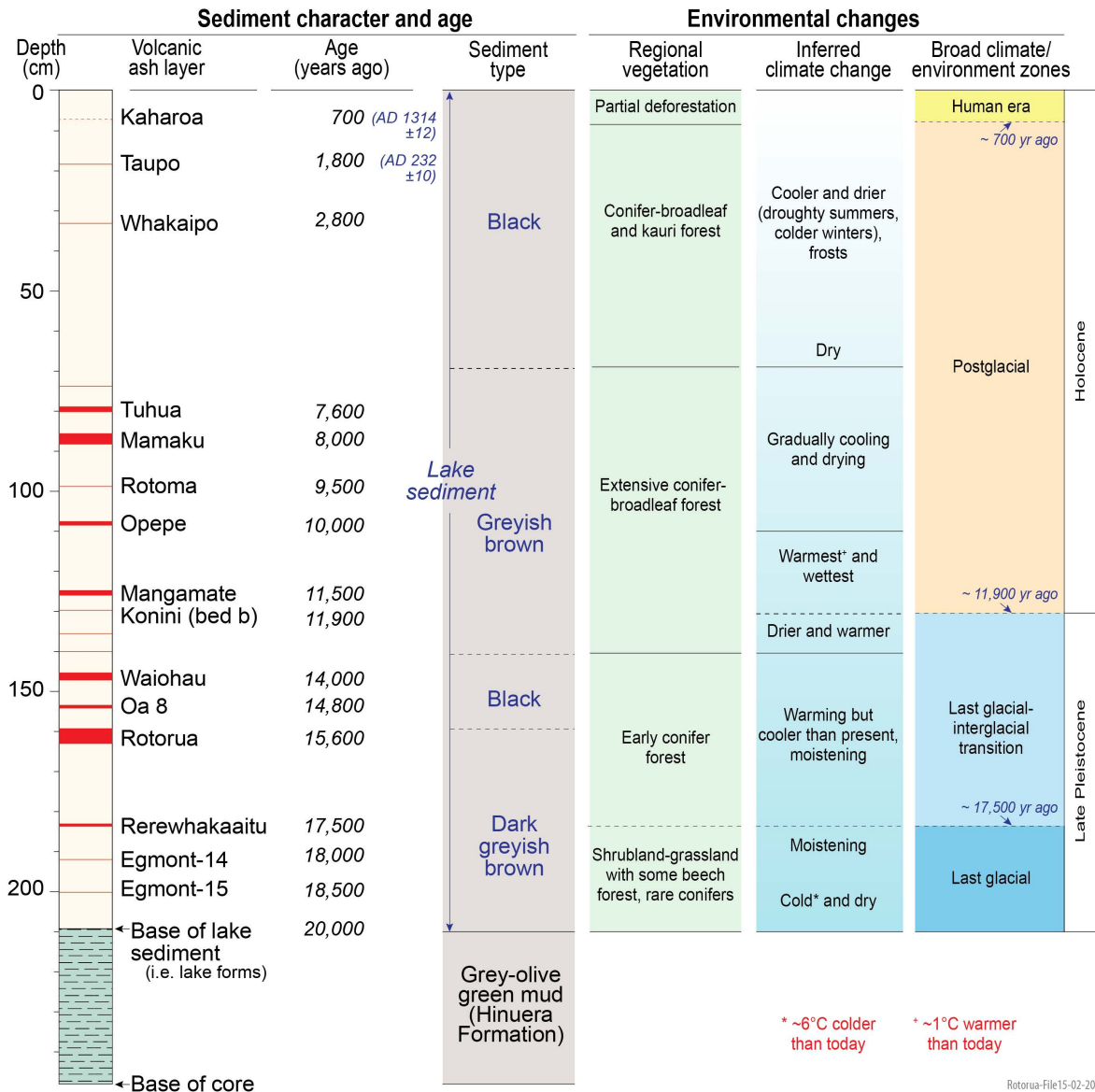
D. Soils of gully bottoms and sides; terrace scarps

Tamahana series	<i>V</i>	On recent sediment or colluvium (gleyed) in gully bottoms
Kirikiroa series	<i>Kk</i>	On steep alluvium on sides of gullies and terrace scarps

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. 23,500 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 2–5 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, 2014, 2019). These tephra, 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 cryptotephra (glass-shard and/or crystal concentrations preserved in sediments but not visible as a layer to the naked eye) (Alloway et al., 2007a; Lowe, 2011; Hopkins et al., 2021) are also present. From recent work on lake cores and peat bogs, such cryptotephra 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 (see Loame et al., 2017).



This figure depicts the stratigraphy and chronology of a sediment core from Lake Rotorua (Hamilton Lake) alongside which environmental changes based on pollen studies by Newnham et al. (1989) have been placed. The diagram is modified after Newnham et al. (1989) and Green and Lowe (1994) (from Lowe, 2014). Tephra sources: a, Okataina Volcanic Centre (VC); b, Taupo VC; c, Tuhua VC (Mayor Island); d, Tongariro VC; e, Egmont Volcano (Taranaki Maunga).

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).

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.

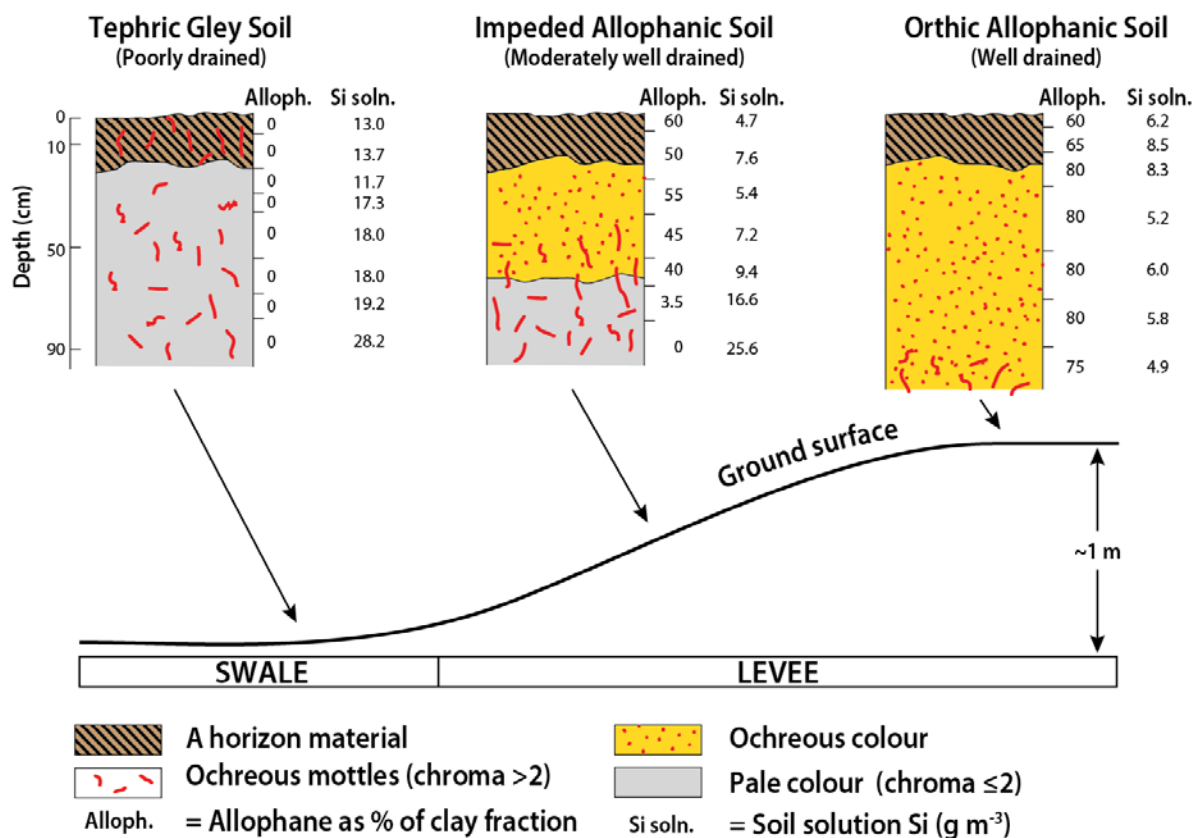
Soils

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 $<10 \text{ g/m}^3$ (ppm), therefore favouring the formation of Al-rich allophane (Singleton et al., 1989; Hewitt et al., 2021). **Te Kowhai 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 $>10 \text{ g/m}^3$ (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, 2012; Hewitt et al., 2021).

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, or both.



Soil drainage leaching sequence and associated mineralogical and soil-solution analyses at Ruakura (after Singleton et al., 1989, and Lowe and Percival, 1993). From left the soil series represented are Te Kowhai, Bruntwood, and Horotiu (as below). 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 on p. 21; Lowe, 1995; Churchman and Lowe, 2012). Cutting tool is ~30 cm long.



Te Kowhai



Bruntwood



Horotiu

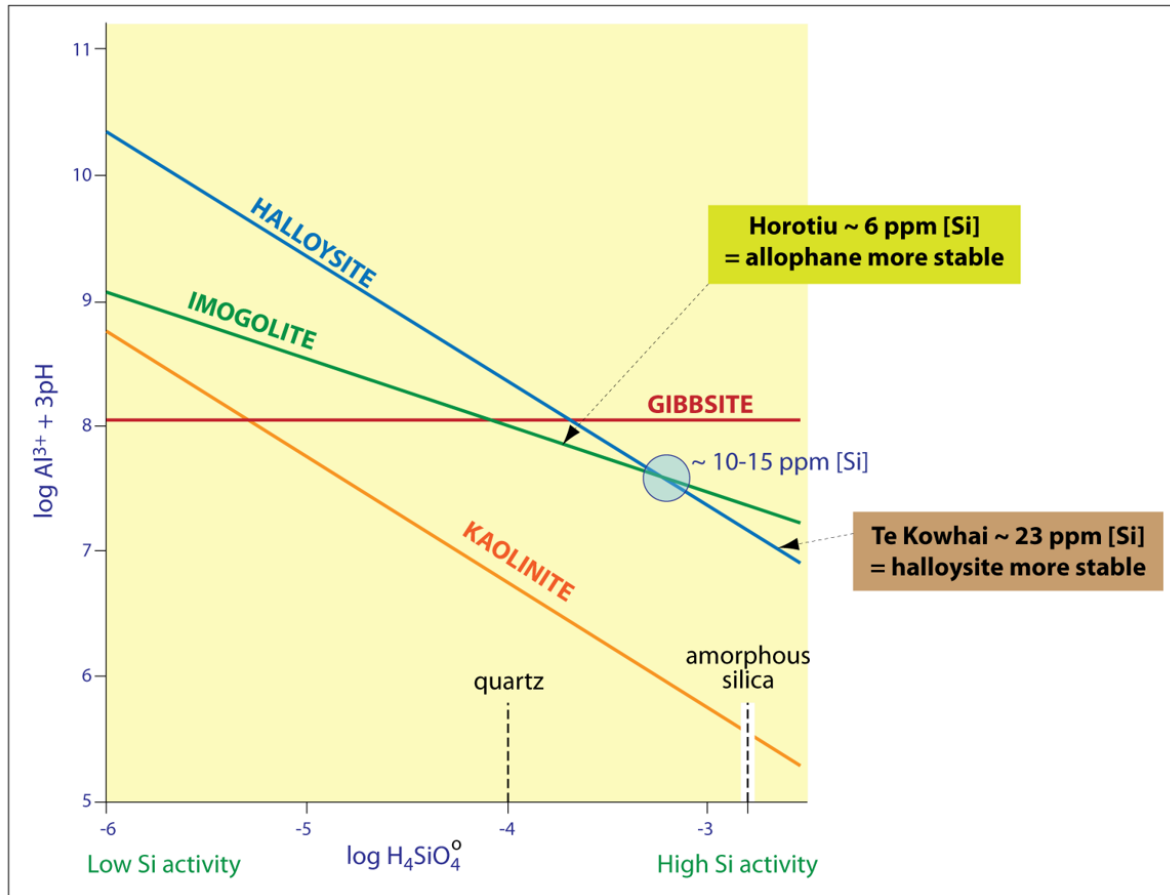
Allophane and halloysite contents, and measurements of silicon in soil solution, in Horotiu, Bruntwood, and Te Kowhai soils near Scott Farm (from Lowe and Percival, 1993, after Singleton et al., 1989)

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)
<i>Horotiu silt loam, well drained (Sample No. SB9944)</i>										
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
<i>Bruntwood silt loam, moderately well drained (SB9952)</i>										
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
<i>Te Kowhai silt loam, poorly drained (SB9945)</i>										
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, based on 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., 2012).

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,
 Aspect: on crest of levee, 10 m west of power pole
 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

Flat to gently undulating Landform: Low angle fan
 Slope: undulating
 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)	Description
Ap	0-18	dark brown (10YR 5/8) 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			Exchangeable cations (meq/100 g)				Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	CEC (meq/100 g)			Base saturation (%)			
			H ₂ O	KCl	ΔpH	NaF	Ca	Mg	K			Na	ECEC	NH ₄ OAc (pH 7)	Σ Cations (pH 8.2)	Σ bases CEC NH ₄ OAc	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)			P Retention (%)	Dithion. cit. (%)		Tamm ox. (%)			Pyrophos. (%)		Reserves (meq/100 g)		Extractable S (ppm)
					H ₂ SO ₄ (0.5 M)	Inorg.	Org.		Fe	Al	Fe	Al	Si	Fe	Al	K _c	Mg _r	
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

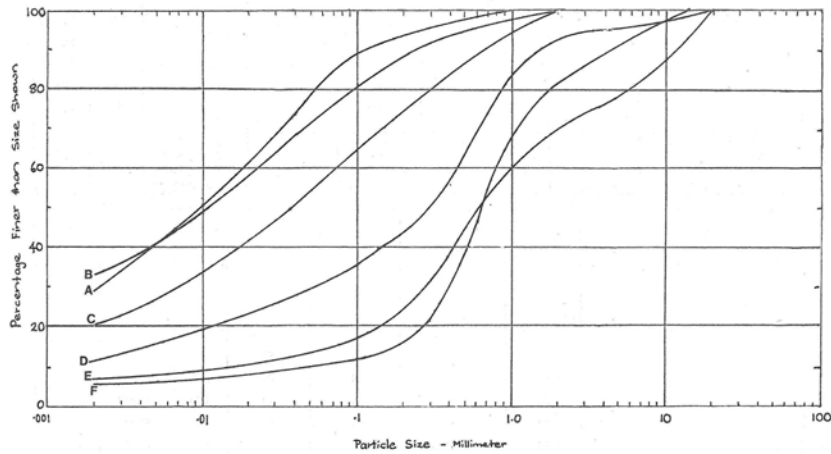
PHYSICS

Hor. Depth (cm)	Hor.	15 bar Field moist (%)	water Air Dry (%)	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)
0-18	Ap	25.6	22.3	2-9	0.80					
18-34	Bw1	43.9	20.5	20-27	0.62					
34-43	Bw2	37.5	18.3	35-42	0.72					
43-55	BC1	23.4	14.8	49-56	0.96					
55-72	BC2	13.5	10.5							
75-100	2C	3.7	3.3							

PARTICLE SIZE DISTRIBUTION (<2 mm) Horotiu Silt Loam

Sample No. SB	Depth (cm)	Hor.	Sand		Silt	Clay	Fine clay	Stones (%)
			2-0.1 mm (%)	0.1-0.05 mm (%)	0.05-0.002 mm (%)	<0.002 mm (%)	<0.0002 mm (%)	
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.	Clay Fraction (%)														
			Mica-Smectite	Mica-Vermiculite	Smectite	Vermiculite	Interlayered Hydrous Micas	Mica	Kaolinite	Halloysite	Gibbsite	Quartz	Cristobalite	Allophane	Feldspar	Anatase	Volcanic glass
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
 Aspect: - Altitude (m): 30 Rainfall (mm): 1270
 Vegetation: Improved pasture species - rye grass, white clover, paspalum, flat weeds
 Land use: Dairying, stud stock, maize cropping

Flat to Slope: gently undulating
 Landform: Low angle fan
 Drainage class: Poorly drained
 Parent material: "Pumice" clays and silts, rarely sands (Hinuera Formation)

PROFILE DESCRIPTION

Horizon	Depth (cm)	Description
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			Exchangeable cations (meq/100 g)						Extr. Acidity (pH 8.2)	Acidity-Al (meq/100 g)	ECEC	CEC (meq/100 g)		Base saturation (%)		
			H ₂ O	KCl	ΔpH	NaF	Ca	Mg	K	Na	H				Al (KCl)	NH ₄ OAc (pH 7)	Σ Cations (pH 8.2)	Σ bases CEC NH ₄ OAc	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)			P Retention (%)	Dithion. cit. (%)		Tamm ox. (%)			Pyrophos. (%)		Reserves (meq/100 g)		Extractable S (ppm)
					H ₂ SO ₄ (0.5 M)	Inorg.	Org.		Fe	Al	Fe	Al	Si	Fe	Al	K _c	Mg _r	
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		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)
		Field moist (%)	Air Dry (%)							
0-18	Ap	17.9	15.1	3-10	1.02					
18-38	Bg1	16.6	13.0	25-32	1.26					
38-53	Bg2	25.9	19.4	41-48	1.17					
53-70	2Cg1	18.0	12.6	57-64	1.09					
70-90	2Cg2	12.2	7.9	73-80	1.16					
90-100	2Cg2	5.7	4.4	91-98	1.17					

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

Soil name	Possible nutrient deficiencies		Stocking rates (stock units/ha)	
	Pasture	Stock	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).

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1.6 Transit into the South Waikato

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 before returning to the Hinuera Surface. Andesite-dacite Maungatautari stratovolcano (797 m, age 1.8 Ma) features near Lake Karapiro (Prentice et al., 2020). 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.

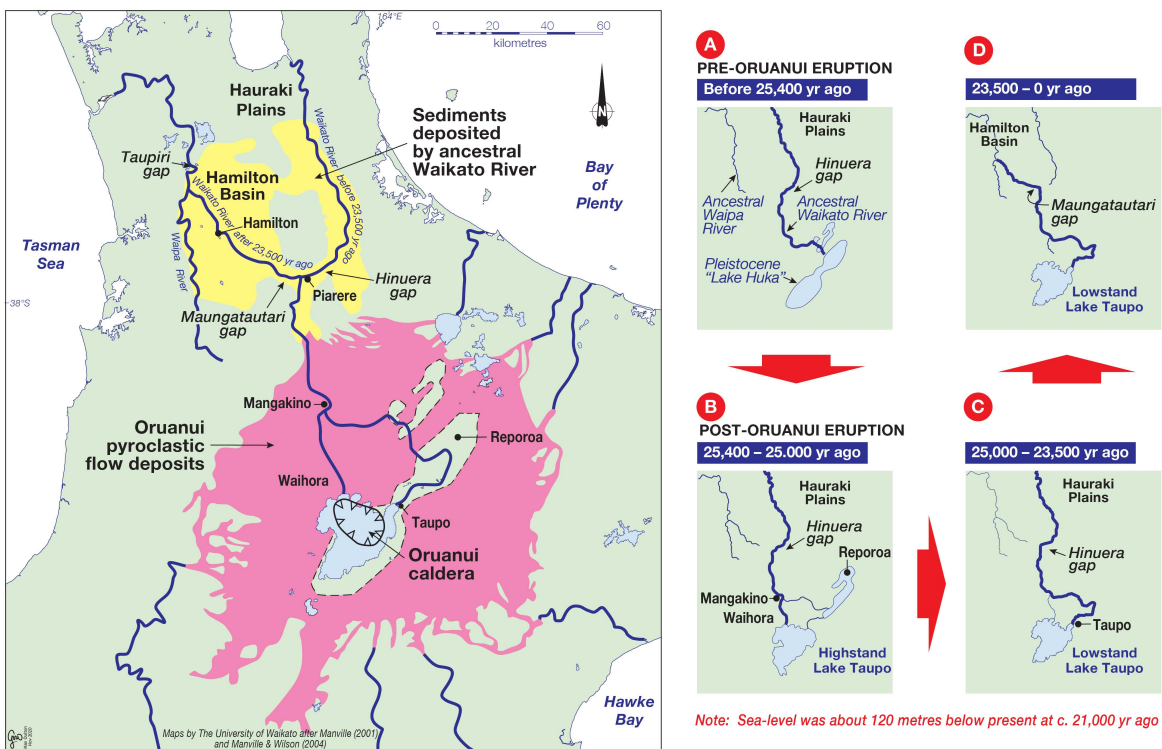
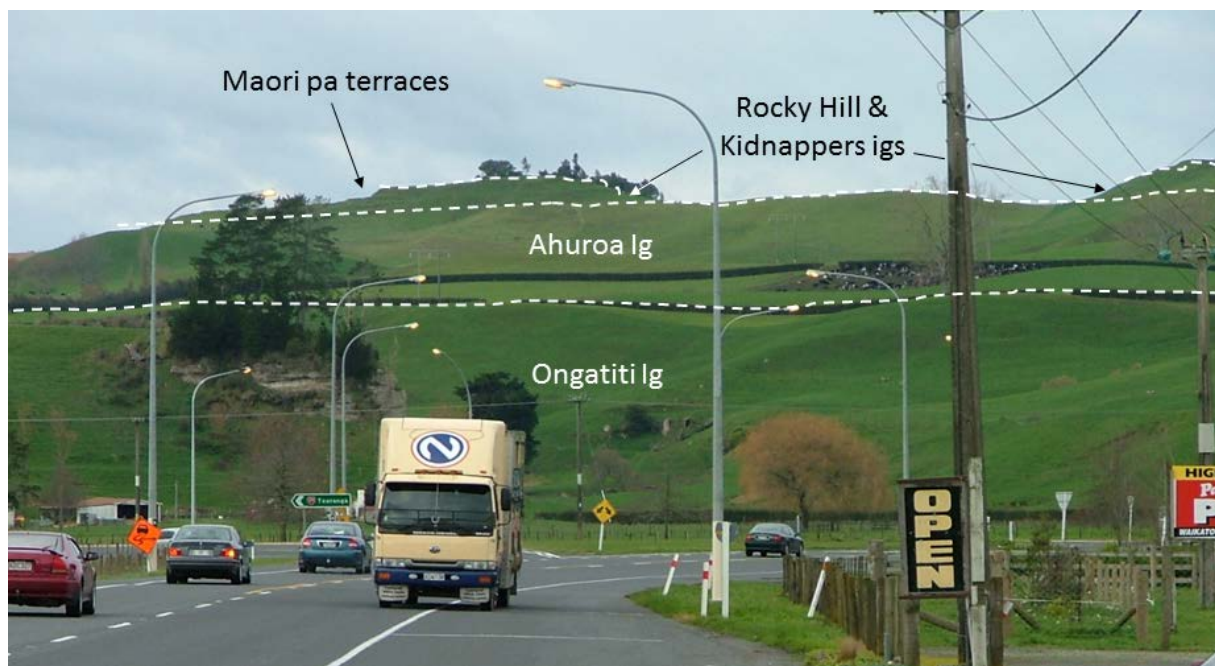


Diagram depicting the impacts of the Oruanui/Kawakawa eruption of Taupo caldera volcano (c. 25,400 cal. yrs BP: Vandergoes et al., 2013) on the ancestral Waikato River (redrawn by D.J. Lowe after Manville, 2001; Manville and Wilson, 2004; Manville et al., 2007; Williams, 2017; Peti et al., 2021). Note 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 representing four welded ignimbrite units (two very closely spaced in time) all derived from Mangakino caldera volcano in TVZ:

Ongatiti (1.3 Ma), Ahuroa (~1.18 Ma), Kidnappers (~1.01 Ma), and Rocky Hill (~1.0 Ma). The Ongatiti Ignimbrite is quarried nearby (Hinuera) and sold as brick used for cladding and paving: '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).

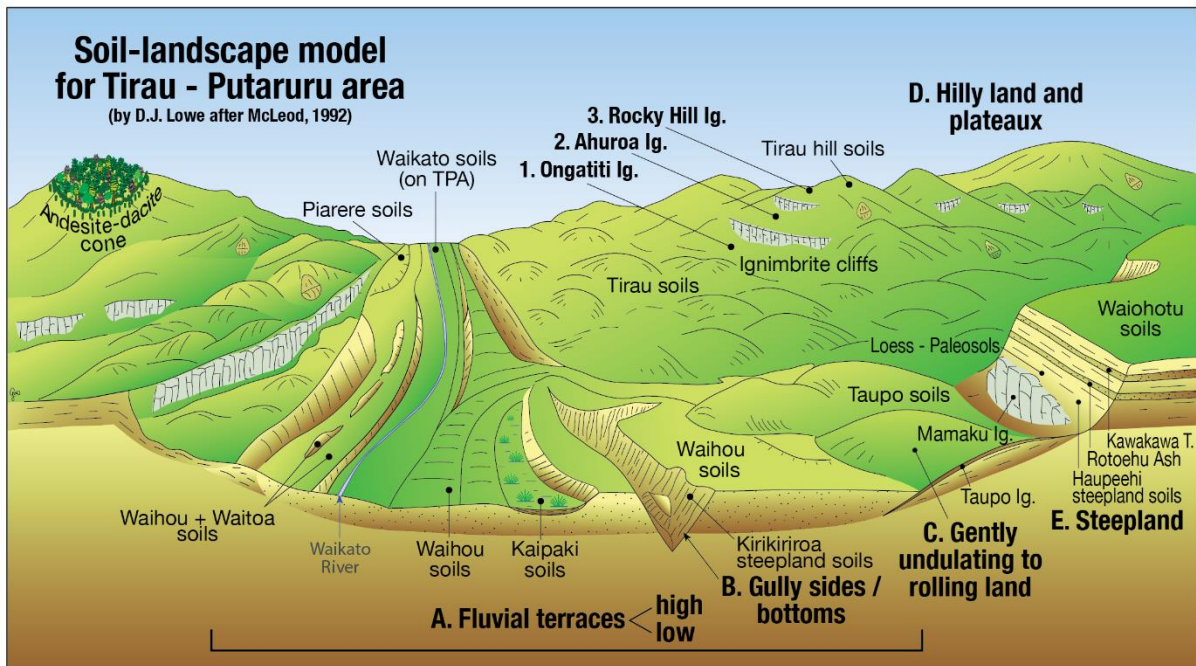


Triple-tier landscape at Piarere relating to four ignimbrite sheets aged c. 1.2 to 1.0 Ma. Photo: D.J. Lowe. (See Lowe and Pittari, 2019.)

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 tephra 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 (sheep and cattle) in the early part of the 20th century (so-called 'bush sickness') in this and other parts of New Zealand. The cause of the 'ill thrift', a cobalt deficiency, was discovered by two groups of Australian scientists in mid-1935 (Hewitt et al., 2021).

The addition of cobalt salt to remedy the problem was first trialled at K.S. Cox's farm in this area on Taupo-tephra-mantled soils. Cobalt is an essential requirement for red blood cell production.



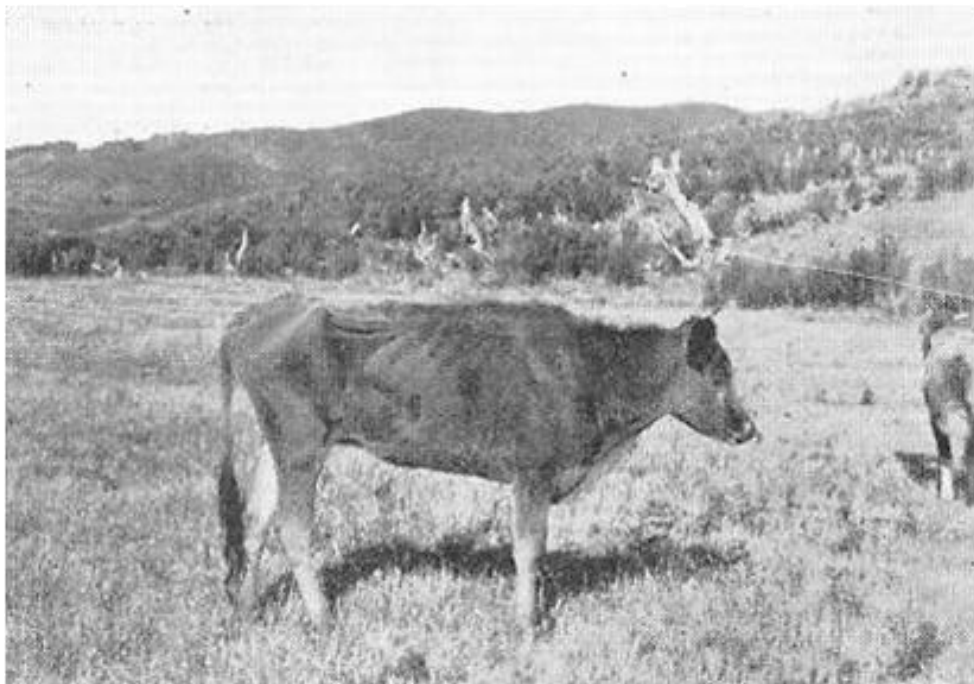
Soil-landscape model for the Tirau-Putaruru area and Tapapa. The three main welded ignimbrite units (Ongatiti, ~1.3 Ma; Ahuroa, ~1.18 Ma; Rocky Hill, ~1.00 Ma), erupted from Mangakino volcano: Briggs et al., 1993), form distinctive plateaux in the landscape and are mantled with tephra-fall deposits and subordinate tephric loess. A fourth (non-welded) ignimbrite, Kidnappers (~1.01 Ma), immediately underlies Rocky Hill in places (Lowe and Pittari, 2019). Fluvial terraces are also mantled with tephras. TPA, Taupo Pumice Alluvium (c. 1700 cal yr BP) (diagram modified by D.J. Lowe after McLeod, 1992).

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See also references on p. 36



Landscape at Litchfield overlain with Taupo soils (see exposure at left) 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. Ignimbrite sheets form the landscape framework. 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 (Hewitt et al., 2021). 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).

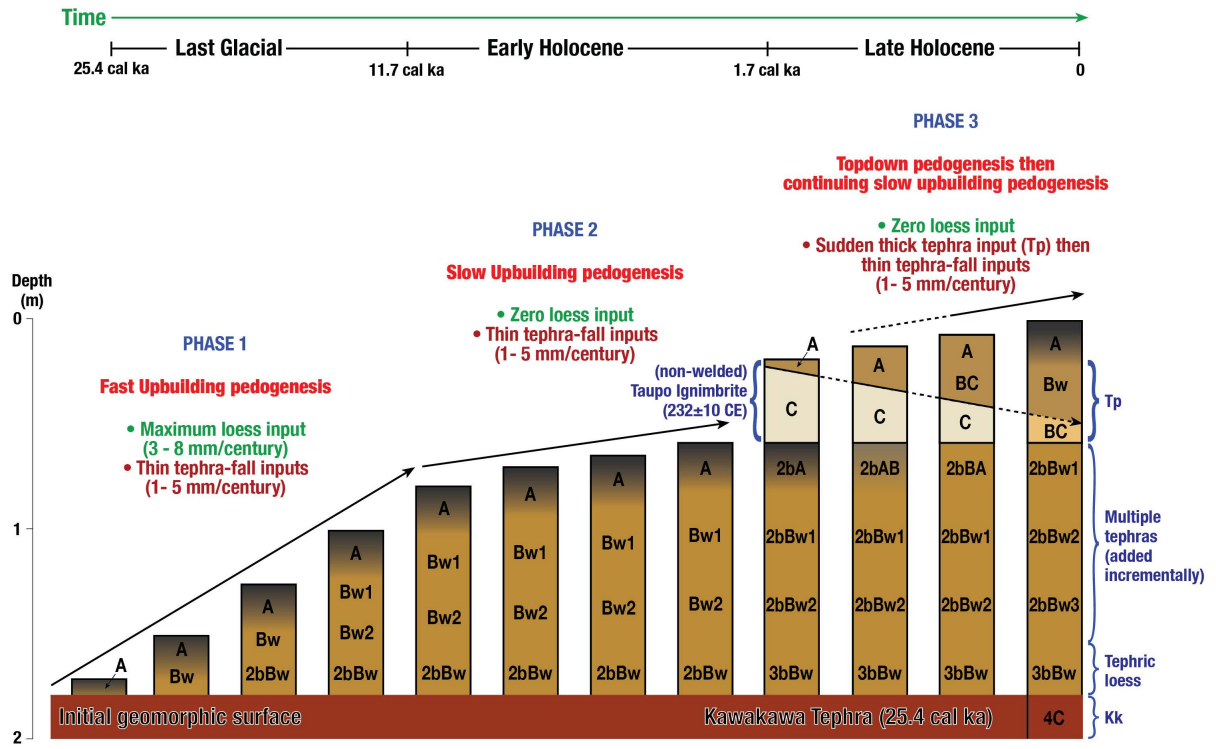
As we head towards Mokai north of Taupo, the landscape steepens with numerous rhyolite lava domes evident within this central part of the TVZ.



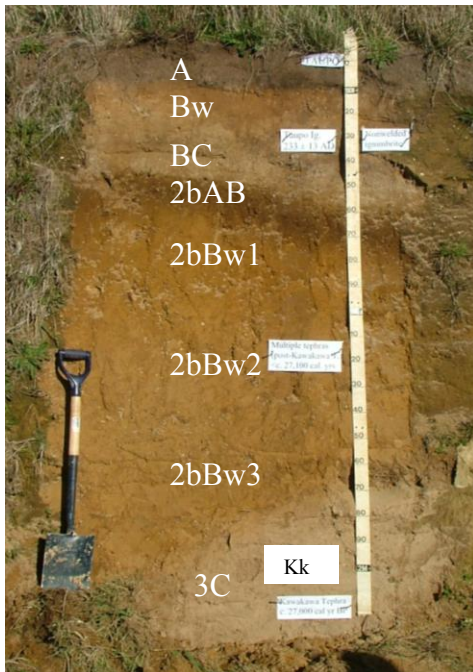
Young pines growing in raw pumice (from Molloy and Christie, 1998)



Logs stacked at Tokoroa in 2007



Model of soil development in the eastern Waikato area near Tirau-Putaruru via upbuilding pedogenesis (after Lowe, 2000; Lowe et al., 2015b; Hewitt et al., 2021). 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. 25.4 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. Horizon nomenclature follows Clayden & Hewitt (1989).



Soil profile at Kokako Rd near Litchfield showing results of upbuilding pedogenesis, both developmental and retardand. This profile is depicted in the diagram above at far right. Photo: D.J. Lowe

Taupo Ignimbrite c. 232 AD (i.e. 1718 cal yr BP)

Multiple thin intermixed tephra layers deposited after Kawakawa Tephra & before Taupo Ignimbrite (i.e. between c. 25.4 cal ka and 1.7 cal ka)

Kawakawa Tephra c. 25,400 cal yr BP

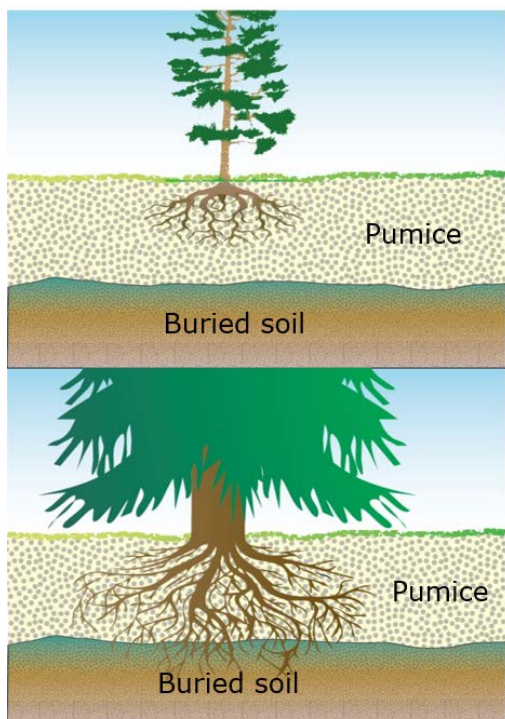
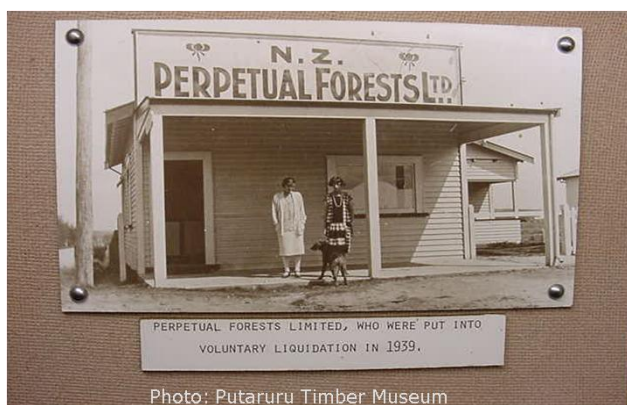


Diagram showing how *P. radiata* can exploit buried soils (redrawn after J.D. McCraw)

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



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See also references on p. 32