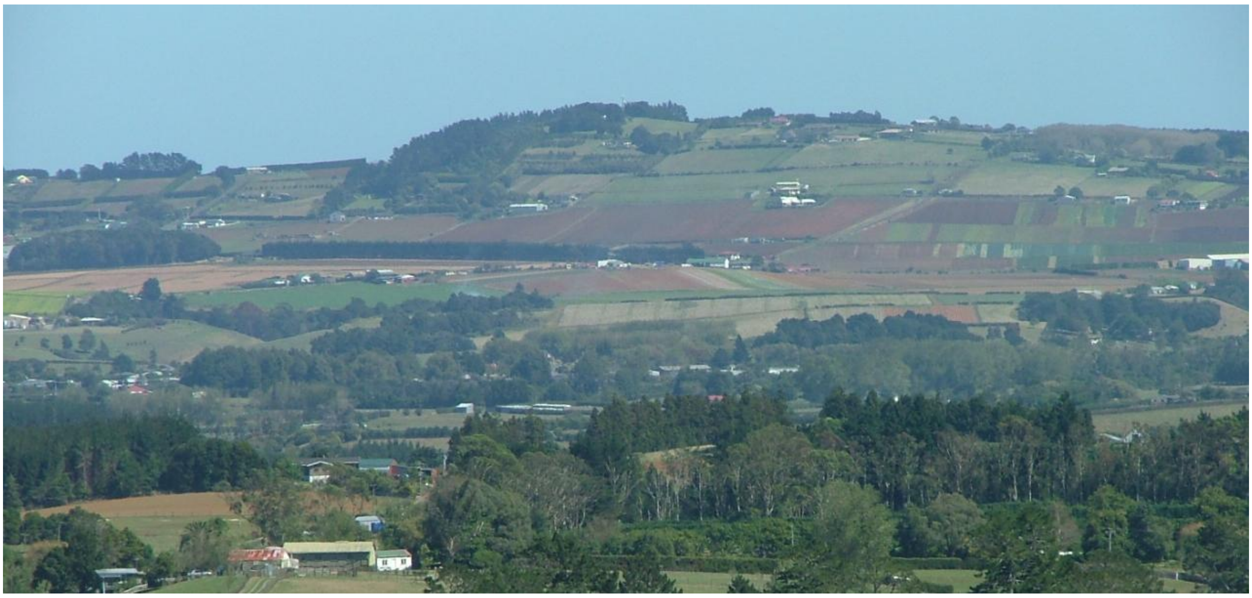
Citation: Lowe, D.J. 2010. Pukekohe silt loam, Pukekohe Hill. *In*: Lowe, D.J.; Neall, V.E., Hedley, M; Clothier, B.; Mackay, A. Guidebook for pre-conference North Island, New Zealand 'Volcanoes to Ocean' field tour (27-30 July, 2010). 19th World Soils Congress, International Union of Soil Sciences, Brisbane. *Soil and Earth Sciences Occasional Publication* No. 3, Massey University, Palmerston North, pp. 1.12-1.23.



Vegetable growing on Ultisols on the Bombay hills east of SH1 in late summer (23 March 2007) – irrigators were operating in some fields. Photo: David Lowe

Potatoes growing in Pukekohe soils on gently sloping shoulder of Pukekohe Hill, 10 October, 2008. View towards southwest where the hills (some basaltic) are bounded by Waikato Fault. Waikato River flows in valley with its mouth at top right (Port Waikato). Photo: David Lowe

1.2 Stop 1 – Pukekohe silt loam, Pukekohe Hill

Location Q12 & R12 783397, elevation 210 m asl, rainfall 1280 mm pa

Introduction

Pukekohe Hill is an excellent starting point for the tour in various ways: it provides a commanding view of important market gardens developed within Ultisols, and associated landuse issues, and the Massey Memorial on the hilltop commemorates Irish-born, South Auckland identity William ('Big Bill') Fergusson Massey (1865-1925), Prime Minister of New Zealand 1912-1925, after whom Massey University is named. Pukekohe town has a population of about 23,000.

Pukekohe Hill

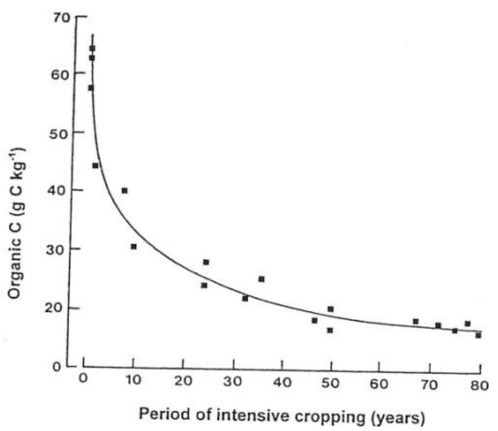
Pukekohe Hill forms a high point (222 m above sea level) within the basaltic South Auckland volcanic field active between c. 1.6 and 0.5 Ma. The hill is underlain by basalt lavas erupted about 0.56 Ma (Briggs et al., 1994; Edbrooke, 2001) and is the youngest effusive centre in the field. But the intensively used, dominantly brown (7.5YR), clayey, strongly structured Ultisols in the area are in most places formed mainly in stongly weathered, distal tephras derived from rhyolitic eruptions in far-off central North Island. The distal weathered tephras, with 60–90 % clay content, comprise a composite sequence with the collective name Hamilton ash beds. They drape over the basalts on which dark reddish-brown (5YR–2.5YR) buried soil horizons are found. The Hamilton ash beds are ~1.1 m to ~3.5 m thick in this area (Rae, 1995). They have an age span of c. 350,000 to c. 100,000 years and in turn are overlain with a patchy, thin (~0.3–0.4 m), composite cover bed veneer of intermixed tephras that have accumulated incrementally millimetre-by-millimetre over the past c. 60,000 years – the base of the cover bed being identified as c. 60 cal ka Rotoehu Ash (Lowe, 1981). The soils thus reflect upbuilding pedogenesis for the last c. 60 ka, and also probably for substantial periods before then (Bakker et al., 1996). An important initial point here regarding parent materials is that the lithological units shown on geological maps are *not* necessarily the parent materials of the modern soils associated with a geological map unit. The volcanic terrains within northern and central North Island are usually layered and so a stratigraphic approach, as will be demonstrated during the tour, is essential to understanding the soils and their relationship with the landscape.

Pukekohe Hill (*pukekohe* means 'hill with kohekohe', the latter being a distinctive 'tropical-looking' tree with large leaves, *Dysoxlum spectable*) was cleared of native broad leaved forest between 1876 and 1900, the development of the main trunk railway generating a demand for sleepers. The hard, dense timber from puriri trees (*Vitex lucens*), common in the Pukekohe area and on Pukekohe Hill, was utilised for railway sleepers. With the forest clearance, horticultural crops of potatoes and onions were grown, although these were first grown in the wider area from the 1850s. Specialised gardening of onions began in 1892 with the first significant commercial crops produced in 1904 (Rae, 1995, after Morris, 1962). The first potatoes were grown on Pukekohe Hill in 1893 (Flynn, 2005). Other vegetables grown on the easy rolling to rolling landscapes include greens (cabbage, lettuce, broccoli, cauliflower, silver beet, snow peas), squash, pumpkin, carrots, spring onions, and asparagus. Production yields are among the highest in New Zealand: onions 55 t/ha; potatoes 60 t/ha; cabbage 30 t/ha (after Molloy and Christie, 1998). Many fields been used continuously or semi-continuously for >30 years, some for >60 years, and some for >100 years, often with more than one crop each year. The vegetables grown in the Pukekohe area are essential for the large Auckland market, and provide about one-third of New Zealand's fresh vegetable production. The total area in vegetable production is about 8000 ha.

Soils

A soil survey of the area (1: 63,360), together with a larger-scale soil map of Pukekohe town (1: 25,000), was published in 1977 to assist the agricultural development and to provide fundamental planning data for future land use – and especially to show the importance of the soils in the Pukekohe area for food production in response to a proposal to relocate the Auckland motorway through Pukekohe (Orbell, 1977). Rae (1995) undertook a soil survey and drilling programme in a small area (0.26 km^2) to the northwest of Pukekohe Hill near Hilltop Rd and Blake Rd to determine the thickness of the Hamilton Ash and depth to the paleosols on the underlying basalts. He then developed GIS-based models to analyse modern and buried paleosol surfaces to examine relationships between drainage and the underlying paleosols (only a weak relationship was found, the modern topography being more important with poorly-drained soils occurring in drainage sinks or depressions) (Rae, 1995).

The bulk of the Patumahoe and Pukekohe soils in the area, formed mainly from Hamilton ash beds, are possibly aged c. 250,000 years (± ~50,000 years?), but as noted above the thin topmost parts of the profile are younger and date from c. 60 ka. The soils become more weathered with depth, probably a result of the accumulatory character of deposition of tephra materials combined with effectively continuous soil formation on them, i.e., upbuilding pedogenesis has dominated (Bakker et al., 1996). Unlike the denser, heavier halloysite-dominated Ultisols further to the south in the Hamilton area, the Pukekohe and Patumahoe soils contain moderate allophane, gibbsite, and kaolinite, and relatively high amounts of crystalline Fe oxides, as well as halloysite and vermiculite. The soils contain clay coatings in the subsoils. The fine-clay/total-clay ratio in the Patumahoe soil (0.7-0.8; fine clay = <0.02 μm) indicates that clay illuviation has occurred but the lobed appearance and non-laminated character of the clay coatings also suggests neoformation (Bakker et al., 1996). The Patumahoe soil has a well developed pedal microstructure with 90 % of the material finer than 20 μm, and many small, irregular iron oxide nodules (10-50 μm) (Bakker et al., 1996). The peds in the B horizons tend to be tightly packed but separate easily (Gibbs et al., 1968). The soils are sticky when wet and topsoils have limited workability then, but they are more friable and have more even moisture contents than the firm, compacted Ultisols around Hamilton (Gibbs et al., 1968). The soils are slowly permeable, resulting in periods of perching (Hewitt, 1998). They are effectively self-mulching, i.e., after cultivation the surface tends to re-aggregate into a strong granular structure which is quite persistent. Differences between the Pukekohe and Patumahoe soils are subtle but local growers suggest that the Pukekohe soils on the hill behave differently from the Patumahoe soils on the lower rolling slopes, being much easier to cultivate and holding their structure better (G.E. Orbell, pers. comm., 2008). However, although the soils are highly suited to vegetable production and are very resilient, frequent cultivation over a long period has increased soil erosion (as described above by Basher and Ross, this volume), reduced soil organic matter and soil biological activity, and degraded soil structure (Barratt, 1971; Basher and Ross, 2002).



Decline in organic C over time in Patumahoe soils under intensive vegetable cropping, Pukekohe (from Haynes and Tregurtha, 1999)

Other environmental issues include nitrogen leaching and groundwater contamination in a peri-urban environment, increases in diseases and pests and use of herbicides, fungacides, pesticides, and insecticides, and loss of soils to urban encroachment (C.W. Ross pers. comm., 2008). Onion white rot has become established in the Pukekohe district and fungicide resistance is widespread (Holland and Rahman, 1999). The production system for onions in this district is regarded as unsustainable because of the disease and insect problems combined with degradation of the soil resource, erosion and leaching.

Both Pukekohe and Patumahoe soils have medium to low fertility status: P-retention is low to medium but can be high (99 % in lower subsoils of Patumahoe soil), K and Mg reserves are low, sulphate tends to be strongly adsorbed on B horizons, and C and N levels are moderate (Hewitt, 1998; Molloy and Christie, 1998). Large amounts of N can be leached through fertilizer use on crops over winter, especially potatoes which are the single biggest contributer to nitrate leaching in the area (Francis et al., 2003). Potatoes planted in early winter receive ~480 kg N/ha, with 70% applied at planting. However, because potato plants do not take up N until at least 30 days after planting, fertilizer N applied at the time of planting is at risk of being leached (around 114 kg N/ha). Similarly, winter cabbages receive 150 kg N/ha at the time of planting in May, with much of this being leached before the plants are large enough to take up the N. August is a better time to apply N fertilizer when the plants are big enough to utilise it. The growing of cover crops during autumn fallowing adds organic matter to the soil and the cover crops will also take up potentially-leachable N from the soil. Francis et al. (2003) showed that oats and ryegrass as a cover crop produced significant quantities of dry matter below ground (roots) campared with sorghum, and 145 kg N/ha of N uptake compared with 62 kg N/ha uptake for sorghum.

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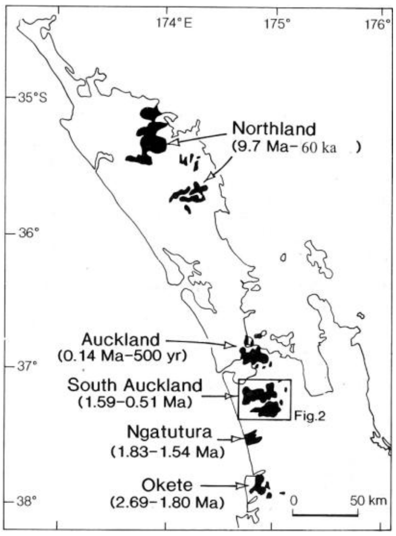
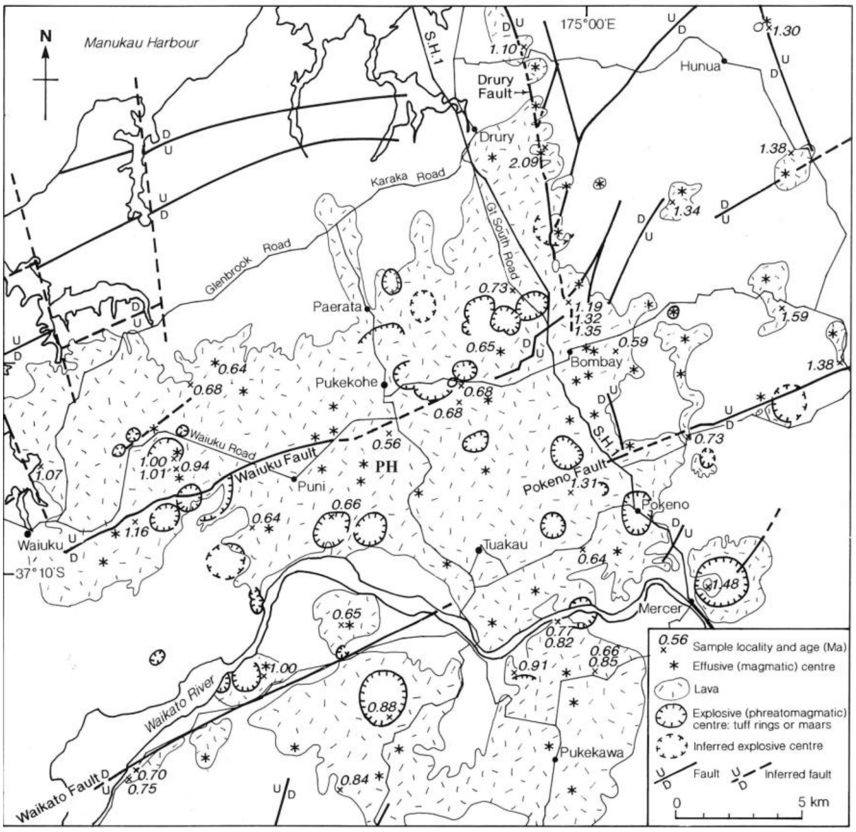
Micromorphological features in a range of tephra-derived soils in North Island including Patumahoe (from Bakker et al., 1996)

Soils		Taupo			Tirau						Horotiu						Naike					Patumahoe				
	Horizon	Ap	Bw	BC	Ap	Bw1	Bw2	Bw3	2C	3bBw	Ap	Bw1	Bw2	Bw3	BCt	2BCt	Ap	Bw2	Bt1	Bt2	bBtg	Ap	Bw	Bt1	Bt2	Bg
	Depth (cm)	2–10	16–24	26–34	5–15	20–30	33–43	50–60	70–80	90–100	5–12	16–26	30–40	41.50	50–57	57–60	3–10	30–40	60–70	82–90	115–125	15–25	35–45	49–59	75–82	85–95
Microstructure	Granular				###	###	===	===			###	###					###					—				
	Spongy								—	—			===	===												
	Subangular blocky																###	###	===	===		###				
	Angular blocky																				—		###	===	—	—
	Single grain	—[1]	—	—											—											
	Massive															—										
Coarse material >20 µm	Pumice fragments	##[3]	###	###	==[2]	###	###	###	###	###	===	###	###	###	###		===					—	—			
	RRF[4]										—	—	—	===	===	###	—	—				===	===	===	—	—
	Quartz, feldspars	—	—	—	===	===	===	===	===	===	—	===	===	===	===	###	===	===	===	===	===	===	===	===	===	===
	Pyroxenes, amphiboles	—	—	—	===	===	===	===	===	===	—	===	===	===	===	===	—					===	—	—		
	Mica										—	—	—	—	—	—	—	===	===	===	===					
	Opaque Fe-Ti ox.	—	—	—	===	===	===	===	===	===	—	—	—	—	—	—	===	===	===	===	===	===	===	===	===	===
	White pseudomorphs																===	===	===	###	—	—		—		
Alteration of coarse material	Pumice fragments				###	===	===	===	===	—	###	===	===	===	—		###					###	###			
	Feldspars																—	—	===	===	===			—	—	—
	Pyroxenes, amphiboles										—	—	—	—	—		—					—	—	===		
	Micas																—	—								
Fine material <20 µm	Undifferentated[5]	===	===	===	===	===	===	===	===	===	===	===	===	===	===											
	Stipple speckled[6]																===					===				
	Striated[6]																	===	===	===	===		===	===	===	===
Pedofeatutes	Clay coatings													—	===	###			—	###	###			—	===	===
	Iron (hypo) coatings													—	===	###				—	===					—
	Iron nodules					—	—	===	===	—								===	===	===	===		===	===	===	===
	Depletion																			—	===		===	===	===	===
	Excrements	===	—		===	###	###	###	===	===	###	===	===	===			###	===	===	—	—	===	—	—	—	—
Ratio	Coarse/fine[7]	6/4	8/2	9/1	4/6	6/4	6/4	6/4	6/4	6/4	3/7	4/6	4/6	5/5	8/2	8/2	2/8	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9

Key

[1] Few –
[2] Common ===
[3] Many ###
[4] Rhyolitic rock fragments
[5] Isotropic
[6] Anisotropic
[7] Coarse >20 µm/fine<20 µm

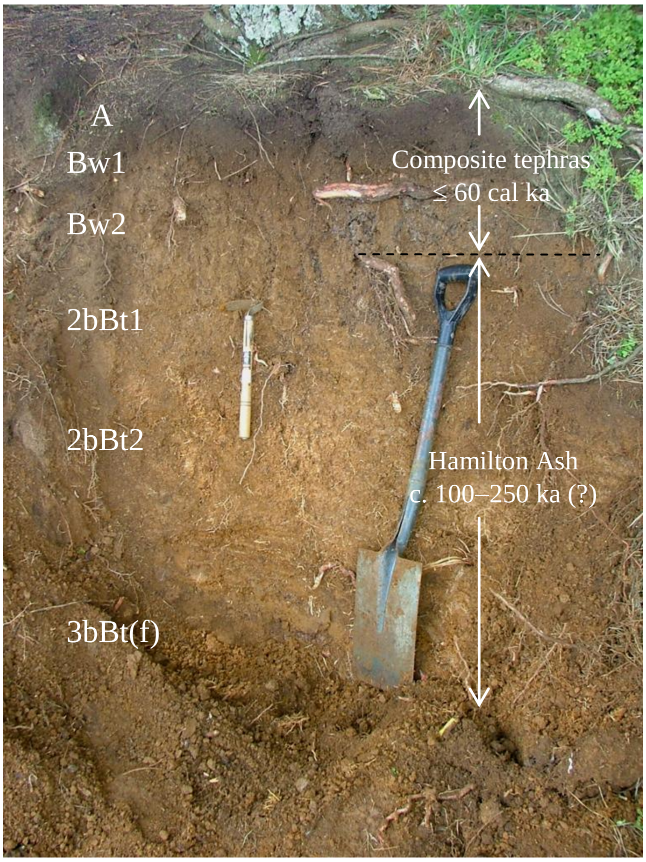




Maps of northern North Island showing locations of intraplate basalt volcanic fields (above) and South Auckland volcanic field including ages and structural patterns (right) (both from Briggs et al., 1994). PH, Pukekohe Hill

Freshly exposed Pukekohe soil at top of Anzac Rd, Pukekohe Hill, on 10 October, 2008. Leo provides the scale for new road turn-around under construction. Photo: David Lowe

Pukekohe silt loam on edge of Massey Memorial Lookout reserve, Pukekohe Hill. Location V16 783397 (bordering Ken Balle's fields)



Mangans in lower subsoil of Pukekohe soil (in close up below, cutting blade is 10 cm long)

Provisional stratigraphy, ages and horizonation. Data for Pukekohe and Patumahoe soils are given below. Pukekohe data (unpublished) from Landcare Research National Soils Database; Patumahoe data from Parfitt et al. (1981). Modern horizonation of Pukekohe soil profile SB8432 (below): B1 = BA; B2 = Bt; 'C' = another Bt horizon. Photos: David Lowe.

Soil Name: PUKEKOHE SILT LOAM Elite Lab No: SB08432

Description of Profile No: 8432 for Project No: SB

Author: GEO Date: 17-Feb-1969

Map reference: 0 0 Map Series: Grid ref unknown
Classification: Brown granular loam,
US Taxonomy:
NZSC: Mottled-acidic Orthic Granular Soil
Survey: Franklin County (part) FRAN Region: Auckland
Location: Northerly facing slope, Upper Queens Street roadside cutting.
Topdressing:
Annual Rain: 1143mm Elevation: 137 m Mean Temp - Annual: 12 C
Landform: Slope Landform Genesis:
Microrelief: Slope: 7 deg Aspect: 45 deg
Rock outcrops:
Slope Movement:
Drainage: Moderately well Land Use: Horticulture
Improvements: fertilised,
Vegetation: BRACKEN-PASPALUM-MARSHMELLOW-ROUGH ROADSIDE
Parent Materials: moderately weathered, ANDESITIC VOLCANIC ASH

Notes

SEE CARD FOR DETAILED ADDITIONAL NOTES. GROSSLY OVERDEEPENED A.P HOR

Horizon	Depth (cm)	Horizon Description
Ap	0-15	dark reddish brown (5YR 3/2) gritty silt loam; moderately weak soil strength; weakly developed medium nut breaking to coarse crumb structure; many live roots; structure - crushing to. crumb described as strong; distinct boundary.
B1	15-25	yellowish red (5YR 4/6) clay loam; moderately weak soil strength; strongly developed fine blocky structure; many faint mottles; many live roots; mottles diffuse, pale grey in patches, together with darker red cont mottles; diffuse boundary.
B2	25-40	brown to dark brown (7.5YR 4/4) clay loam; moderately firm soil strength; strongly developed medium nut structure; few faint mottles; few clay coatings; few live roots; roots tend to follow incipient prismatic struct, thin coatings are aggregate faces, mottles diffuse & reddish; diffuse boundary.
C1	40-63	strong brown (7.5YR 5/8) clay loam; moderately weak soil strength; moderately developed medium nut breaking to strongly developed coarse crumb structure; few live roots; structure crushing easily to. many f, few med white (?Gibbsite) flecks;

Horizon	Horizon depth (cm)	Lab letter	Sample depth (cm)	pH H2O	pH 1M KCl	pH 1M NaF	pH CaCl2	H2O Moist	C (%)	N (%)	C/N	Truog P (ug/g)	Phosphorus fractions (mg %) 0.5 M H2SO4	Inorg.	Organic	Total	P retn (%)
				A1A	A1A	A1B	A1A		A3A	A4A		A5A	A5B		A5D	A5E	A5C
Ap	0-15	A	-					5.9	2.70								60
B1	15-25	B	-					5.0	0.70								73
B2	25-40	C	-					4.8	0.60								77
C1	40-63	D	-					4.9	0.60								78

Horizon	Horizon depth (cm)	Lab letter	Sample depth (cm)	Cation exchange (NH4OAc @ pH7 me %) CEC	Sum bases	%BS	Ca	Mg	K	Na	KCl Ex. Al (me. %)	Titratable acidity (me. %)	Reserve Mgr (me. %)	Reserve Kc (me. %)	S Total (ug/g)	Phosphate ext. (ug/g) S	SO4
				A6E	6A3	6A5	A6B				A6H	A6I	A7B	A7A		A11	A11
Ap	0-15	A	-	19.4	10.3	53	8.6	1.00	0.10	0.55							
B1	15-25	B	-	14.7	4.24	29	2.4	0.92	0.11	0.81							
B2	25-40	C	-	13.1	2.54	19	0.9	0.83	0.17	0.64							
C1	40-63	D	-	13.2	1.69	13	0.2	0.70	0.05	0.74							

Horizon	Horizon depth (cm)	Lab letter	Sample depth (cm)	Pyrophosphate-extractable (%) Fe	Al	C	Acid oxalate-extractable (%) Fe	Al	Si	Mn	ODOE	Dithionite-citrate extractable (%) Fe	Al	Stones >2mm (%)	Moisture factor
				A8B			A8A					A8C			A2
Ap	0-15	A	-				0.53	0.39						n.d	1.045
B1	15-25	B	-				0.26	0.30						n.d	1.080
B2	25-40	C	-				0.29	0.29						n.d	1.063
C1	40-63	D	-				0.25	0.31						n.d	1.060

Soil Name: PUKEKOHE SILT LOAM Elite Lab No: SB08432

Mineralogy: Treated Clay Fraction (see Analysis Summary) (%) PART 1

Horizon	Lab letter	Sample depth (cm)	Clay (%)	Mica	Chlorite	Vermiculite	HIV	Smectite	Kandite	Kaolinite	Halloysite	Gibbsite	Goethite	Hematite	VG Am.SiO2	Serpentines	Pyrophylite	Zeolite	Talc
Ap	A	-		8	0	15	0	0	65			1	0	0		0	0	0	
B1	B	-		9	0	3	9	0	65			1	0	0		0	0	0	
B2	C	-		4	0	8	0	0	65			8	0	0		0	0	0	
C1	D	-		4	0	0	4	0	65			20	0	0		0	0	0	

Mineralogy: Treated Clay Fraction (see Analysis Summary) (%) PART 2

Horizon	Lab letter	Sample depth (cm)	Clay (%)	Interstratified minerals Mica-Vermiculite	Mica-HIV	Mica-Smec	Mica-Chlorite	Chlorite-Vermic	Chlorite-Smec	Kaolin-Smec	IHM	Allophane +Imogo	Quartz	Feldspar	Cristobalite
Ap	A	-		0	8	0	0	0	0	0	0	<1	0	0	2
B1	B	-		6	3	0	0	0	0	0	0	<1	0	0	3
B2	C	-		8	0	0	0	0	0	0	0	<1	0	0	5
C1	D	-		3	2	0	0	0	0	0	0	<1	0	0	3

Soil Name: PUKEKOHE SILT LOAM Elite Lab No: SB08432

WHOLE SOIL MINERALOGY (%)

Horizon	Lab letter	Sample depth (cm)	Carbonate min. (CaCO3)	Allophane+Imogolite	Ferrihydrite	Mica	Chlorite	Quartz	Feldspar	Kandite	Gibbsite	Hematite	Goethite	Lepidocrocite	Serpentine group	Extractable (%) -Dithio Fe	Pyro phos. Al	Acid-oxalate Fe	Al	Si
Ap	A	-			<1													0.53	0.39	
B1	B	-			<1													0.26	0.30	
B2	C	-			<1													0.29	0.29	
C1	D	-			<1													0.25	0.31	

Classification: Pukekohe silt loam

NZSC: Allophanic [or Acidic] Orthic Granular Soils; tephric, rhyolitic; silty/loamy; slow
Soil Taxonomy: Clayey, mixed, thermic Typic Kandiudults [or Andic if in upper profile BD ≤1.0 g/cm^3 and Alo + 1/2Feo >1.0]

Build-up of redistributed (eroded) soil along hedge line forming an artificial terrace (Pukekohe soils). Photo: David Lowe

PATUMAHOE SILT LOAM

Location: 9 m SE of main track on NE boundary of second block SE of glasshouse
Grid ref: N47/380173
Aspect: -
Altitude (m): 91
Rainfall (mm): 1200
Slope: Near level
Landform: Undulating ash mantled plain
Vegetation: Ryegrass, white clover, docks, paspalm, flatweeds. Buffer strip between track and experimental plots.
Drainage class: Well drained to moderately well drained
Land use: Experimental area for horticultural crops research. Generally market gardening and dairying in surrounding district.
Parent material: Hamilton Ash Formation over basalt (with palaeosol)

PROFILE DESCRIPTION

Ap1 0- 6 cm 7.5YR 3/2 silt loam; friable; strongly developed medium and coarse nut structure crushing under pressure to moderately developed fine crumb structure; few black Mn nodules up to 8 mm; abundant roots; many coarse pores; distinct irregular boundary,

Ap2 6-15 near 10YR 3/3 silt loam; moderately firm; brittle; weakly developed fine nut structure crushing under pressure to weakly developed fine crumb structure; few distinct inclusions of underlying B horizon; few fine hard black Mn concretions; few fine distinct 2.5YR 4/8 nodules (porcelinite) many roots; few coarse and medium pores; few very fine black charcoal fragments; diffuse wavy boundary,

Ap3 15-26 10YR 3/3 heavy silt loam; moderately firm; brittle; moderately developed medium and fine nut structure crushing easily to moderately developed coarse and medium granular structure; many roots; many large (to 4 cm) inclusions of B horizon; abundant coarse and medium pores (few up to 5 mm); many black Mn concretions; distinct irregular boundary,

Bt1 26-38 7.5YR 4/6 crushing to 7.5YR 5/6 clay loam; moderately firm; brittle; few distinct fine inclusions of overlying horizons; many roots, few coarse and many medium pores; abundant continuous very thin cutans (skeletans) moderately developed fine block structure crushing to strongly developed coarse crumb structure; moderately sticky; non plastic; diffuse wavy boundary.

Bt2 38-58 7.5YR 4/6 crushing to 5YR 5/8 clay loam; moderately weak; brittle; slightly sticky; non plastic; strongly developed coarse block structure crushing to strongly developed coarse and medium crumb structure; few roots; few fine distinct 5YR 4/4 hard mottles; few coarse pores; many thin discontinuous cutans (skeletans); diffuse wavy boundary.

Bt3 58-82 between 7.5YR 5/6 and 5YR 5/6 crushing to near 5YR 5/8 clay loam; very weak; brittle; slightly sticky; slightly plastic; few coarse diffuse 5YR 4/6 soft mottles; few roots; few coarse and medium pores; many thin discontinuous cutans (skeletans) moderately developed fine block structure crushing to strongly developed coarse crumb structure; distinct wavy boundary,

Bg1 82-98 7.5YR 5/6 clay loam; moderately weak; brittle; non sticky; slightly plastic; many distinct and diffuse fine 5YR 4/4 mottles; many coarse and very coarse and few medium pores; very few roots; very few thin discontinuous cutans (skeletans); weakly developed medium block structure crushing to strongly developed medium crumb structure; distinct wavy boundary,

Bg2 98-119 7.5YR 5/6 clay loam; moderately weak; brittle; non sticky; non plastic; slightly slippery; many distinct coarse and very coarse 5YR 4/6 mottles; very few pores; few roots; many distinct continuous thin cutans; moderately developed medium and coarse block structure crushing to weak fine crumb structure; diffuse wavy boundary,

Bg3 119-134 7.5YR 5/6 clay; moderately weak; brittle; slightly sticky; slightly plastic; moderately developed medium and coarse blocky structure crushing to moderately developed fine crumb structure; many medium and fine 5YR 4/6 mottles; many fine 7.5YR 7/4 near vertical sheets (following structural cracks); very few roots; very few pores; many thin discontinuous cutans; distinct wavy boundary,

2Bw 134-165 7.5YR 5/6-10YR 5/6 clay loam; moderately weak; brittle; non-sticky; non plastic; weakly developed coarse block structure; crushing to strongly developed coarse crumb structure; few coarse and very few medium pores; no roots; few fine diffuse (near 7.5YR 5/6) mottles; distinct wavy boundary,

3Bw 165-187 cm 7.5YR 5/8 slippery silt loam; moderately weak; brittle; non sticky; slightly plastic; many fine white nodular inclusions (?halloysite); many distinct 5YR 5/6 patches; many glistening crystals; few discontinuous thin cutans; no roots; distinct boundary,

4Bt 187 + 7.5YR 5/6 clay loam; very firm; brittle; non sticky; non plastic; few distinct medium black Mn concretions; abundant coarse clean quartz crystals; abundant coarse pores; massive; abundant continuous very thin cutans; no roots,

over (on auger) 2.5YR 4/6 slippery silt loam; non sticky; non plastic.

CHEMISTRY PATUMAHOE

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
9578 A	0-6	Ap1	7.0	6.2	-0.8	9.3	25.0	1.53	0.78	0.43		0.17	20.1	19.9	27.9	24.4	47.8	(100)	58
B	6-15	Ap2	6.4	5.2	-1.2	9.2	12.9	0.98	0.34	0.40		0.00	22.6	22.6	14.6	20.9	37.2	70	39
C	15-26	Ap3	6.0	4.8	-1.2	9.0	10.5	0.69	0.15	0.34		0.03	24.7	24.7	11.7	20.0	36.4	59	32
D	26-38	Bt1	5.6	4.7	-0.9	9.7	6.7	0.57	0.05	0.56		0.00	22.6	22.6	7.9	16.4	30.5	48	26
E	38-58	Bt2	5.2	4.2	-1.0	10.0	5.7	0.50	0.04	0.45		1.2	28.2	27.0	7.9	16.4	34.9	41	19
F	58-82	Bt3	5.3	4.6	-0.7	10.7	4.8	0.39	0.03	0.34		0.23	37.8	37.6	5.8	18.6	43.4	30	13
G	82-98	Bg1	5.3	4.8	-0.5	11.0	4.1	0.44	0.02	0.35		0.11	41.7	41.6	5.0	20.5	46.6	24	11
H	98-119	Bg2	5.0	4.8	-0.2	10.9	1.9	0.86	0.02	0.49		0.03	46.0	46.0	3.3	22.7	49.3	15	7
I	119-134	Bg3	5.0	4.5	-0.5	10.5	0.5	0.80	0.03	1.30		0.35	36.3	35.9	2.9	20.7	38.8	12	6
J	134-165	2Bw	5.1	4.0	-1.1	10.0	0.3	1.00	0.03	1.66		2.9	23.3	20.4	6.3	16.0	26.7	21	13
K	165-187	3Bw	5.0	4.2	-0.8	10.6	0.4	0.66	0.03	1.19		1.5	27.4	25.9	4.0	16.3	29.9	15	8

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)
9578 A	0-6	Ap1	5.0	0.45	76	95	73	64	4.1	1.15	0.70	0.45	0.01	0.43	0.21	0.10	1.9	19
B	6-15	Ap2	3.5	0.30	74	94	67	65	4.4	1.23	0.63	0.43	0.03	0.56	0.28	0.10	2.4	22
C	15-26	Ap3	3.3	0.29	76	95	65	66	4.5	1.26	0.77	0.51	0.03	0.66	0.32	0.10	1.7	26
D	26-38	Bt1	1.2	0.11	14	30	25	83	5.5	1.43	0.27	0.40	0.01	0.94	0.37	0.10	1.2	338
E	38-58	Bt2	0.9	0.07	14	29	19	93	5.7	1.69	0.30	0.67	0.11	1.35	0.56	0.11	1.4	920
F	58-82	Bt3	0.9	0.07	25	43	17	99	5.4	2.5	0.48	1.89	0.72	1.01	0.70	0.11	1.8	1152
G	82-98	Bg1	0.9	0.07	32	47	22	99	4.9	3.1	0.59	2.9	1.15	0.66	0.64	0.10	1.8	1148
H	98-119	Bg2	0.8	0.06	36	48	18	100	4.6	4.0	0.75	3.8	1.71	0.40	0.56	0.09	1.8	1132
I	119-134	Bg3	0.5	0.02	23	29	9	99	3.5	2.6	0.61	2.5	1.10	0.27	0.43	0.07	1.8	844
J	134-165	2Bw	0.3	0.01	10	13	6	83	3.2	0.79	0.27	0.48	0.12	0.50	0.24	0.09	1.5	452
K	165-187	3Bw	0.4	0.02	16	20	10	93	3.2	1.51	0.67	1.45	0.59	0.80	0.42	0.07	12.0	497

PARTICLE SIZE DISTRIBUTION (<2 mm) Patumahoe

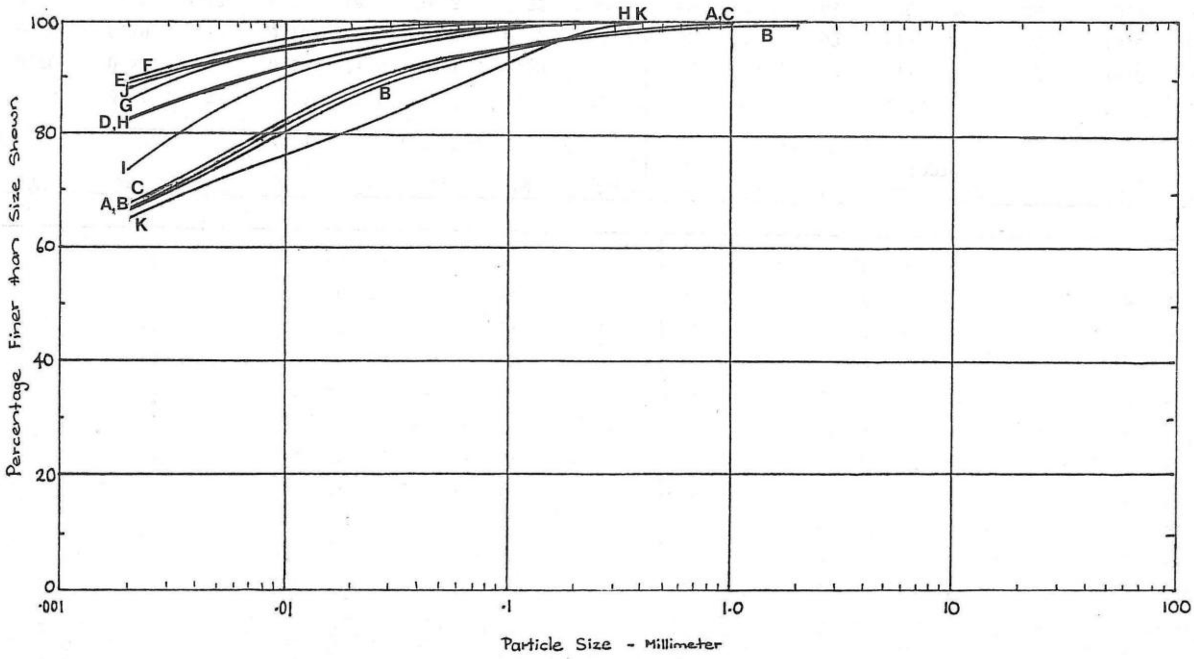
Sample No. SB	Depth (cm)	Hor.	Sand 2-0.1 mm (%)	Sand 0.1-0.05 mm (%)	Silt 0.05-0.002 mm (%)	Clay <0.002 mm (%)	Fine clay <0.0002 mm (%)	Fine clay / Total clay	Stones (%)
9578A	0-6	Ap1	4	3	27	66	45	0.68	(<1)
B	6-15	Ap2	4	3	26	67	46	0.69	(1)
C	15-26	Ap3	4	2	27	67	46	0.69	(<1)
D	26-38	Bt1	2	1	15	82	68	0.83	
E	38-58	Bt2	1	1	9	89	75	0.84	
F	58-82	Bt3	0	1	9	90	68	0.76	
G	82-98	Bg1	1	2	10	87	61	0.70	
H	98-119	Bg2	1	0	16	83	54	0.65	
I	119-134	Bg3	1	2	23	74	42	0.57	
J	134-165	2Bw	0	2	10	88	63	0.72	
K	165-187	3Bw	7	6	21	66	45	0.68	

PHYSICS

Hor. Depth (cm)	Hor.	15 bar water Field moist (%)	15 bar water Air Dry (%)
0-6	Ap1	30.8	24.8
6-15	Ap2	29.8	23.8
15-26	Ap3	30.2	23.7
26-38	Bt1	45.8	31.0
38-58	Bt2	53.4	33.2
58-82	Bt3	64.4	31.4
82-98	Bg1	71.0	31.4
98-119	Bg2	75.5	30.8
119-134	Bg3	68.2	34.4
134-165	2Bw	64.4	42.2
165-187	3Bw	55.2	31.7

Core Depth (cm)	Dry bulk density (T/m³)	Total porosity (%)	Large pores (%)	Field Cap. (at 0.2 bar) (% v/v)	Wilting Pt. (at 15 bar) (% v/v)	Available water (% v/v)
0-6	1.04					
7-10	1.00					
16-19	0.95					
20-23	0.90					
31-34	0.78					
–	–					
	1.06					
	0.94					
	0.81					
	0.78					
	–					
	–					

SB 9578 Patumahoe



Mineralogy Patumahoe

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	Hematite
9578A	0-6	Ap1			2	9			42	17	20	1	1	7			
B	6-15	Ap2			4	23			31	19	15	1	1	6			
C	15-26	Ap3			5	20			30	20	17	1	1	5			
D	26-38	Bt1			4	20			17	33	15	tr	tr	10			
E	38-58	Bt2			2	14			11	35	22	tr	tr	16			
F	58-82	Bt3				16			11	40	21	tr	tr	11			
G	82-98	Bg1				12			5	42	21	tr		19			
H	98-119	Bg2				15				46	16			23			
I	119-134	Bg3				11				65	5			15			
J	134-165	2Bw								88	tr			12			
K	165-187	3Bw				24				60	4						

Sample No. SB	Sand Fraction (%): Quartz	Feldspar (acid)	Andesine	Glass	Kaolinite	Biotite	Horneblende	Augite	Hypersthene	Epidote	Cristobalite	Quartz Ag.	Magnetite	Plant opal
9578A	a		C	C		R	S	tr	R	tr	S		S	S
B	a		c	a			S	tr	R		S	R	S	S
C	a		c	C			S/R	tr	R		S	R	R	S
D	a/A		c	C			S		S		S		S	S
E	a		c	c	C		R			tr	S	S	S	R
F	a/A		c/S	c	S		R		tr	tr	S		S	R/S
G	a/A	tr	S	c	C		R			tr	S	S	S/c	R
H	a		R		a						S/c	S	S/c	
I	C			R	A	tr					S	S	c	
J	A	tr		R	C	R					S	S/c	c/C	
K	C	R	R		a	a					S	S	S	

Total Element Analysis

Sample No. SB	Hor.	Fe (%)	Mn (%)	Ti (%)	Ca (%)	K (%)	P (%)	Si (%)	Al (%)	Mg (%)	Na (%)	Cr (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Ba (ppm)	Ign. loss (%)
9578A	Ap1	5.53	0.48	0.68	0.78	0.38	0.17	21.1	11.7	0.31	<0.2	67	21	69	125	36	46	14.7	344	19.6
B	Ap2	5.79	0.46	0.70	0.44	0.38	0.17	21.8	12.1	0.30	<0.2	63	5.0	68	117	37	53	14.5	354	17.5
C	Ap3	5.74	0.42	0.70	0.39	0.39	0.16	22.0	12.0	0.26	<0.2	66	7.7	69	117	33	52	13.0	341	17.0
D	Bt1	6.70	0.06	0.71	0.19	0.22	0.05	18.2	16.3	0.22	<0.2	62	7.7	65	95	25	46	9.2	351	17.4
E	Bt2	6.32	<0.02	0.70	0.24	0.26	0.10	18.7	18.3	0.32	<0.2	58	14.4	70	86	21	21	7.6	369	19.0
F	Bt3	6.70	<0.02	0.67	0.10	0.14	0.06	14.5	19.7	0.26	<0.2	49	12.8	78	84	23	9.9	6.9	366	20.0
G	Bg1	6.06	<0.02	0.61	0.08	0.12	0.07	14.0	20.2	<0.20	<0.2	48	13.8	73	83	22	12.3	5.3	430	21.0
H	Bg2	5.88	<0.02	0.57	0.03	0.12	0.07	14.3	20.4	<0.20	<0.2	37	13.1	75	89	19.2	5.9	6.6	616	20.0
I	Bg3	4.64	<0.02	0.46	<0.01	0.12	0.04	17.3	19.7	0.26	<0.2	27	10.0	59	104	14.8	7.9	3.9	1060	16.4
J	2Bw	4.81	<0.02	0.48	<0.01	0.12	<0.02	19.7	17.9	<0.20	<0.2	30	8.5	46	84	14.1	8.2	5.7	1100	14.3
K	3Bw	4.65	<0.02	0.46	0.05	0.50	0.03	19.5	17.3	0.27	<0.2	22	<4.0	32	69	16.7	18.6	6.5	936	15.2

Classification: Patumahoe clay loam

NZSC: Allophanic Oxidic Granular Soils; tephric, rhyolitic; clayey; slow
Soil Taxonomy: Clayey, mixed, thermic Andic Palehumults

"We're taking soil samples today ... in other words, FIELD TRIP!"