Soil-landscape Modelling and Soil Property Variability for Forestry Land Evaluation in Longwood Forest, Southland

Phase 1: Soil-landscape Model Development

Progress Report No. 1 for Rayonier New Zealand

by

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Abstract

Large scale, quantitative information about the variability of target soil properties is required for forest management. This project is attempting to determine whether or not the New Zealand Soil Classification system (NZSC), when used in combination with a soil-landscape model, adequately communicates this information. In the first phase of this project a soil-landscape model was developed and a pilot variability study conducted.

The soils in the study area, located in the Woodlaw Block of the Longwood Range, are formed from either Permian andesite or greywacke on moderately steep to steep hill slopes under a moist cool climate and a vegetation cover of beech and podocarp forests.

The soil-landscape model was developed using the land systems approach. The model consists of predictive relationships between topographic features and soil classes. There is a clear relationship between slope steepness, the abundance of surface boulders and the gravel content of the soil. A soil-landscape unit map showing the distribution of predicted soil classes has been produced.

The results of the pilot variability study have showed that the soils sampled are acidic and have moderate to high P-retention values. An analysis of variance indicated that both of these properties are significantly variable between sites and between horizons. There appears to be a relationship between land component type and the magnitude and variability of these properties. The clay mineralogical analysis revealed that the dominant clay minerals present in all the soils sampled are chlorite-vermiculite, kaolinite, sepiolite, and allophane. The presence of allophane and kaolinite may be related to the moderate to high P-retention values.

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Table of Contents

Introduction

Rayonier New Zealand Limited has recognised the need to incorporate soil information into the forestry land evaluation systems they are developing. More specifically, they are seeking large scale, quantitative information regarding the variability of individual soil properties which have a direct influence on forest management.

It is generally accepted that conventional soil surveys do not adequately provide this information due largely to their small scale and high cost. Rayonier, therefore, wish to find the most appropriate means of collecting, organising, and communicating the soil information they require.

The aim of this project is to determine whether or not the soil classes of the New Zealand Soil Classification system (NZSC), mapped using a soil-landscape model, adequately account for and therefore communicate the variability of soil properties important for forest management. Three objectives were set to achieve this aim:

- to develop an initial soil-landscape model for the Woodlaw land system
- to establish the relationship between the variability of target soil properties and the mapped soil classes
- to analyse soil class maps and individual property maps using a GIS.

Each of these objectives represents a phase of the project.

The first phase (objective) of this project has been completed. The resulting initial soil-landscape model and the methods used in its development are described and discussed in this report. In addition, a pilot variability study was conducted to assist in the planning of phase two and the development of the soil-landscape model. The results of this study and their implications are presented and discussed. Some of the samples taken in this study were analysed in order to determine their clay mineralogy. The results and implications of these analyses are presented and discussed also. This report begins by describing the location and natural environment of the study area.

Study Area

Location

The Longwood Forest is located on the Longwood Range, a moderately low mountain range in Southland, the southern-most region of the South Island of New Zealand. This range is situated between the Aparima River to the east and the Waiau River to the west. Its axis runs in an approximately northwest-southeast direction. The location of the Longwood Forest and the Woodlaw Block is illustrated by Figure 1.

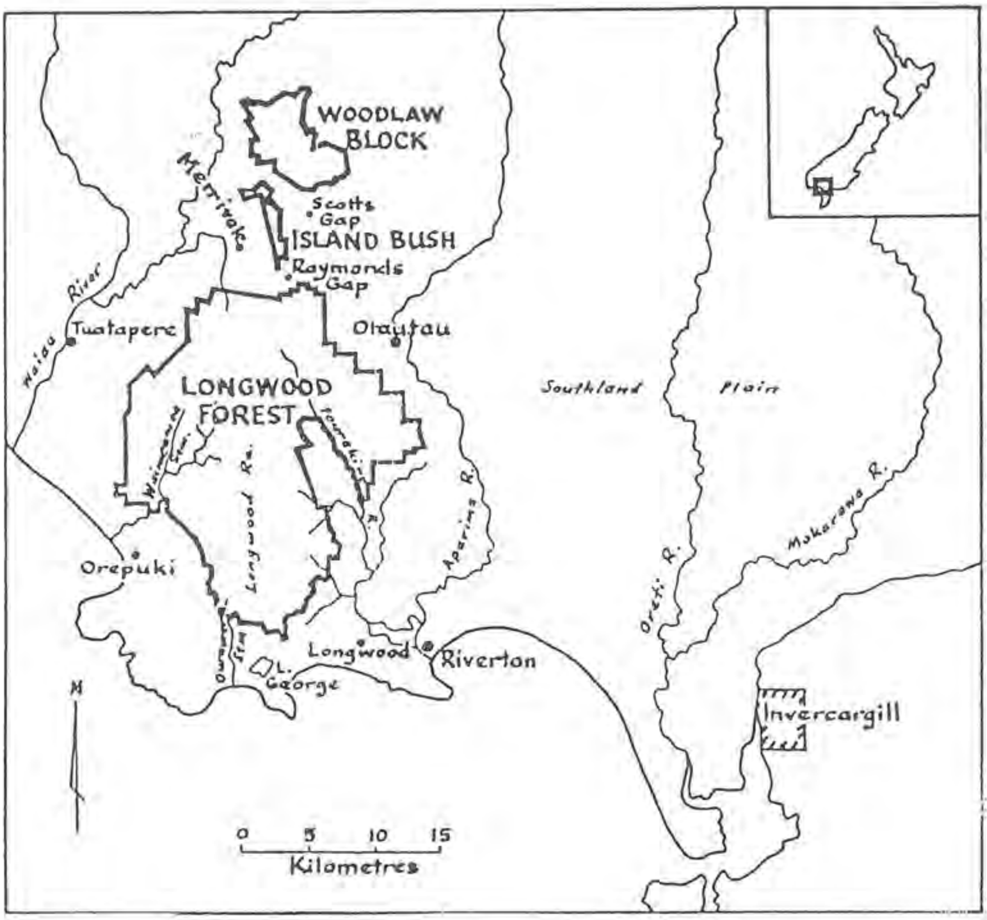

Figure 1. Maps showing the location of the Longwood Range and Woodlaw Block (From: Hamel, 1983, 6).

The initial soil-landscape model has been developed within the Woodlaw Block of the Longwood Forest. The Woodlaw Block is situated on the northern-most outlier of the Longwood Range some 10 kilometres north of the main range (Figure 1). The two intensive study sites (training windows) are positioned in the northern end of the Woodlaw Block, window 214 to the northwest, window 210 to the northeast. The location of each is depicted in Figure 2.

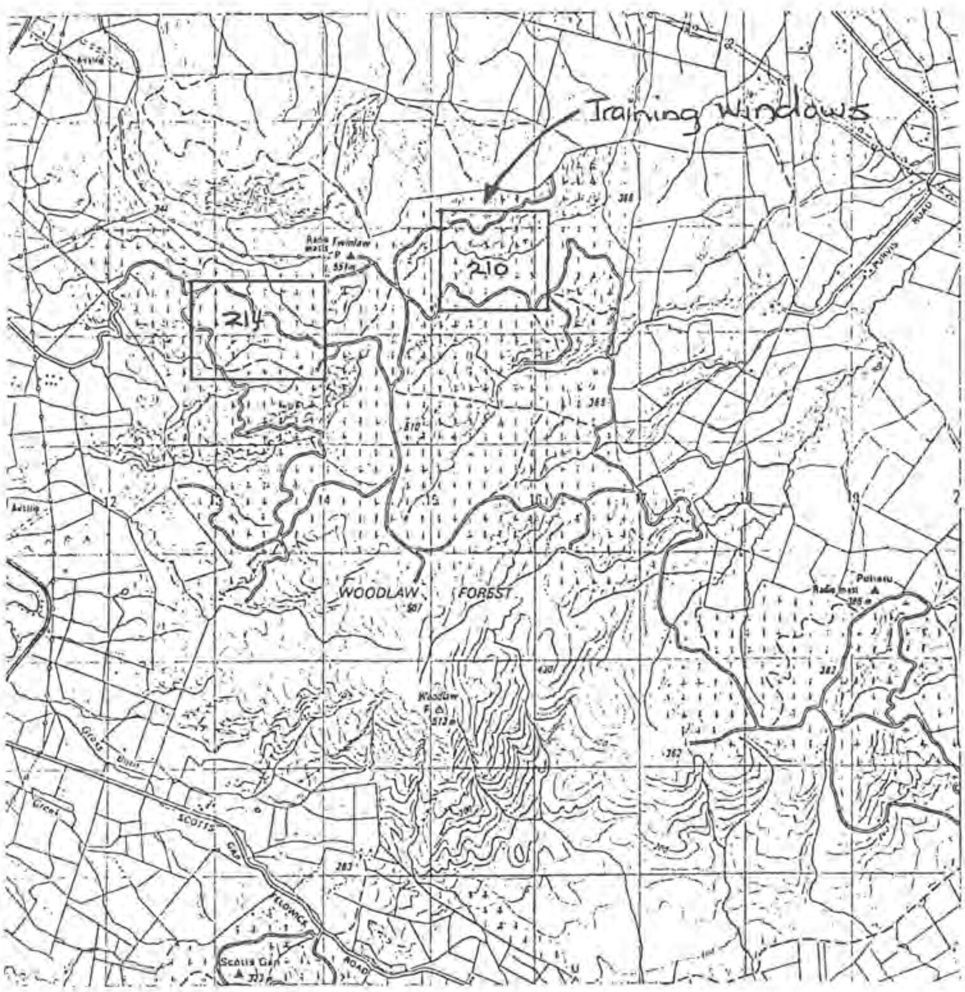

Figure 2. Map showing the location of the two training windows within Woodlaw Block (From: Topographic map NZMS 260 D45, 1985).

Natural environment

Climate

Hamel (1983) generally described the climate as being cool, moist, and windy. The mean annual temperature of the lowlands is between 7.5-10.0 ° C (Hamel, 1983) while the annual rainfall in the Longwood Range is between 800-1600 mm (Challis and Lauder, 1977; Hamel, 1983; Hay, 1989).

The rainfall is relatively evenly distributed throughout the year with fog and drizzle being brought by the westerly winds. However, rainstorms from the southwest are common during the winter months. The dominant west to southwest flowing winds are intercepted by the Longwood Range. The result of this is a rainfall gradient occurring across the range in a southwest-northeast direction. The westerly (windward) side of the range receives up to twice as much rainfall (1600 mm per annum) as the easterly flanks (1000 mm per annum) due to the rain-shadow effect. During winter, snow may remain on the main ridges for up to several weeks (McGlone and Bathgate, 1983).

The windiness may result from Southland's proximity to the region of most intense westerly wind circulation in the Southern Ocean. In fact, Southland's climate as a whole may be sensitive to fluctuations in the frequency and intensity of these strong westerly winds. It is thought that changes in atmospheric circulation that have taken place since the maximum of the last glaciation have significantly influenced Southland's climate. The climate began changing towards the current regime after 7000 yr B.P. due to an intensifying southwesterly circulation (McGlone and Bathgate, 1983).

Native vegetation

The pre-European vegetation of the Longwood Range was dominated by *Nothofagus* (Beech) species and podocarp-hardwoods. *Nothofagus menziesii* (Silver Beech) being dominant on the cold, wet summits of the range. However, on very exposed and poorly drained summit areas they were replaced by subalpine shrubland consisting of *Dacrydium biforme, Mysiue divaricata, Phyllocladus alpinus, Pseudopanax colensoi, Dracophyllum longifolium*, and several *Coprosma* species (McGlone and Bathgate, 1983). *Coprosma* species still exist within the exotic plantation forests in the Woodlaw Block today.

The cold, wet side slopes of the range were forested by *Dacrydium cupressinum* (Rimu) in association with *Podocarpus ferrugineus* (Miro), *Weinmannia racemosa, P. hallii,* and *Metrosideros umbellata.* The podocarps being dominant on the ridge crests while small trees such as *Griselina littorals, Fuchsia exorticata, Carpodetus serratus*, and *Aristotelia serrata* dominated the dark, moist gully bottoms (McGlone and Bathgate, 1983).

Podocarpus spicatus (Matai) and *Dacrycarpus dacrydiodes* were dominant on the low foot hills which were somewhat warmer and drier. The above described vegetation distribution is influenced by elevation and the southwest-northeast tending rainfall gradient. Figure 3 illustrates the forest pattern of western Southland. From this map it can be seen that on the eastern and flanks of the Woodlaw Block, podocarp species were dominant while *Nothofagus* species were dominant on the summits and eastern flanks (McGlone and Bathgate, 1983).

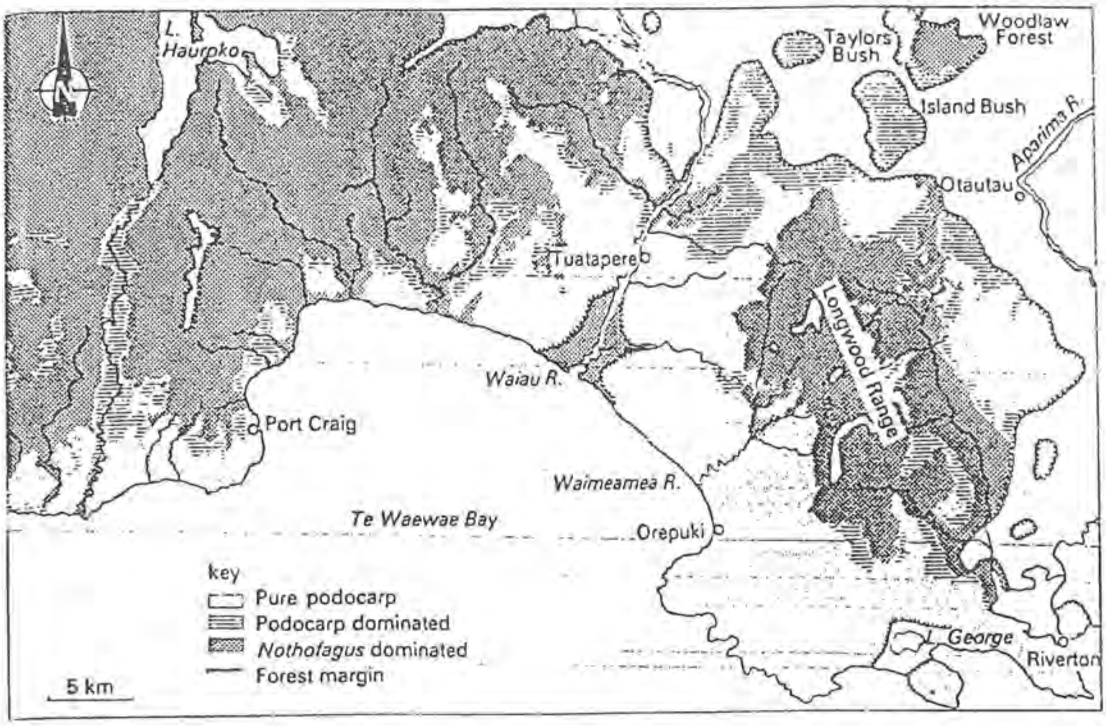

Figure 3. Map showing the 1858 forest distribution of western Southland (From: McGlone and Bathgate, 1983, 297).

A vegetation history of the Longwood Range has been presented by McGlone and Bathgate (1983) and is summarised here. Grassland and small shrubs became established around 12,000 yr B.P. Shrublands, dominated by *Dracophyllum*, expanded and *Nothofagus menziesii* though rare was present between 12,000 and 9,400 yr B.P. Between 9,400 and 7,000 yr B.P. there was a rapid change from shrubland/grassland to forests. The composition of these forests changed during the period 7,000 to 4,000 yr B.P. in that *Dacrycarpus* species declined while *Podocarpus ferrugineus* increased. From 4,000 to 1,000 yr B.P. *Dacrycarpus* continued to decline while there was a rapid increase in *Nothofagus menziesii* and *Dacrydium cupressinum*. There was relatively little natural change in the forests of the Longwood Range between 1,000 and 700 yr B.P. However, forest clearance by Polynesian people resulted in a severe decline in *Podocarpus spicatus* (Matai) and *Dacrycarpus* species. Grass and shrubland soon replaced the cleared forests (McGlone and Bathgate, 1983).

The native vegetation history of the Longwoods, before human intervention, has clearly been influenced by the interaction of climatic and topographic factors. Topographic factors such as elevation and aspect influence the distribution of vegetation via their effect on local climates. Climatic changes result in changes in vegetation composition and dominance. However, McGlone and Bathgate (1983) suggested that one of the main factors influencing vegetation change may have been soil evolution. As the soils became more developed the phosphates made available from the parent material were slowly leached and fixed thus reducing the amount available for plant uptake. The increasing dominance of tree species more tolerant to infertile soils, such as *Dacrydium cupressinum* and *Nothofagus* species, with time may therefore be explained by the increasing infertility of the soils (McGlone and Bathgate, 1983). The pattern of native vegetation was most likely influenced by a combination of topographic, climatic, and edaphic factors.

Topography

The Longwood Range is a low mountain range with a maximum elevation of 870 m. It forms a boundary between two distinct geographic regions, the Southland Plains to the east and Fiordland to the west. The landforms of the range are relatively subdued (McGlone and Bathgate, 1983). The present topography of the Longwood Range was first shaped by faulting and folding in the Pliocene and was completed by the regional and differential uplift of the Kaikoura Orogeny (Wood, 1978).

The topography of the Woodlaw Block was described as hilly land by Bruce *et al.* (1973). The Longwood Range occurs within the central hill and mountain range physiographic unit (Figure 4) delineated by O'Byrne (1986). The strongly eroded landscape of the Longwood Range could be described as hilly or steep land with rounded to moderately steep slopes. The dominant landforms within this landscape include mountains and hills with intervening valleys (Hamel, 1983; O'Byrne, 1986; Milne *et al.*, 1995).

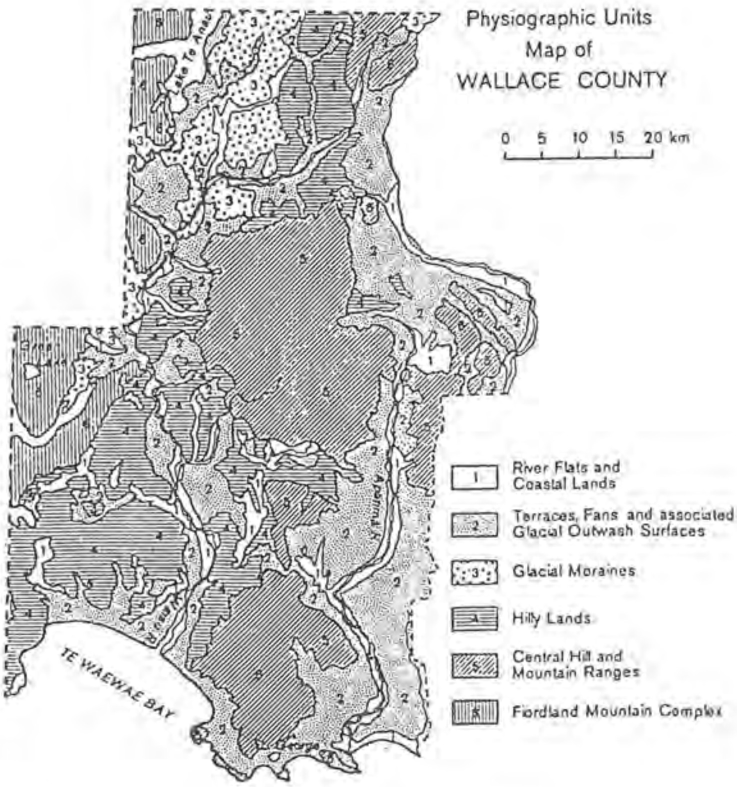

Figure 4. Map of the distribution of physiographic units in Wallace County (From:O'Byrne, 1986, 7).

Geology

The rocks discontinuously extending from the Takitimu Mountains through the Longwood Range to Bluff are of Carboniferous to Permian age (286-245 Ma). They have been classified into three groups, the Takitimu Group, the Longwood Complex, and the Productus Creek Group. The Productus Creek Group, comprised of sandstone, tuffaceous sandstone, and limestone, overlies both the Takitimu Group and the Longwood Complex. The Longwood Complex consists of peridotite, gabbro, anorthosite, and troctolite layered intrusive centres and is the "root zone" of the Brook Street Terrane (Turnbull and Uruski, 1993, 11). Its history of intrusion, assimilation, and deformation is highly complex (Challis and Lauder, 1977). The distribution of these groups is illustrated by the map in Figure 5. It can be seen from this map that the Woodlaw Block is formed chiefly from Takitimu Group rocks.

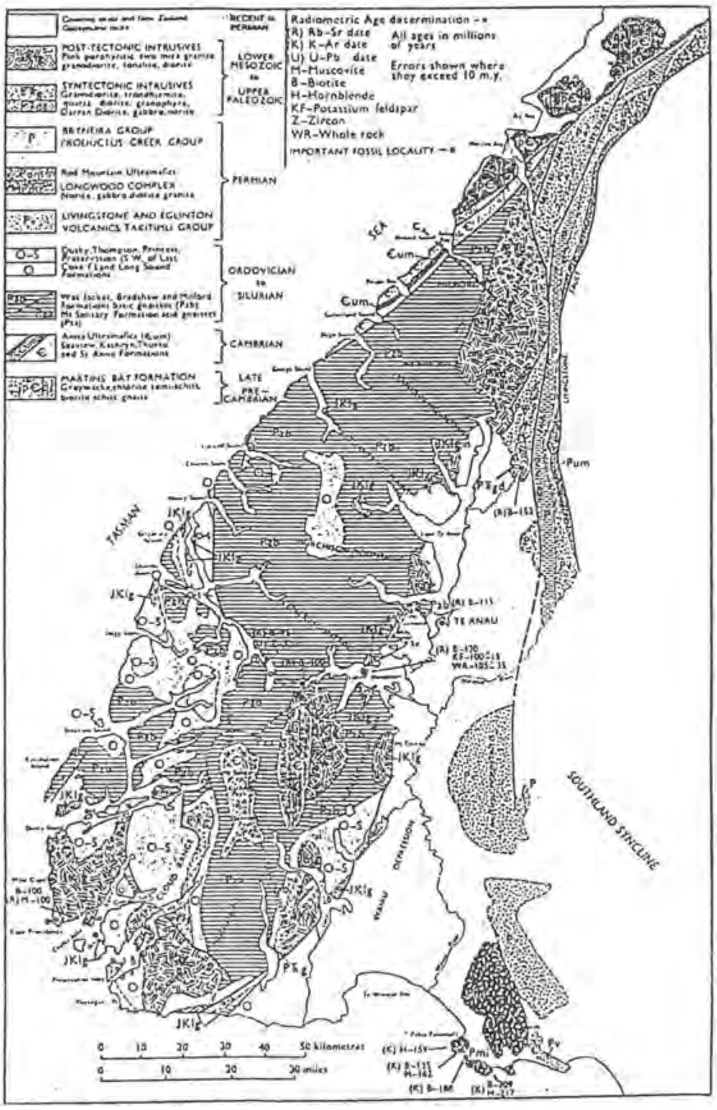

Figure 5. Map showing the distribution of the major geological units that comprise the basement geology of the western Southland region (From: Suggate *et al.*, 1978, 101).

The Takitimu Group forms the upper part of the Brook Street Terrane which is an "assemblage of island arc lavas, marine volcanoclastic rocks, and associated shallow intrusives" (Houghton, 1985, 649; Turnbull and Uruski, 1993). The Takitimu Group forms the Takitimu Mountains, the southern Wairaki Hills, Twinlaw (within Woodlaw), and the eastern foothills of the Longwood Range (Mutch, 1978a). It is thought to have accumulated adjacent to an active island arc in a marine basin and comprises products of effusive and explosive volcanism and turbidite sedimentation (volcanic/plutonic igneous rocks and volcanoclastic sediments) in an alternating sequence. These rocks have undergone some metamorphism. Basic rocks such as gabbro and diorite subsequently intruded the Takitimu Group during or immediately after the last stages of volcanism (Houghton, 1985; Turnbull and Uruski, 1993). These rocks, known as the White Hill Intrusives, are similar to the Takitimu Group rocks in composition but are of a coarser grain size. Their mineralogical and chemical similarities with the Takitimu Group rocks suggests that they are co-magmatic. These intrusives also include weakly porphyritic basaltic dykes which cut across the coarser intrusives. It appears that the most of the intrusion occurred during the late Permian (Houghton, 1986). The individual rock types of the Takitimu Group include pyroclastic breccia, spilitic and andesitic tuff, siltstone and mudstone, spilitic pillow lava, augite basalt, vesicular andesite lava, and andesite, microdiorite and diorite sills. The eastern flanks of the Longwood Range are comprised of a sequence of basaltic flows, and volcanic breccias (Williams, 1967; Mutch, 1978a).

Houghton (1985) presented a model of the Takitimu Group magmatism. This is summarised as follows. Basaltic magma rose from shallow reservoirs in large volumes and in so doing partially melted the mafic crust which produced rhyodacitic magma. Some basalt was rapidly erupted at the surface while basaltic andesites and andesites formed in magma chambers. Due to effusive and explosive eruptions a thick apron of volcanic/volcanoclastic material was deposited. Near to the end of the volcanism the sequence was intruded by basaltic magma. This intrusion influenced the metamorphism that was occurring as a result of the burial of the volcanic/volcanoclastic sequence. A tectonic event put an end to the volcanic activity. The strata that make up the Productus Creek Group include fossiliferous volcanic greywacke, roundstone boulder to cobble conglomerate, fossiliferous tuffaceous limestone to calcareous mudstone, and coarse to fine lithic and crystal tuff (Mutch, 1978b).

The high degree of neotectonic activity and rapid uplift rates occurring in the South Island can be attributed to the island's position on the boundary between the Pacific and Indo-Australian plates. An average uplift rate adjacent to the Alpine Fault of 6.2 mm/yr over the last million years has been estimated. However, in Fiordland, radiocarbon dates obtained from wood samples taken from a marine terrace suggest an uplift rate of around 1.5 mm/yr over the last 7,000 years (Bishop, 1991). The Takitimu Mountains are separated from the Longwood Range by the Ohai depression which indicates that uplift has not occurred along the whole length of the Takitimu-Longwood axis. The whole region, except for a few small rocky islands along the Takitimu-Longwood axis, was totally submerged during the Oligocene (Wood, 1978). Within the Waiau-Whakatipu fault fold zone the Takitimu Mountains and Longwood Range are considered to be major domal uplifts (Suggate *et al.*, 1978). The Longwood Range may be described as a fault bound block (Hay, 1989). A major shear zone occurs along its western margins while to the east and north it is faulted against the Takitimu Group (Turnbull and Uruski, 1993).

Significant loess deposits are restricted to elevations below 300 m where the material has originated from floodplains (McGlone and Bathgate, 1983; McIntosh and Eden, 1988). The main source of the loess deposited in northeast Southland is the floodplain of the Mataura River (McIntosh, 1988). As the prevailing wind is from the west or southwest the loess deposits become thinner and their textures become finer with distance east of the Mataura River. The loess deposits are thin and discontinuous on the western banks of the river (McIntosh and Eden, 1988; McIntosh, 1988). In northern and eastern areas of Southland the loess is derived from schist rocks whereas in the southern and western areas it is mainly derived from tuffaceous greywacke (Churchman and Bruce, 1988). It is thought that the loess deposits that form the parent material of modern soils may have been deposited during the latter part of the last glaciation (Bruce, 1973a; Bruce, 1983). Climatic conditions under which loess is deposited tend to be rather cold and dry. Such conditions are characteristic of glaciations. Multi-layered loess deposits, derived from tuffaceous greywacke, occur in the lower Waiau valley to the west of Woodlaw. The source areas for these deposits were the Waiau River floodplain and the shallow continental shelf (Bruce, 1973b). Bruce *et al.* (1973) mapped the Woodlaw Block as having a loess cover of variable thickness ranging from no loess to more than one metre. To date no deposits of loess have been positively identified within the Woodlaw Block. However, the relatively silty textures and the fragipan found in one pedon suggest that thin deposits of loess may have contributed to the development of the soils described in this project.

Soils

By far the dominant soil classes identified within Woodlaw to date are Acid, Firm, and Orthic Brown Soils. However, small areas of Recent and Pallic Soils occur also. These soils have formed under the influence of the above factors of soil formation (climate, vegetation, topography, and parent material) over time. These factors influence the nature and type of processes which operate to form the soil. Therefore they influence the soils' characteristics. Changes in one, some, or all of the soil forming factors through space result in the spatial variation of soil characteristics and thus a pattern of soil distribution.

Methodology

Land systems approach

The land systems approach has been adopted for the development of the soil-landscape model in this project. The term land system has been defined by Christian and Stewart (1953) as 'an area within which there is a recurring pattern of topography, soils, and vegetation with a relatively uniform climate'. It is also defined to be the area of validity of a soil-landscape model (Lynn, and Basher, 1994). This approach involves defining the extent of the land system (area for which the model is to be valid) and then developing the model in training windows within this area. Usually the developed model is then tested in other areas within the land system.

It seems that the land area encompassing the majority of the Woodlaw Block (low mountains) is distinguishable from the surrounding lands and is thus definable on the basis of geology, topography, climate, and age. There most certainly appears to be a recurring pattern of geology, topography, and soils with a broadly uniform climate within this area. From all accounts it appears that there was a recurring pattern of native vegetation also. It is therefore proposed that, for the purposes of this project, this land area be defined as the Woodlaw land system.

Model development

The relationships between observable landscape features (topographic, geologic, vegetative, and temporal) and soil classes were investigated in two intensive study areas (training windows 214 and 210) of approximately 30 ha in area within the Woodlaw land system. A separate area comprising one land component only has also been included to aid in the development of the model. These study sites were selected on the basis of their: (1) representativeness of Woodlaw as a whole, (2) potential for having multiple delineations, (3) accessibility, and (4) degree of heterogeneity. Potential study sites were investigated by both field reconnaissance and aerial photograph interpretation.

Once the windows were chosen, the geomorphic (soil-landscape) units which they contained were delineated via aerial photograph interpretation and field investigation. The soil classes were then determined by conducting detailed descriptions of soil pedons within the delineated geomorphic units. The detailed descriptions were supported by the brief descriptions of auger samples taken on a judgement basis. Horizonation, boundary depths, moist colours, and textures were recorded from the auger samples. The criteria used to select the soil morphological attributes to describe when conducting the detailed pedon descriptions were their: (1) importance in the New

Zealand Soil Classification (NZSC) of Hewitt (1993), (2) importance to forestry management, and (3) potential relationship to observable landscape features.

The construction of the soil-landscape model was conducted in two stages. Firstly, the landscape framework of the model was designed. This involved identifying and defining the observable landscape features to be used and arranging them in an hierarchical system in accordance with the land systems approach. This was achieved by developing a working ledger by which each soil-landscape unit is to be characterised. Secondly, the soil class data were related to the defined observable landscape features and thus soil-landscape relationships were developed.

The model is presented in the form of a table supported by a map of the soil-landscape units, and a stylised cross-sectional representation of the landscape.

The laboratory characterisation of the soil samples taken from each horizon of each pedon described (apart from pedons 11, 13, and 14) is still to be completed. The properties most important for soil classification will be measured by an independent laboratory. This will allow for tentative field classifications to be checked and modified if necessary and thus enable more confidence to be had in the assigned classifications. It is important for the next phase of the project (testing of the NZSC) that a reasonable level of confidence is had in the soil classifications.

The Initial Soil-landscape Model

The soil-landscape model presented below is a draft of the initial model. A small amount of additional work is required to 'fine tune' this initial model. The initial model will then be tested and a final model will be developed for the Woodlaw land system as a part of the associated project being conducted by Dr R.D. Taskey.

Model Construction

As mentioned previously, this soil-landscape model was developed in two stages: (1) the design of a landscape framework, and (2) the correlation of soil classes with the observable landscape features.

Landscape framework

The landscape framework consists of a four tiered hierarchy of geomorphic and topographic features consistent with that discussed by Lynn and Basher (1994). These features have been identified and defined on the basis of their structure, configuration, composition, position, age, and genesis (R. Taskey, 1997 unpublished). The broadest level is the land system. At the second level the land system is subdivided into land components. These may be further subdivided into land elements which is the third level in the hierarchy. A land component may consist of one land element only but more commonly will consist of two or more land elements. Land elements can be further subdivided by descriptive landscape modifiers which are more specific observable landscape features such as elevation, aspect, and slope steepness.

Land components are individually recognisable geomorphic features of around three hectares or smaller. They are defined as 'areas within which environmental conditions are uniform or vary in a simple or consistent way' (Lynn and Basher, 1994). Some examples include landslide complexes, side slopes, and structural benches. Land elements are identified on the basis of their form, structure or position within the land component. They are often defined as the 'area between a break or inflection in slope' (Lynn and Basher, 1994). Examples of land elements are shoulder slopes, back slopes, and foot slopes (R. Taskey, 1997 unpublished).

The land components that have been identified within the Woodlaw land system and incorporated into the model are:

- Main ridge: high elevation flat to convex broad summits
- Nose slope: convex-convex end of a spur exhibiting divergent surface water flow
- Parallel side slope: linear-linear side slope
- Convex-linear side slope: exhibits divergent water flow
- Divergent side slope: linear-convex or convex-convex broad sloping flank of a hill, mountain, or ridge
- Convergent side slope: linear-concave broad sloping flank of a hill, mountain, or ridge
- Channel: a narrow, relatively shallow stream channel (dry or flowing)
- Landslide complex: a rotational or translational mass movement feature that has a discrete failure pattern, side scarp, and head scarp
- Structural bench: a ledge or shelf bordered by steeper slopes above and below (a tread-riser sequence) and formed by bedrock movement (faulting)
- Rock outcrop: an area of exposed bedrock still connected to the source rock (R. Taskey, 1997 unpublished).

The land elements that subdivide these land components are:

- Summit: the uppermost part of a component bounded by shoulder slopes
- Back slope: the mid portion of a side slope occurring between the shoulder slope and the foot slope. They may be linear, convex, or concave and are subdivided into upper, mid, and lower back slopes

- Foot slope: the lower part of a side slope occurring between the back slope and the toe slope. It is usually concave
- Toe slope: the lowest part of a slope occurring immediately below the foot slope
- Bench summit: a flat or near level shelf bounded by steeper slopes above and below
- Bench riser: the steep slope above or below a bench summit
- Earthflow: the foot or toe of a landslide complex, formed by mass movement as opposed to faulting (R. Taskey, 1997 unpublished).

The above land elements may be further subdivided by the following descriptive modifiers:

- Elevation classes:
    - E1 = 100-350 m
    - E2 = 300- 400 m
    - E3 = 400-480 m
    - E4 = >480 m

  The rationale for assigning these classes is:
    - 480 m is the lower limit of mafic rock out-crops
    - 400 m is lower limit of landslide complex head regions except in the region south of window 210
    - 350 m is upper limit of landslide complex head regions to the south of window 210
    - wind, low temperatures and snow are more common above 400 m
    - on exposed aspects wind, low temperatures and snow may be common down to 300 m
- Aspect classes:
    - A1 = 330°-90° (sunny and sheltered)
    - A2 = 90°-150° (shady and sheltered)
    - A3 = 150°-250° (shady and windy)
    - A4 = 250°-330° (sunny and windy)
- Slope steepness classes:
    - S1 = 0°-5°
    - S2 = 5°- 20°
    - S3 = 20°-30°
    - S4 = > 30°

  The rationale for assigning these classes is:
    - 5° is critical steepness for significant sheet and rill erosion
    - 20° is the upper limit for the safe operation of heavy machinery
    - 30° is critical steepness for mass movement
- Surface boulder abundance classes:
    - B1 = <10%
    - B2 = ≥ 10%

The rationale for assigning these classes is:

- $\geq$ 10% may affect management operations and productivity
- the presence of surface boulders seems to be somewhat indicative of soils with gravelly horizons beneath

- Lithology classes:
  - L1 = mafic porphyry
  - L2 = mafic breccia
  - L3 = sandstone
  - L4 = siltstone

Soil modifiers

Within the soil-landscape model the above observable landscape features are related to soil classes. Important additional information about the soils related to the landscape features is provided by the following soil modifies. These modifiers accompany the soil class information.

- Soil depth classes:
  - D1 = <50 cm
  - D2 = 50-100 cm
  - D3 = 100-200 cm
  - D4 = >200 cm

The rationale for assigning theses classes is:

- <50 cm defines a shallow soil in *Soil Taxonomy* (Soil Survey Staff, 1994) and trees on soils of this thickness are more susceptible to wind throw
- 100 cm is around the depth limit of ripping

- Parent material classes:
  - P1 = colluvium
  - P2 = loess
  - P3 = alluvium
  - P4 = residuum
- Drainage classes
  - R1 = well drained
  - R2 = moderately well drained
  - R3 = imperfectly drained
  - R4 = poorly drained
  - R5 = very poorly drained
- Soil rock fragments
  - F1 = <15%
  - F2 = 15-35%
  - F3 = >35% (R. Taskey, 1997 unpublished).

Model presentation

Here the developed soil-landscape model is presented in the form of a table (Table 1), a cross sectional diagram (Figure 6), and a map (Figure 7). These designations are the result of the second stage of the model development where the soil classes are related to the observable landscape features described above.

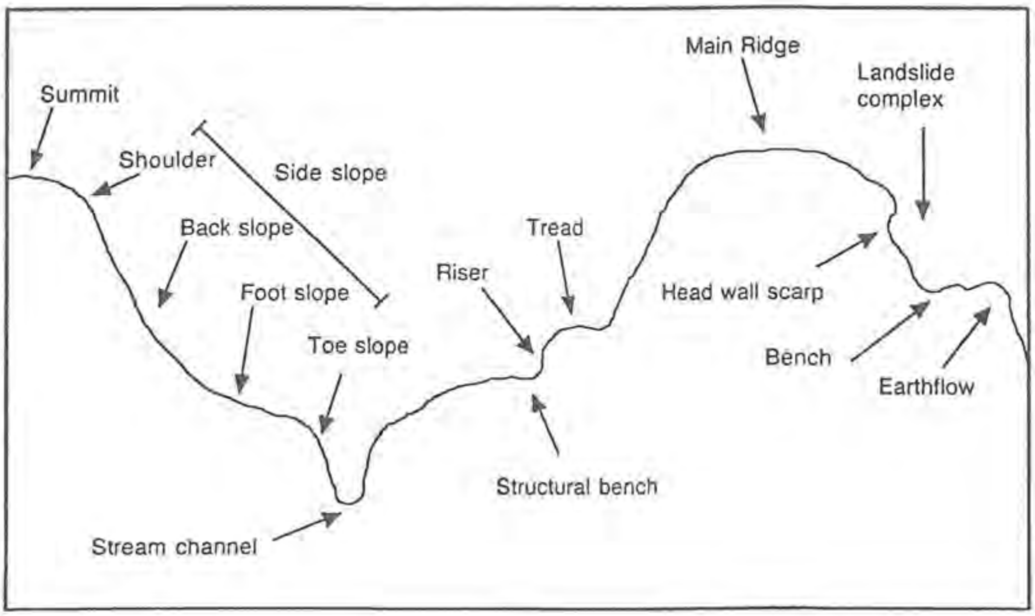

Figure 6. Stylised cross-sectional diagram illustrating the relative positions of land components and elements in the landscape.

Table 1. Table representing the soil-landscape model developed for the Woodlaw land system.

Land component	**Land element**	**Modifying attributes**	**Soil class**
Divergent side slopes	upper back slopes	shady/sheltered aspect and < 10% boulders	BAT; Mp, Ss; K; r/m
		sunny/sheltered aspect and ≥ 10% boulders	RXA; Ml, Ss; K; m/s
	mid back slopes	shady/windy aspect	BOP; Ms; Z/C; m
		sunny/windy aspect	BOT; Ma, An; K; m
	lower back slopes		BOT; Mm, Ss; C; m/s
Convergent side slopes	mid back slopes		BAT; Mm, Ss; Z/C; m
	lower back slopes		BFP; Ms; Z; r/m
Structural benches	narrow summits		BAT; Mp, An; C; m
	broad summits	300-400m elevation	BAT; Mp, Ss; Z; m/s
		400-480m elevation	BAM; Mm, An; Z/C; m/s
	mid back slopes		BAT; Ms; Z/C; m
Landslide complexes	bench summit	300-400m, 5-20°, and < 10% boulders	BAT; Ms; Z/C; r/m
	bench riser	400-480m, 20-30°, and ≥ 10% boulders	PJT; Ma, An; K; r/m
Main ridge	broad summit		BFA; Ms; Z/C; m/s

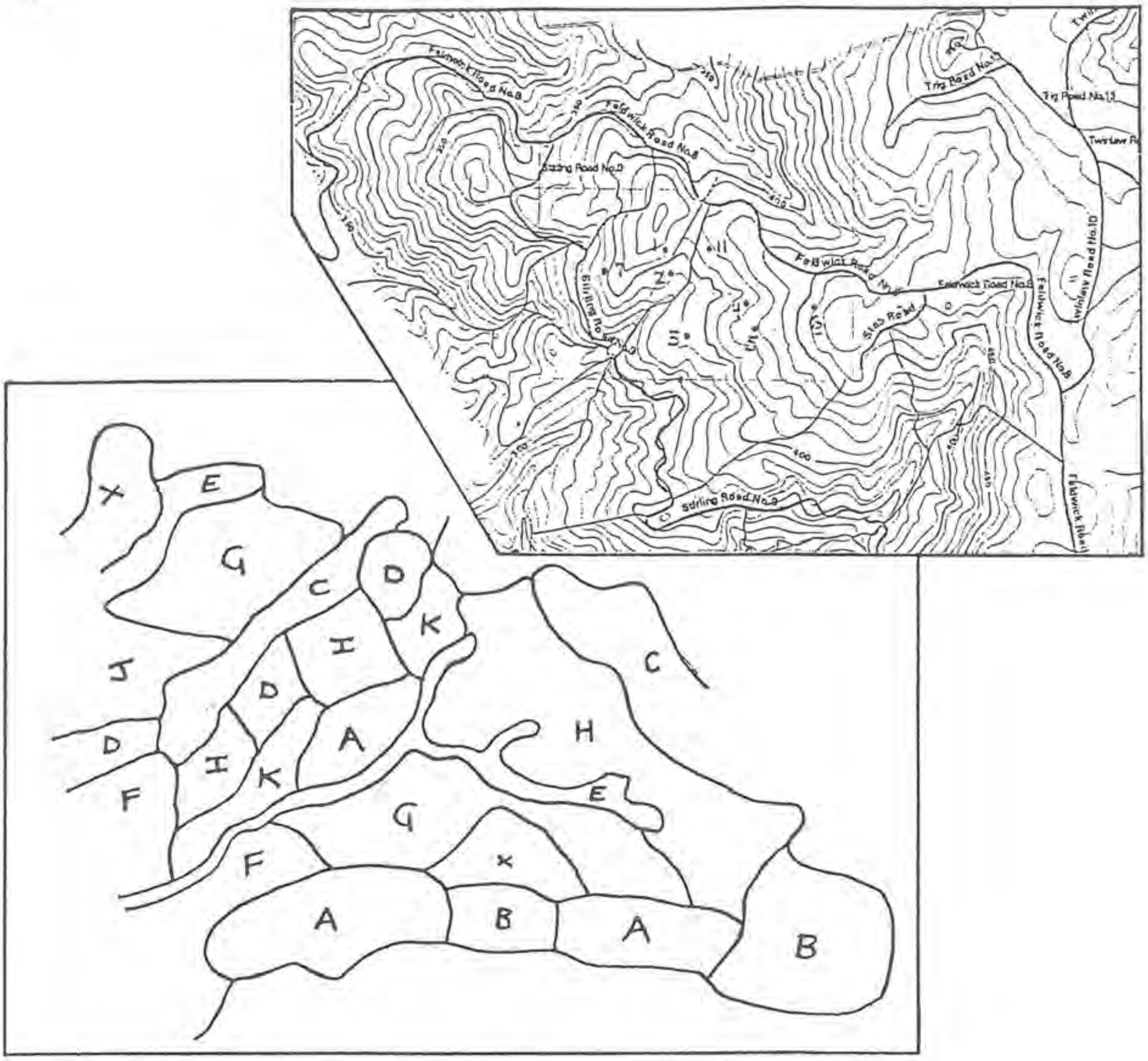

Figure 7. Map showing the delineated soil-landscape units within training window 214.

Discussion

All of the soil classes that include a skeletal horizon occur on slopes between 20° and 30° steepness (slope steepness class S3). From another point of view, all but one of the five soil classes that occur on slopes between 20° and 30° steepness have a skeletal horizon. In other words, there is a clear relationship between slope steepness and the gravel content of the soils. This relationship suggests that as slope steepness increases so too will the coarse fraction of the soil. Also, the soil classes with a skeletal horizon occur only in either the divergent side slope or the landslide complex land components.

Three out of the four soil classes that have a skeletal horizon were associated with more than 10% surface boulders. This indicates that abundance of rocks on the land surface (an observable landscape feature) can be related to the proportion of gravel in the soil. It could be postulated that as the abundance of surface boulders increases so too will the soils' coarse fraction.

It appears that Orthic Brown Soils occur only on mid and lower back slopes of divergent side slopes.

Soil classes (NZSC) of the model

Three soil orders are represented in the two training windows, Brown Soils, Recent Soils, and Pallic Soils. However, Brown Soils are overwhelmingly the dominant order with perhaps up to 80% of the training windows being occupied by them. Relatively little variation in soil classes exists in the areas studied. However, soils that are identical at the subgroup level may be differentiated at the soilform level (Clayden and Webb, 1994). Table 2 lists each component of the soil classes found. The descriptions of each pedon are given in the appendix.

Table 2. Subdivision of soil classes represented in the soil-landscape model.

Order	Group	Subgroup	P.M.	Lithology	Texture	Permeability
Brown	Acid	Mottled	Mm			
		Typic	Mp	An		
				Ss	K	
					S	
			Mm			
			Ms		Z/C	m
						r/m
	Firm	Pallic	Ms			
		Acidic	Ms			
	Orthic	Pallic	Ms			
		Typic	Ma			
			Mm			
Recent	Rocky	Acidic	Ml			
Pallic	Argillic	Typic	Ma			

Elsewhere in this report the soil classes of the model will be referred to by their code (e.g. BAT). The soil classification to the subgroup level are thus written in full together with their code below.

- Typic Acid Brown Soils (BAT)
- Mottled Acid Brown Soils (BAM)
- Acidic Firm Brown Soils (BFA)
- Pallic Firm Brown Soils (BFP)
- Pallic Orthic Brown Soils (BOP)
- Typic Orthic Brown Soils (BOT)
- Acidic Rocky Recent Soils (RXA)
- Typic Argillic Pallic Soils (PJT)

Soil-landscape unit characterisation

All of the soil-landscape units characterised here are within training window 214 apart from soil-landscape unit K. Further information (auger data) is required before the soil-landscape units within window 210 can be formally defined. The landscape features and soil classes associated with each delineated soil-landscape unit (Figure 7) are presented in Table 3.

The auger data taken in window 214 have largely supported the soil pedon descriptions. Within each unit there was found to be some variance in the depth to the paralithic contact. This means that the parent material class of the soilform is likely to vary, within the delineations, from that of the described pedon. Within soil-landscape unit A the parent material class was found to vary from Mp to Mm and in some cases to Ms. Ms graded to Mm within unit B while unit G showed a grading from Mp to Ms. Within unit I the parent material class was predominantly Mp. However, there were some areas where it was Mm.

Units B, G, and I contain a complex of soils. That is, they have been found to contain two soil classes that cannot realistically be differentiated at the scale adopted. Both units B and G were assigned to the Typic Acid Brown subgroup. The auger data subsequently showed that there were some areas within these units where the soil was mottled sufficiently for it to be assigned to the Mottled Acid Brown subgroup. In the case of units B and G the dominant class is BAT while the subdominant class is BAM. Within unit I the difference in the soils comes out at the order level (Brown and Recent Soils). Two pedon descriptions have been done within this unit, in a Typic Acid Brown Soil, the other in a Acidic Rocky Recent Soil. The auger data confirmed the existence of both of these soils throughout the unit. It is possible that the BAT soil is dominant while the RXA soil is subdominant. However, it should be recognised that the RXA subgroup does not cover an insignificant area within unit I.

The delineated soil-landscape units represent land components with the exception of the structural bench land component which is sub-divided into two separate units, one representing the bench summits and the other representing the bench side slopes. These two soil-landscape units therefore represent land elements.

Table 3. Data characterising the soil-landscape units.

S-L unit	Land component	Land element	Landscape modifiers	NZSC Soil class(es)	Soil class modifiers
A	Structural bench	Summits	E2-E3; A3; S1-S2; B1; L2&L3	BAT; Mp, An; C; m BAT; Mp, Ss; Z; m/s BAM; Mm, An; Z/C; m	D1; P1&P4; R1&R3; F1-F2
B	Structural bench	Mid back slope	E3; A3; S2; B1; L1	BAT; Ms; Z/C; m BAM (sub) (complex)	D3; P1&P4; R1; F1
G	Convergent side slope	Mid back slope	E3; A4; S2; B1; L3	BAT; Mm, Ss; Z/C; m BAM (sub) (complex)	D2; P1&P4; R1; F2
H	Convergent side slope	Lower back slope	E3; A3; S2; B1; L1	BFP; Ms; Z; r/m	D3; P1; R1; F1
I	Divergent side slope	Upper back slope	E3; A1-A2; S3; B1-B2; L3	BAT; Mp, Ss; K; r/m RXA; Ml, Ss; K; r/m (sub) (complex)	D1; P1&P4; R1; F3
J	Divergent side slope	Mid back slope	E2; A3; S3; B2; L1	BOP; Ms; Z/C; m	D3; P1&P4; R1; F1
K	Landslide complex	Earthflow	E2; A1; S2; B1; L4	BAT; Ms; Z/C; r/m	D4; P1&P4; R1; F2

Pilot Variability Study

In planning the sampling scheme of a scientific study it is important to have a measure of variability of the phenomena being studied so that the number of observations required to provide meaningful results can be determined (Swan and Sandilands, 1995). A pilot study into the variability of two soil properties in the Woodlaw land system was conducted in order for the sampling scheme of phase two (soil property variability) of this project to be planned. It was hoped that this pilot study would also aid in the selection of soil properties to be studid and in the further development of the soil-landscape model.

The methods used in the collection of samples, the measurement of properties, and the statistical analysis of the data are outlined here. The results of both the chemical and the statistical analysis are then given. The variability of the two properties and implications for phase two of the project are discussed.

Methods and materials

Sample collection

At soil pedons (sites) 1 to 7, and 9, soil samples from two depths representing the A and B horizons (samples taken at approximately 0-10 cm and 20-30 cm) were collected at seven spatially separate locations. The general arrangement of the sample locations at each site is illustrated in Figure 8.

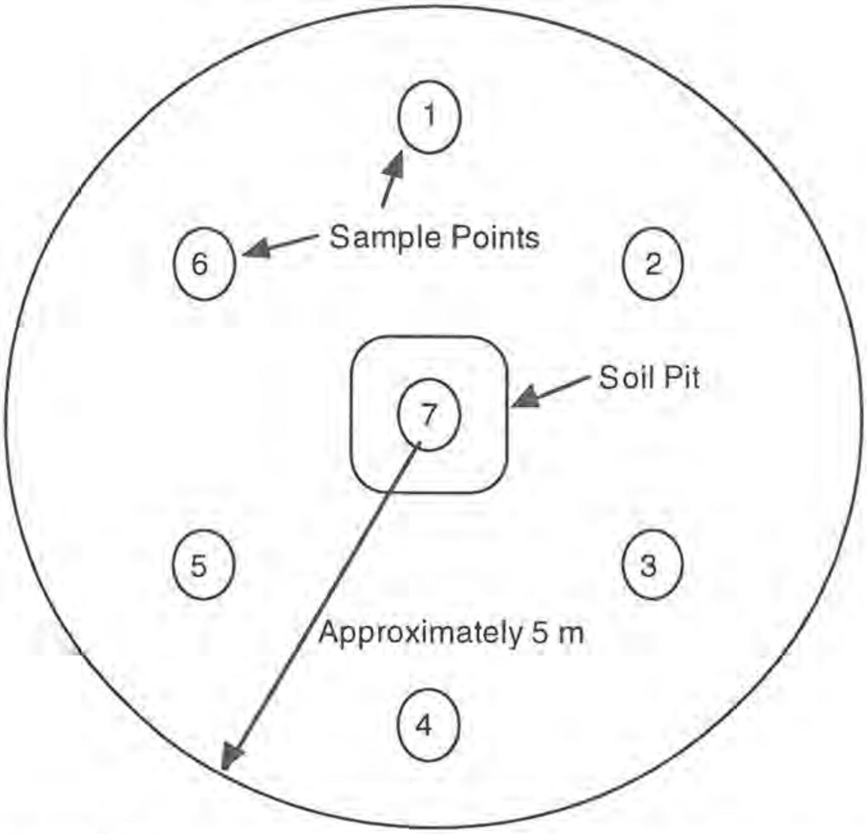

Figure 8. A plan view of the general arrangement of sample points at a pedon site.

Laboratory analysis

The pH values of the soil samples were measured in H_2O and only one measurement made for each sample. Six grams of ground, air-dry soil was placed in a centrifuge tube and 15 ml of distilled water was added. The soil and water were then mixed by an end-over-end shaker for one hour. After shaking, the samples were centrifuged at 2000 rpm for 15 minutes. The pH of the resulting supernatant was then measured.

The measurement of P-retention involved weighing approximately 5 g of air-dried soil and placing it in a centrifuge tube with 25 ml of P-retention solution. The soil and solution were then mixed by shaking in an end-over-end shaker for 16 hours. The mixed samples were centrifuged at 2000 rpm for 15 minutes. The resultant supernatants were diluted with nitric vanadomolybdate acid reagent, shaken well, and left to stand for 30 minutes. Then the absorbance was read at 466 nm. Percent P-retention was calculated from a standard curve of percent phosphate retention against absorbance.

Statistical anlysis

Initially, means and sample variances of the data were calculated. Later an analysis of variance was conducted on the soil property data using the computer programme *Genstat 5*. For each source of variation (the values of the two properties vary between sites, horizons, and site-horizons), the degrees of freedom (d.f.), sum of squares (s.s.), mean squares (m.s.), mean square ratios, F probabilities, and standard errors of differences (s.e.d.) were computed. Residual plots and box-whisker plots of the data were also produced using the computer programme *Minitab*.

Results and discussion

The calculated means of the pH and P-retention data are given in Tables 4 and 5 respectively. Means of both horizons at each site (site-horizon means), the overall means of each site (site means), and the overall mean of each horizon (horizon means) were calculated. The sample variance of both horizons at each site was also calculated.

Table 4. Means of the pH data (given in pH units).

Site Number	* Land Component†	Site-Horizon Means		Site Means	Sample Variance	
		A	B		A	B
1	DSS	4.92	4.95	4.93	0.017	0.058
2	SB	4.71	4.76	4.74	0.008	0.008
3	SB	4.56	4.63	4.60	0.006	0.005
4	CSS	4.46	4.62	4.54	0.005	0.010
5	SB	4.42	4.66	4.54	0.006	0.004
6	SB	4.50	4.59	4.54	0.006	0.006
7	DSS	4.95	4.89	4.92	0.026	0.017
9	LC	4.64	4.70	4.67	0.017	0.002
Horizon Means		4.65	4.72			

* DSS = divergent side slope, SB = structural bench, CSS = convergent side slope, LC = landslide complex.

Table 5. Means of the P-retention data (%).

Site Number	Land Component†	Site-Horizon Means		Site Means	Sample Variance	
		A	B		A	B
1	DSS	55.8	61.0	58.4	47.6	77.4
2	SB	70.3	78.7	74.5	47.6	88.4
3	SB	65.9	73.8	69.9	10.2	7.3
4	CSS	59.8	65.4	62.6	139.2	324.0
5	SB	68.9	75.6	72.3	7.8	56.3
6	SB	72.4	78.8	75.6	15.2	14.4
7	DSS	50.4	55.7	53.1	10.9	17.6
9	LC	61.2	71.7	66.5	13.7	10.2
Horizon Means		63.1	70.1			

Nature of the pH data

From the data in Table 4 it is clear that pH values of all the soils sampled are relatively low. The site means range from 4.54 to 4.93. In other words, these soils are relatively acidic. This may have significant ramifications for other soil chemical properties. Acid soils tend to have lower cation exchange capacities as reactions occur involving H^+ ions that reduce the amount of negative charge on colloid surfaces. Low pH is also associated with low base saturations (the proportion of negative exchange sites occupied by exchangeable bases Ca^{2+}, Mg^{2+}, K^+, and Na^+). In general, the lower the pH, the more H^+ ions occupy negative exchange sites thus displacing the exchangeable bases (McLaren and Cameron, 1996). The availability of phosphorus is influenced by the pH of the soil. Low pH, leading to high levels of soluble iron, manganese, and aluminium, can result in the precipitation of insoluble phosphate compounds thus making the phosphate unavailable for plant uptake. Most of the major plant essential nutrients are least available at low soil pH (McLaren and Cameron, 1996).

Nature of the P-retention data

The values presented in Table 5 indicate that these soils have moderate to high P-retentions. The lowest site mean is 53.1% while the highest is 75.6%. This means that the soils have a moderate to high capacity to fix phosphate and thus significant amounts of the phosphorus in these soils is unavailable for plant uptake. This may explain, to some extent, why many trees within the Woodlaw Block are showing signs of P-deficiency (Smith, 1997, pers.com.). Phosphate ions can be adsorbed onto aluminosilicate clay minerals such as allophane via non-specific adsorption and (more dominantly) specific adsorption at positive exchange sites. Some small amounts of phosphate may also be adsorbed onto phyllosilicate minerals much of which by 1:1 minerals such as kaolinite (McLaren and Cameron, 1996).

Differences between sites and horizons

The horizon means reveal that the A horizons tend to have a slightly lower pH than the B horizons. For P-retention they show that the A horizons have lower values than the B horizons on average. In terms of the variance, both horizons are quite similar for pH but the B horizons are generally more variable than the A with respect to P-retention. It is interesting to note that site 7, which is classified as Pallic Orthic Brown Soils, has the second highest site mean pH value while for P-retention its site mean value is the lowest. Of more significance however, is that there appears to be a relationship between the type of land component and the values of the two measured properties. The land component for each site is given in Tables 4 and 5. The two highest site mean pH values and the two lowest site mean P-retention values occur at sites 1 and 7, both of which are located on divergent side slopes (a land component). These are the only two sites sampled in this pilot study that occur in this type of land component. These two sites also have the greatest variance with respect to pH (Table 4). Figures 9 and 10 are box plots of the pH and P-retention data, respectively. Each horizon at each site is represented by a box. The thin vertical lines extent up to the maximum and down to the minimum value. The horizontal line represents the median value.

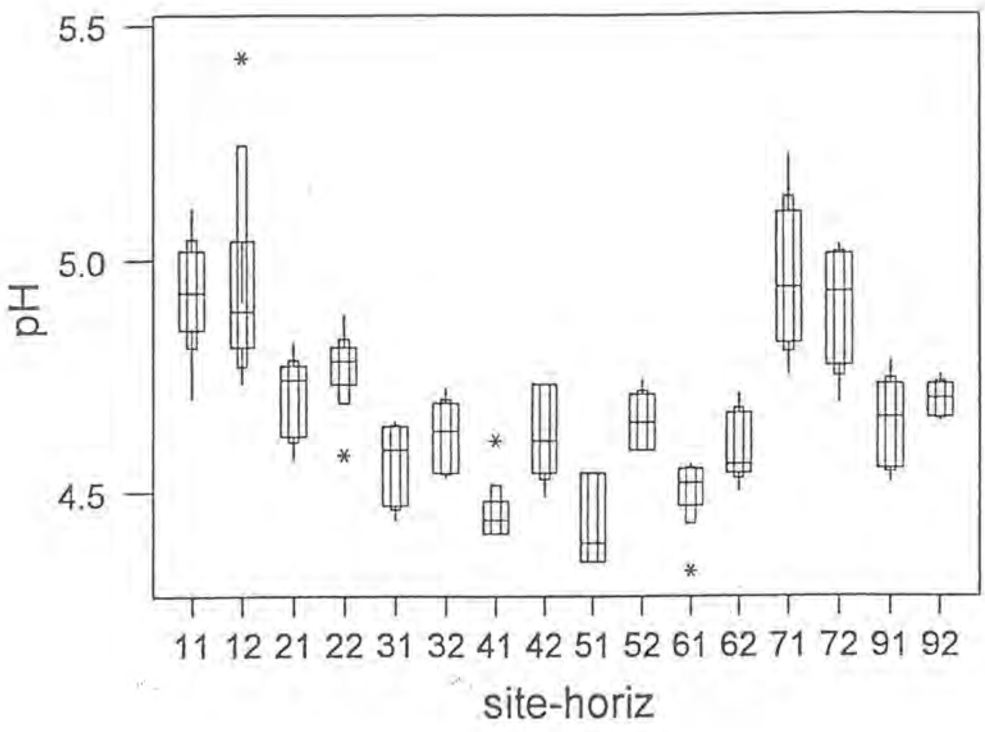

Figure 9. Box plots of the pH data for each horizon at each site.

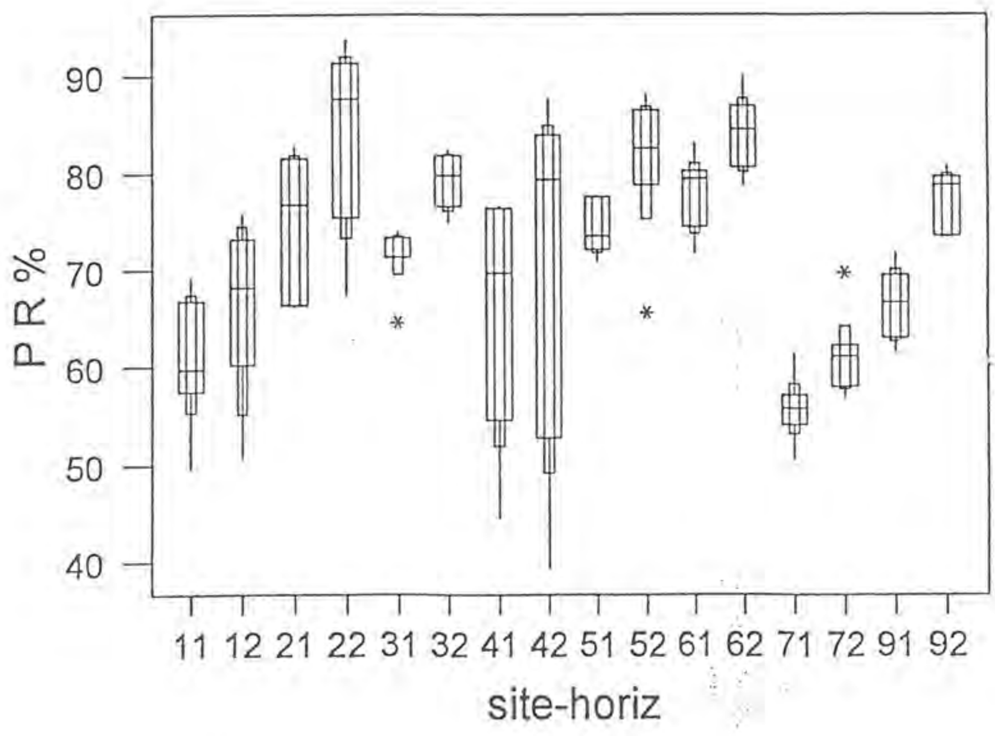

Figure 10. Box plots of the P-retention data for each horizon at each site.

The top end of the large box represents the upper quartile while the bottom end represents the lower quartile. The site-horizons on the x-axis are identified by two digit numbers: the first digit gives the site number while the second identifies the horizon (1 representing the A horizons, 2 representing the B horizons).

The similarity between the two sites (1 and 7) situated on divergent side slopes can clearly be seen in Figure 9, the boxes for each site standing well above the rest. However, the similarities are not borne out for the P-retention data in Figure 10. This means that although the mean P-retention values for the two sites are similar the distribution of the data are quite different. The striking feature about Figure 10 is the distribution of the data at site 4. The data for both horizons have much larger ranges than the others and are strongly skewed towards the higher values. The sample variance (a measure of how much the values vary about the mean) for this site, given in Table 5, indicates that the P-retention values are much more variable than for the other sites. However, this difference is not reflected by its mean (see Table 5). It appears that this difference may also be due to the type of land component. Site 4 is located on a convergent side slope (see Table 5) and is the only such site included in this pilot study. Perhaps the different slope shapes and forms of these land components cause differences in soil water movement which is in some way influencing the soil solution, and which in turn affects its chemical properties.

Analysis of variance

Tables 6 and 7 give the results of the analysis of variance for the pH and P-retention data, respectively.

Table 6. The results of the analysis of variance conducted on the pH data.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Mean square ratio	F-probabilities
Site	7	2.66611	0.38087	32.20	<0.001
Horizon	1	0.17194	0.17194	14.54	<0.001
Site-horizon	7	0.18032	0.02576	2.18	0.043
Residual	95	1.12354	0.01183		
Total	110	4.07179			

Table 7. The results of the analysis of variance conducted on the P-retention data.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Mean square ratio	F-probabilities
Site	7	6355.83	907.98	16.43	<0.001
Horizon	1	1379.29	1379.29	24.95	<0.001
Site-horizon	7	82.67	11.81	0.21	0.982
Residual	95	5250.98	55.27		
Total	110	13036.75			

The most important column of Tables 6 and 7 is the second from right, the mean square ratio. The other data in these tables were used to determine these ratios. The residual mean square always gives an unbiased estimate of the variance and it is assumed that the treatment mean squares do also. The ratio of the two independent estimates of variance comes from an F-distribution. The values in the mean square ratio column were calculated by dividing the treatment mean squares by the residual mean square. To determine whether the resultant mean square ratios indicate significant variability or not an F-distribution 5% table is consulted and the $F_{0.05}$; v_1, v_2 is determined, where v_1 and v_2 are the treatment and residual degrees of freedom, respectively. Five percent is taken to be the threshold defining significant variability and signifies that there is a 5% probability that a particular value will be encountered again. In the case of this pilot variability study the five percent mean square ratio value for the site and site-horizon treatments is about 2.11. For the horizon treatment it is about 3.95. In general, the greater the mean square ratio is the greater the variability will be (Swan and Sandilands, 1995).

The mean square ratios for the site treatment clearly exceed the 5% threshold for both properties, as do those for the horizon treatment. However, with the site-horizon treatment only the ratios for pH exceed the threshold. This is reflected by the F-probabilities which show that in all cases, apart from the P-retention site-horizon treatment, there is much less than a 5% probability that the same values will be encountered. Conversely the F-probabilities indicate that there is a high probability that the values will be different. Thus, it can be said that both properties show significant variability between sites and between horizons.

Implications

These results have some important implications for the soil-landscape model development and the planning of phase two of this project.

Only the pH data have any direct implications for the soil-landscape model development. Sites 1, 3, 4, 5, 6, and 9 had their field-assigned classification changed from Orthic Brown Soils to Acid Brown Soils to reflect the lower pH values determined by the laboratory analysis.

In terms of property selection for phase two, both pH and P-retention are worthy of consideration as they both exhibit significant variability. However, although the variability of P-retention is significant between sites and between horizons it is not between different site-horizon combinations (e.g. between 2A and 6B).

More importantly, these results have implications for the required sampling density. Because only seven samples taken at eight sites were sufficient to detect significant variability in two soil properties, both between sites and between horizons, then similar numbers may suffice in phase two. In other words, significant variability in soil properties can be detected without taking an unreasonably large number of samples.

The apparent relationship between the type of land component and the magnitude and variability of soil property values has an important implication for the design of the sampling scheme. This is that the type of land component that a delineation of a soil class is located on or within may be a source of variation in soil properties if that soil class is associated with more than one land component. This is the case for the BAT subgroup. Therefore, the different land components that the selected BAT subgroup replicates occur on should be recorded so that any resulting variation can be explained. These possible relationships between the soil properties and land components may be significant in terms of the project as a whole because they suggest that prediction of some soil properties using some land components could be possible.

Clay Mineralogical Analysis

An understanding of the dominant clay minerals in a soil is important as it may help to understand how the soil has formed and to explain some of its physical and chemical characteristics (Churchman *et al.*, 1991). More specifically it can provide information on the parent material, the nature of the weathering environment, the cation exchange capacity (CEC), and the consistence of the soil.

The types of clay minerals present in a soil are influenced by the parent material, climate, vegetation, and time factors of soil formation as well as the drainage class of the soil. Therefore, significant differences in clay mineralogy may suggest variation in at least one of these factors and so could provide information useful to the development of a soil-landscape model.

An investigation into the clay mineralogy of four separate soil pedons (sites) within the Woodlaw Block was conducted. The results of two analytical techniques used in the identification of clay minerals were interpreted to reveal the main clay minerals present.

Methods and materials

Four soil samples, taken from the B horizons of pedons 3, 4, 7, and 9 during the course of the pilot variability study, were analysed using two common techniques. These were X-ray diffractometry (XRD) and differential thermal analysis (DTA).

A variety of chemical and heat treatments was used in the preparation of the XRD samples to enable the adequate differentiation of the minerals. Two cation saturation treatments, K^+ and Mg^{2+} were used. Two separate Mg^{2+} samples were further chemically treated, one with formamide and the other with ethylene glycol. Four heat treatments were applied: three K^+ saturated samples were heated to 110, 300, and 550°C while one Mg^{2+} sample was also heated to 550°C.

The DTA samples were heated at a rate of 30°C per minute to a temperature of 750°C. The semiquantitative results obtained were based on the thermogram of a kaolinite standard.

A table of the diagnostic XRD peaks (d-spacings) of common clay minerals found in soils was compiled from a number of references to enable the interpretation of the resultant patterns. These peaks are given in Table 8 below. Table 9 is a compilation of the diagnostic endothermic and exothermic DTA peaks. The clay minerals subsequently identified are italicised.

Table 8. Diagnostic (mainly first order) XRD peaks (nm) of clay minerals (Hume and Nelson, 1982; Lowe and Nelson, 1983; Wilson, 1987; Dixon and Weed, 1989).

Mineral	**Treatment**							
	K^+	Mg^{2+}	Mg^{2+} (Form)	Mg^{2+} (Glyc)	K^+ 110°C	K^+ 300°C	K^+ 550°C	Mg^{2+} 550°C
Kaolinite	*0.72*	*0.72*	*0.72*	*0.72*	*0.72*	*0.72*	----	----
Halloysite	0.72-07.4	0.72-0.74	1.04	1.0-1.1	0.7-0.74	0.72	----	----
Serpentines	0.73	0.73		0.73	0.73	0.73	0.73	0.73
Illite/mica	1.0	1.0		1.0	1.0	1.0	1.0	1.0
Chlorites	1.42-1.44	1.42-1.44		1.42-1.44	1.42-1.44	1.42-1.44	1.42-1.44	1.42-1.44
Vermiculite	1.0	1.4		1.4	1.0-1.2	1.0	1.0	1.0
Smectites	1.2	1.5		1.8	1.0	1.0	1.0	1.0
Rectorite		2.5		2.7				1.93
Hydrobiotite		2.47		2.46				1.0
Tosudite		2.89		3.22				2.34
Corrensite		2.91		3.2				2.37
Chlorite-vermiculite	*1.4*	*1.4*		*1.4*	*1.4*	*1.4*	*1.2*	*1.2*
Mica-vermiculite	1.0-1.43	1.0-1.43						
Kaolinite-smectite				0.72-0.85		0.72-0.96		
Illite-smectite	1.07	1.07		1.1-1.25				0.98
Illite-chlorite-smectite	1.23	1.23		1.42	1.15			
HIV	*1.4*	*1.4*		*1.4*	*1.4*	*1.2*	*1.0*	*1.0*
Talc	0.93-0.96	0.93-0.96		0.93-0.96	0.93-0.96	0.93-0.96	0.93-0.96	0.93-0.96
Pyrophyllite	0.92	0.92		0.92	0.92	0.92	0.92	0.92
Gibbsite (002)	0.485	0.485		0.485	0.485			
Sepiolite (331)	*0.319*	*0.319*		*0.319*	*0.319*	*0.319*	*0.319*	*0.319*
Swelling chlorite	1.4	1.4		1.7-1.78	1.4	1.4		

Table 9. Diagnostic endothermic and exothermic DTA peaks (°C) for various clay minerals (Lowe and Nelson, 1983; Paterson and Swaffield, 1987).

Mineral	Endothermic Peak	Exothermic Peak	Endo/Exo Peaks
Kaolinite	*500-600*	*900-1000*	
Chrysotile	700	850	
Montmorillonite	100-250 (2nd peak at 700)		800-900 (shallow)
Saponite	150 (large)	850 (small)	
Vermiculite			800-900
Chlorite (+HIC)	500-600 (625-690)	750-900	
Sepiolite	100 (large)		
Palygorskite	400-450		
Imogolite	390-420 (large)	1000	
Quartz	573		
Hydroxide/Boehmite	500		
Gibbsite/Bayerite	300-350		
Fe oxides	300		
Carbonate	500-800		
Allophane	*110-190*		
Halloysite	500		
Organo-minerals		200-500	

Results

All four pedons generally have the same mineralogy. Moreover, pedons 4, 7, and 9 have identical mineralogies while that of pedon 3 is slightly different to the rest.

At pedon 3 the presence of chlorite-vermiculite (a random mixed layer mineral) is indicated by a peak occurring at around 1.4 nm after all treatments apart from heating to 550°C where it retreats to around 1.2 nm. The presences of hydroxy interlayered vermiculite (HIV) is suggested by the peaks at 1.2 nm after heating to 300°C and at 1.0 nm after heating to 550°C. A small peak at about 1.0 nm following the formamide treated sample may indicate the presence of a small amount of halloysite. However, as there is the possibility that some samples may have been left in the open air too long before being analysed, thus allowing them to take on moisture, then this peak could be attributable to experimental error. Also, the total lack of evidence of halloysite at the other pedons further questions the peak found here. Sepiolite, a Mg-rich clay mineral, appears to account for the peaks that consistently appear at 0.33 and 0.32 nm. A number of other less common minerals may also account for these peaks. However, sepiolite seems to fit best and the presence of a Mg-rich mineral is quite plausible given the basic nature of much of the soil parent materials. The consistent peak at about 0.72 nm indicates that kaolinite occurs in this pedon.

There is no evidence for HIV at pedons 4, 7, and 9 — that is, no peak occurs at 1.2 nm after heating to 300°C. No peak at 1.0 nm with formamide treatment confirms the absence of halloysite. All evidence points to chlorite-vermiculite, kaolinite, and sepiolite being present in these pedons.

The DTA analysis showed very similar endothermic peaks for all pedons. The peak consistently occurring around 170-180°C may be indicative of allophane, a short-range order aluminosilicate clay mineral. The presence of relatively small amounts of allophane in some pedons has already been indicated by the NaF field test. The presence of this DTA peak may suggest that allophane is present in quantities larger than previously thought. Another endothermic peak occurring between 510 and 520°C confirms that kaolinite is present in all pedons.

Implications

The presence of allophane in any significant amounts could have some very significant implications in terms of nutrient availability, in particular P-retention. Generally as the amount of allophane in the soil increases so too does its P-retention. The P-retention data given above indicates that these soils have moderate to high P-retentions which may well be the result of moderate concentrations of allophane.

The absence of highly expandable or 'shrink-swell' clay minerals, such as montmorillonite, has significant implications for the physical properties of these soils. These minerals significantly contract during dry periods and expand when wet. This leads to a large amount of movement and disturbance within the soil known as argilliturbation. Soils without these minerals may be more resistant to erosion (R. Taskey, 1997 pers.com.). These minerals have very high CEC values so that soils containing large amounts of them tend to have high CEC values also (McLaren and Cameron, 1990).

Clearly, the pedons that were sampled are spatially separate yet they have almost identical clay mineralogies. This lack of variability suggests uniformity in parent materials, weathering environment, and age. As a result, there may be a tendency towards uniformity rather than variability in other soil physical and chemical properties. These similarities are reflected in the similar classifications assigned to the described soils.

Conclusions

The interaction of the soil forming factors operating in the vicinity of the Woodlaw land system has resulted in a recurring pattern of topography (moderately steep slopes), parent materials (basic igneous rocks and greywacke), and in past vegetation (beech and podocarp forests) under a relatively uniform climate (moderately high rainfall and moderate—low temperatures). This in turn has given rise to a recurring pattern of soils. However, as there is little significant variation in topography, parent materials, and climate the soils are similar also. This is reflected in the fact that 86% of the described soils were assigned to the Brown order.

Despite the similarity of these soils it appears that the differences that are evident, which are brought out at the group, subgroup and soilform levels of the NZSC, can be related to topographic features (also parent material to a lesser extent) and thus should be able to be predicted from them. Clear relationships have been found between slope steepness, the abundance of surface boulders and the gravel content of the soil. The soils have been found to vary within the delineated soil-landscape units at the soilform level but not, however, at the subgroup level.

All the soils sampled in the pilot variability study were found to be relatively acidic, a characteristic that may be reducing the availability of nutrients such as phosphorus. The low pH and the presence of allophane and kaolinite clay minerals may explain the moderate to high P-retention values observed.

There appears to be a relationship between the land components of the soil-landscape model and the magnitude and variability of the two soil properties measured in the pilot laboratory analysis, pH and P-retention. Divergent side slopes were found to have the highest and most variable pH values and the lowest P-retention values on the average. In contrast, convergent side slopes were associated with very variable P-retention values. These findings imply that the type of land component may be a source of variability in a soil property. Moreover, it suggests that the potential exists for some soil properties being predictable from some land components.

The analysis of variance has shown that the two measured properties are significantly variable between sites and between horizons. It can be concluded that a sampling density similar to that used in the pilot variability study will provide the information desired from phase two.

The dominant clay minerals present in the four soils (B horizons) were found to be chlorite-vermiculite, kaolinite, sepiolite, and allophane. The similarities in the clay mineralogies of the sampled soils lends further credence to the conclusion that the parent materials, climate, and age of materials is similar throughout much of Woodlaw.

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Appendix: Soil Pedon Descriptions

The data collected from the detailed pedon descriptions are given below and are based mainly on Milne et al. (1995) and Clayden and Hewitt (1989). In each description information regarding the nature of the site is given first. The soil morphological data are then given, followed by the soil parent material and drainage class. Classifications are based on Hewitt (1993) and Clayden and Webb (1994) (*NZSC*) and Soil Survey Staff (1994) (*Soil Taxonomy*). Classifications for the latter are provisional (some laboratory data are needed). Because all but one of these pedons was described within clear cut areas they all have the same land use (exotic production forestry) and the same or very similar land management practices (cleared and mounded). The exception to this is pedon number 13 which has the same land use as the others but has not been cleared or mounded (standing *Pinus radiata*).

Pedon 1

Soil-landscape unit: I

Site Data:

- Location:
    - map reference: NZMS 260 D45 132571.
    - word description: 450 m, 120° south-east of the intersection of Feldwick and Stirling Roads.
- Elevation: 425 m.
- Geomorphic position: profile on 21.5° linear slope with 110° aspect contained within the upper back slope of a hill slope in hill country.
- Erosion/Deposition: n/a
- Vegetation: Douglas Fir seedlings, assorted grass species, bracken, and ferns.

Soil data:

Ap

0-22 cm — Very dark greyish brown (10YR 3/2) silt loam (28% clay, 15% sand) with 25% medium sub-angular gravels; slightly sticky; slightly plastic; peds slightly firm and semi-deformable; low penetration resistance; apedal earthy; profuse very fine and fine polyhedral peds; common micro-fine and extremely fine, few very fine to coarse roots; non allophanic; abrupt smooth boundary.

Bw

22-40 cm — Yellowish brown (10YR 5/6) clay loam (30% clay, 40% sand) with 50% coarse sub angular gravels; slightly sticky; slightly plastic; peds slightly firm and semi-deformable; low penetration resistance; apedal earthy; profuse fine polyhedral peds; common micro-fine and extremely fine, few very fine to coarse roots; non allophanic; abrupt irregular boundary.

CR

40-97 cm moderately weathered yellowish brown sandstone; non allophanic.

Parent material: Felspathic greywacke colluvium and residuum.

Drainage class: Well drained.

Soil classification:

- NZSC: Typic Acid Brown Soils; Mp, Ss; K; r/m.
- Soil Taxonomy: Typic Haplumbrept, loamy-skeletal, mixed, mesic.

Pedon 2

Soil-landscape unit: A.

Site data:

- Location:
    - map reference: NZMS 260 D45 133569.
    - word description: 625 m, 105° south-east of the intersection of Feldwick and Stirling Roads.
- Elevation: 395 m.
- Geomorphic position: profile in a slight depression with a 5.5° concave slope and a 200° aspect on the summit of a structural bench at the foot of a hill slope in hill country.
- Erosion/Deposition: n/a
- Vegetation: Douglas Fir seedlings, assorted grass species, bracken, and ferns.

Soil data:

L

10-8 cm No data.

F

8-0 cm No data.

Ap

0-18 cm Dark brown (10YR 4/3) silt loam (31% clay, 15% sand) with 2% fine sub-angular gravels; slightly sticky; moderately plastic; peds slightly firm and semi-deformable; low penetration resistance; strongly pedal; profuse very fine to fine polyhedral peds; few microfine, common extremely fine and very fine roots; non allophanic; abrupt smooth boundary.

Bt

18-44 cm Yellowish brown (10YR 5/6) silty clay (41% clay, 10% sand) with 3% fine and medium sub-angular gravels; moderately sticky; moderately plastic; peds slightly firm and semi-deformable; moderate penetration resistance; 20% very fine to fine krotovina; strongly pedal; profuse very fine to fine polyhedral peds; common distinct discontinuous clay coatings on ped faces; few microfine and extremely fine, few very fine and fine roots; non allophanic; abrupt irregular boundary.

CCR

44-60 cm — Yellowish brown (10YR 5/6) silty clay (41% clay, 10% sand) with 50% coarse to very coarse sub-angular gravels; sesquioxide coatings on gravel faces; abrupt irregular boundary.

R

60- 81 cm — moderately weathered brecciated andesite porphyry; non allophanic; sesquioxide coatings on gravel faces.

Parent material: Brecciated andesite porphyry colluvium and residuum.

Drainage class: Well drained.

Soil Classification:

- NZSC: Typic Acid Brown Soils; Mp, An; C; m.
- Soil Taxonomy: Ochreptic Hapludalf, fine-loamy, mixed, mesic, shallow.

Pedon 3

Soil-landscape unit: A.

Site data:

- Location:
  - map reference: NZMS 260 D45 134567.
  - word description: 856 m, 128° south-east of the intersection of Feldwick and Stirling Roads.
- Elevation: 390 m.
- Geomorphic position: profile in a very slight hollow on a 4° linear-convex slope and a 245° aspect on the second level summit of a structural bench in hill country.
- Erosion/Deposition: n/a
- Vegetation: Douglas Fir seedlings, assorted grass species, bracken, and ferns.

Soil data:

Ap

0-22 cm — Slightly moist; very dark greyish brown (10YR 3/2) silt loam (26% clay, 20% sand) with 20% fine to medium and 10% coarse sub-angular gravels; slightly sticky; slightly plastic; peds weak and semi-deformable; low penetration resistance; krotovina; strongly pedal; profuse fine to medium polyhedral peds; many microfine and extremely fine, few very fine roots; non allophanic; abrupt smooth boundary.

Bt

22-40 cm — Slightly moist; yellowish brown (10YR 5/4) silt loam (32% clay, 20% sand); moderately sticky; moderately plastic; peds weak and semi-deformable; moderate penetration resistance; krotovina; strongly pedal; profuse fine to medium polyhedral peds; common distinct discontinuous clay coatings on ped faces; common microfine and extremely fine roots; non allophanic; distinct wavy boundary.

CR

40-70 cm Moderately weathered yellowish brown sandstone; few extremely fine and microfine roots in cracks.

Parent material: Tuffaceous lithic greywacke residuum and colluvium.

Drainage class: Well drained.

Soil classification:

- NZSC: Typic Acid Brown Soils; Mp, Ss; Z; m/s
- Soil Taxonomy: Ochreptic Hapludalf, loamy-skeletal, mixed, mesic, shallow.

Pedon 4

Soil-landscape unit: G.

Site data:

- Location:
    - map reference: NZMS 260 D45 134568.
    - word description: 872 m, 110° south-east of the intersection of Feldwick and Stirling Roads.
- Elevation: 410 m.
- Geomorphic position: profile on a 16° convex slope with a 285° aspect contained within the mid back slope of a hill slope in hill country.
- Erosion/Deposition: active rill erosion.
- Vegetation: Douglas Fir seedlings, assorted grass species, bracken, and ferns.

Soil data:

FH

1-0 cm No data.

Ap

0-18 cm Slightly moist; dark brown (10YR 4/3) silt loam (28% clay, 15% sand) with 5% fine to medium sub-angular gravels; moderately sticky; moderately plastic; peds slightly firm and friable; few krotovina; strongly pedal; profuse very fine to fine polyhedral peds; many microfine and extremely fine roots; very weakly allophanic; distinct smooth boundary.

Bt

18-64 cm Slightly moist; yellowish brown (10YR 5/6) silty clay (36% clay, 10% sand) with 2% fine to medium sub-angular gravels; moderately sticky; moderately plastic; peds slightly firm and friable; strongly pedal; profuse medium to fine polyhedral peds; common distinct discontinuous clay coatings on ped faces; common microfine and extremely fine, few very fine roots; weakly allophanic; abrupt wavy boundary.

CCR

64-94 cm Yellowish brown (10YR 5/6) silt loam with 55% coarse sub-angular gravels; slightly sticky; slightly plastic; apedal earthy; sesquioxide coatings on gravel faces; few microfine and extremely fine, few very fine roots; abrupt wavy boundary.

R

94-110 cm Yellowish brown (10YR 5/6) sandy loam; highly weathered sandstone.

Parent material: Tuffaceous lithic greywacke residuum and colluvium.

Drainage class: Well drained.

Soil classification:

- NZSC: Typic Acid Brown Soils; Mm, Ss; Z/C; m.
- Soil Taxonomy: Ultic Hapludalf, fine-loamy, mixed, mesic.

Pedon 5

Soil-landscape unit: A

Site data:

- Location:
  - map reference: NZMS 260 D45 135567.
  - word description: 933 m, 114° south-east of the intersection of Feldwick and Stirling Roads.
- Elevation: 420 m.
- Geomorphic position: profile on a 4° slightly concave slope with a 225° aspect contained within the third level summit of a structural bench in hill country.
- Erosion/Deposition: n/a
- Vegetation: Douglas Fir seedlings and assorted grass species.

Soil data:

Ap

0-20 cm Moderately moist; (2.5Y 5/3) silt loam (30% clay, 20% sand) with 5% medium to coarse sub-angular gravels; slightly sticky; moderately plastic; peds slightly firm and semi-deformable; moderate penetration resistance; common krotovina; strongly pedal; profuse fine to medium polyhedral peds; common microfine and extremely fine, few very fine and larger roots; moderately allophanic; distinct smooth boundary.

Bt(f)

20-49 cm Moderately moist; light yellowish brown (2.5Y 6/4) silty clay (38% clay, 20% sand) with 25% coarse to fine sub-angular gravels; common fine to very fine distinct reddish yellow (7.5YR 6/6) mottles; slightly sticky; moderately plastic; peds slightly firm and semi-deformable; moderate penetration resistance; moderately pedal; many fine to medium polyhedral peds; common distinct discontinuous clay coatings on ped faces; few microfine and extremely fine, few very fine and larger roots; weakly allophanic; distinct wavy boundary.

CCR

49-79 cm — Light yellowish brown (2.5Y 6/4) moderately weathered andesitic breccia.

Parent material: Andesitic breccia residuum and colluvium.

Drainage class: Imperfectly drained.

Soil classification:

- NZSC: Mottled Acid Brown Soils; Mm, An; Z/C; m/s.
- Soil Taxonomy: Ochreptic Hapludalf, fine-loamy, mixed, mesic.

Pedon 6

Soil-landscape unit: B.

Site data:

- Location:
    - map reference: NZMS 260 D45 138567.
    - word description: 1078 m, 103° south-east of the intersection of Feldwick and Stirling Roads.
- Elevation: 460 m.
- Geomorphic position: profile in a slight hump on a 14° linear slope with a 240° aspect contained within the mid back slope of a structural bench in hill country.
- Erosion/Deposition: slight rill erosion.
- Vegetation: Douglas Fir seedlings, assorted grass species, and ferns.

Soil data:

Ap

0-36 cm — Moderately moist; dark yellowish brown (10YR 4/4) silt loam (31% clay, 25% sand) with 8% medium and 2% coarse sub-rounded gravels; slightly sticky; moderately plastic; peds slightly firm and friable; strongly pedal; profuse fine to medium polyhedral peds; many microfine and extremely fine, common very fine, and common fine to medium roots; non allophanic; distinct smooth boundary.

Bt

36-74 cm — Moderately moist; yellowish brown (10YR 5/6) silty clay (36% clay, 20% sand) with 8% medium and coarse sub-angular gravels; slightly sticky; moderately plastic; peds slightly firm and friable; moderately pedal; many fine to medium polyhedral peds; common distinct discontinuous clay coatings on ped faces; many microfine and extremely fine roots; very weakly allophanic; indistinct smooth boundary.

BtC

74-119 cm — Moderately moist; yellowish brown (10YR 5/6) silt loam (26% clay, 35% sand) with 20% fine to medium sub-angular gravels; slightly sticky; moderately plastic; peds weak and friable; moderately pedal; many medium polyhedral peds; common distinct discontinuous clay coatings on ped faces; common microfine and extremely fine roots; non allophanic; abrupt smooth boundary.

CCR

119-135 cm — Brownish yellow (10YR 6/6); common medium (2.5Y 4/8) mottles; apedal massive; few prominent sesquioxide coatings on gravel faces; few extremely fine and microfine roots; non allophanic; abrupt smooth boundary.

R

135-on cm — Moderately weathered porphyritic andesite.

Parent material: Porphyritic andesite colluvium and residuum.

Drainage class: Well drained.

Soil classification:

- NZSC: Typic Acid Brown Soils; Ms; Z/C; m.
- Soil Taxonomy: Ultic Hapludalf, loamy, mixed, mesic.

Pedon 7

Soil-landscape unit: J.

Site data:

- Location:
    - map reference: NZMS 260 D45 131569.
    - word description: 459 m, 147° south-east of the intersection of Feldwick and Stirling Roads.
- Elevation: 395 m.
- Geomorphic position: profile on a 21° linear slope with a 240° aspect contained within the mid back slope of a hill slope in hill country.
- Erosion/Deposition: particle erosion now stabilised.
- Vegetation: Douglas Fir seedlings, assorted grass species, and ferns.

Soil data:

Ap

0-22 cm — Yellowish brown (10YR 5/4) silt loam (31% clay, 15% sand) with 10% fine to coarse sub-angular gravels; moderately sticky; very plastic; peds slightly firm and friable; few krotovina; strongly pedal; profuse fine to medium polyhedral peds; many microfine and extremely fine, common very fine to fine roots; non allophanic; abrupt smooth boundary.

ABt

22-37 cm — Pale brown (10YR 6/3) silt loam (31% clay, 15% sand) with 20% medium to coarse sub-angular gravels; slightly sticky; very plastic; peds slightly firm and friable; strongly pedal; profuse very fine to medium polyhedral peds; common microfine and extremely fine roots; non allophanic; distinct smooth boundary.

Bt

31-74 cm — Light yellowish brown (10YR 6/4) silty clay (36% clay, 15% sand); moderately sticky; very plastic; peds slightly firm and semi-deformable; strongly pedal; profuse fine to medium polyhedral peds; common distinct discontinuous clay coatings on ped faces; few microfine and extremely fine roots; non allophanic; abrupt smooth boundary.

C

74-102 cm — Greyish brown (2.5Y 5/2) silt loam (22% clay, 35% sand); slightly sticky; moderately plastic; peds weak and friable; apedal massive; few microfine and extremely fine roots; non allophanic; abrupt smooth boundary.

CR

102-on cm — Moderately weathered porphyritic andesite.

Parent material: Porphyritic andesite colluvium and residuum.

Drainage class: Well drained.

Soil classification:

- NZSC: Pallic Orthic Brown Soils; Ms; Z/C; m.
- Soil Taxonomy: Ultic Hapludalf, clayey, mixed, mesic.

Pedon 8

Soil-landscape unit: ?

Site data:

- Location:
  - map reference: NZMS 260 D45 160581.
  - word description: 1812 m, 76.5° north-east of Twinlaw trig station.
- Elevation: 365 m.
- Geomorphic position: profile in a slight hollow on a 14° convex slope with a 120° aspect contained within the lower back slope of a hill slope in hill country.
- Erosion/Deposition: n/a.
- Vegetation: Assorted grass species, bracken, *Coprosma rotundifolia*, and ferns.

Soil data:

F

2-0 cm — No data.

Ap

0-20 cm Slightly moist; dark yellowish brown (10YR 4/4) silty clay with 3% fine sub-rounded gravels; slightly sticky; very plastic; peds weak and semi-deformable; strongly pedal; profuse fine to medium polyhedral peds; many microfine and extremely fine, few very fine, and few fine roots; non allophanic; distinct smooth boundary.

Bt

20-62 cm Slightly moist; yellowish brown (10YR 5/8) loamy clay with 10% medium to coarse sub-rounded gravels; moderately sticky; moderately plastic; peds slightly firm and friable; common krotovina; 2% extremely fine Manganese concretions; strongly pedal; profuse fine to medium, few coarse polyhedral peds; common distinct discontinuous clay coatings on ped faces; common microfine and extremely fine, few very fine roots; weakly allophanic; abrupt smooth boundary.

CCR(f)

62-109 cm Slightly moist; strong brown (7.5YR 5/8) loamy clay with 3% medium to very coarse sub-rounded gravels; 25% red (2.5YR 4/8) and olive (5Y 5/3) mottles; moderately sticky; moderately plastic; peds weak and semi-deformable; few microfine and extremely fine roots; non allophanic; distinct wavy boundary.

CR

109-on cm Moderately weathered lithic greywacke.

Parent material: Colluvium on interbedded pebbly lithic greywacke residuum.

Drainage class: Moderately well drained.

Soil classification:

- NZSC: Typic Orthic Brown Soils; Mm, Ss; C; m/s.
- Soil Taxonomy: Ultic Hapludalf, clayey, mixed, mesic.

Pedon 9

Soil-landscape unit: K.

Site data:

- Location:
    - map reference: NZMS 260 D45 159579.
    - word description: 44.75° to logging tower (in aerial photographs).
- Elevation: 365 m.
- Geomorphic position: profile on a very slight hump with a 8° slightly convex slope and a 50° aspect contained within an earthflow of a landslide complex in hill country.
- Erosion/Deposition: n/a.
- Vegetation: Assorted grass species, dead *Coprosma rotundifolia*, and ferns.

Soil data:

Ap

0-17 cm — Moderately moist; dark brown (10YR 4/3) silt loam (30% clay, 20% sand) with 2% fine to medium sub-angular gravels; slightly sticky; moderately plastic; peds weak and friable; low penetration resistance; common krotovina; strongly pedal; profuse fine to very fine polyhedral peds; few microfine and extremely fine, common very fine, few fine to coarse roots; non allophanic; abrupt irregular boundary.

Bt1

17-160 cm — Moderately moist; brownish yellow (10YR 6/6) silty clay (37% clay, 15% sand) with 25% coarse sub-angular gravels and boulders; slightly sticky; moderately plastic; peds weak and friable; moderate penetration resistance; common krotovina; strongly pedal; profuse fine polyhedral peds; common distinct discontinuous clay coatings on ped faces; few microfine and extremely fine, few very fine and fine roots; non allophanic; indistinct smooth boundary.

Bt2

160-210 cm — Moderately moist; brownish yellow (10YR 6/6) silty clay (40% clay, 15% sand) with 2% fine to coarse sub-angular gravel; moderately sticky; moderately plastic; peds slightly firm and semi-deformable; moderate penetration resistance; strongly pedal; profuse fine polyhedral peds; common distinct discontinuous clay coatings and few sesquioxide coatings on ped faces; few microfine and extremely fine, few very fine roots; non allophanic; indistinct smooth boundary.

C

210-295 — Reddish yellow (7.5YR 6/8) loamy silt (12% clay, 15% sand); slightly sticky; slightly plastic; peds weak and friable; moderate penetration resistance; apedal massive; non allophanic; indistinct smooth boundary.

Parent material: Andesitic colluvium over very highly weathered siltstone.

Drainage class: Well drained.

Soil classification:

- NZSC: Typic Acid Brown Soils; Ms; Z/C; r/m.
- Soil Taxonomy: Ultic Hapludalf, clayey, mixed, mesic.

Pedon 10

Soil-landscape unit: ?

Site data:

- Location:
  - map reference: NZMS 260 D45 161578.

- word description: 1812 m, 87.5° north-east of Twinlaw trig station.
- Elevation: 375 m.
- Geomorphic position: profile on a 23° linear slope with a 265° aspect contained within the mid back slope of a hill slope in hill country.
- Erosion/Deposition: slight rill erosion.
- Vegetation: Assorted grass species, dead *Coprosma rotundifolia*, California thistles, and ferns.

Soil data:

L

4-0 cm — Abrupt smooth boundary.

Ap

0-37 cm — Moderately moist; very dark grey (10YR 3/1) loamy silt (15% clay, 40% sand) with 40% fine to very coarse sub-angular gravels; slightly sticky; moderately plastic; peds weak and friable; very low penetration resistance; strongly pedal; profuse very fine polyhedral peds; very few microfine and extremely fine, few fine to medium, very few coarse roots; non allophanic; distinct smooth boundary.

Bt

37-72 cm — Moderately moist; brownish yellow (10YR 6/6) silt loam (21% clay, 30% sand) with 30% fine to very coarse sub-angular gravels and 30% sub-angular boulders; slightly sticky; moderately plastic; peds weak and friable; low penetration resistance; few krotovina and spheroidal pores; strongly pedal; profuse very fine polyhedral peds; common distinct discontinuous clay coatings on ped faces; very few microfine, extremely fine, very fine, and medium roots; non allophanic.

Parent material: Moderately weathered porphyritic andesite and andesitic breccia colluvium.

Drainage class: Well drained.

Soil classification:

- NZSC: Typic Orthic Brown Soils; Ma, An; K; m.
- Soil Taxonomy: Ochreptic Hapludalf, silty, mixed, mesic.

Pedon 11

Soil-landscape unit: H

Site data:

- Location:
  - map reference: NZMS 260 D45 134571.
  - word description: 669.5 m, 122° south-east of the intersection of Feldwick and Stirling Roads.
- Elevation: 418 m.

- Geomorphic position: profile adjacent to a forest dimple on a 10° convex slope with a 210° aspect contained within the lower back slope of a hill slope in hill country.
- Erosion/Deposition: n/a.
- Vegetation: Assorted grass species, Douglas Fir seedlings, dead *Coprosma rotundifolia*, and ferns.

Soil data:

Ap

0-19 cm Slightly moist; dark greyish brown (10YR 4/2) silt loam (25% clay, 15% sand) with 2% fine to medium sub-angular gravels; slightly sticky; slightly plastic; peds slightly firm and semi-deformable; strongly pedal; profuse very fine and fine polyhedral peds; few microfine, extremely fine, very fine, fine and medium roots; non allophanic; abrupt smooth boundary.

Bt

19-44 cm Slightly moist; light yellowish brown (10 YR 6/4) silt loam (29% clay, 15% sand) with 2% fine and medium sub-angular gravels; slightly sticky, moderately plastic; peds slightly firm and semi-deformable; moderately pedal; many fine and medium polyhedral peds; common distinct discontinuous clay coatings on ped faces; common microfine and extremely fine, few very fine, few medium and fine roots; non allophanic; abrupt smooth boundary.

2BCx

44-75 cm Slightly moist; pale brown (10YR 6/3) silt loam (40% clay, 20% sand) with 10% fine and medium sub-angular gravels; slightly sticky, non-plastic; peds slightly firm and brittle; apedal massive; common distinct discontinuous clay coatings on ped faces; few microfine and extremely fine roots; non allophanic; abrupt smooth boundary.

3C

75-92 cm Slightly moist; light yellowish brown (10 YR 6/4) silt loam (27% clay, 30% sand) with 2% fine sub-angular gravels; common very fine distinct reddish yellow (7.5 YR 6/6) mottles; slightly sticky; moderately plastic; peds slightly firm and semi-deformable; apedal massive; non allophanic; abrupt smooth boundary.

4C

92-96 cm Light yellowish brown (10YR 6/4) silt loam (40% clay, 20% sand) with 20% fine, medium, and coarse sub-angular gravels; peds slightly firm and semi-deformable; apedal massive; non allophanic.

Parent material: Mixed volcanic colluvium (andesitic) overlying interbedded moderately weathered andesite and greywacke.

Drainage class: Well drained.

Soil classification:

- NZSC: Pallic Firm Brown Soils; Ms; Z; r/m.
- Soil Taxonomy: Typic Fragiudalf, fine-silty, mixed, mesic.

Pedon 12

Soil-landscape unit: ?

Site data:

- Location:
  - map reference: NZMS 260 D45 158580.
  - word description: 1526 m 82° north-east of Twinlaw trig station.
- Elevation: 400 m.
- Geomorphic position: profile on a 26° concave slope with a 85° aspect contained within the bench riser of a landslide complex in hill country.
- Erosion/Deposition: n/a.
- Vegetation: Assorted grass species, dead *Coprosma rotundifolia*, and ferns.

Soil data:

L

13-8 cm No data.

F

8-0 cm No data.

Ap

0-48 cm Slightly moist; dark greyish brown (10YR 4/2) loamy silt (15% clay, 10% sand) with 20% sub-angular boulders, 15% coarse and 10% fine and medium sub-angular gravels; slightly sticky; slightly plastic; peds weak and semi-deformable; low penetration resistance; moderately pedal; many fine polyhedral peds; common microfine and extremely fine, few very fine, medium, and fine roots; weakly allophanic; distinct wavy boundary.

Bt

48-64 cm Slightly moist; brown (10YR 5/3) silt loam (20% clay, 10% sand) with 20% sub-angular boulders, 20% coarse and 15% fine and medium sub-angular gravels; slightly sticky; slightly plastic; peds slightly firm and semi-deformable; moderate penetration resistance; few very fine krotovina; moderately pedal; many fine and very fine polyhedral peds; common distinct discontinuous clay coatings on ped faces; few microfine, extremely fine, and fine roots; distinct wavy boundary.

C

64-105 cm Slightly moist; light yellowish brown (10YR 6/4) loamy silt (12% clay, 35% sand) with 25% sub-angular boulders, 25% coarse and 15% fine and medium sub-angular gravels; slightly sticky; slightly plastic; peds firm and brittle; high penetration resistance; apedal massive; weakly allophanic; few microfine roots.

Parent material: Andesite breccia and porphyritic hornblende andesite colluvium.

Drainage class: Well drained.

Soil classification:

- NZSC: Typic Argillic Pallic Soils; Ma, An; K; r/m.
- Soil Taxonomy: Ochreptic Hapludalf, loamy-skeletal, mixed, mesic.

Pedon 13

Soil-landscape unit: ?

Site data:

- Location:
  - map reference: NZMS 260 D45 150572.
  - word description: 900 m 123° south-east of Twinlaw trig station.
- Elevation: 510 m.
- Geomorphic position: profile on a 2.5° linear-convex slope with a 35° aspect contained within the broad summit of a main ridge in hill country.
- Erosion/Deposition: n/a.
- Vegetation: Twenty five year old Pinus radiata trees, some ferns and *Coprosma rotundifolia*.

Soil data:

L

3.5-0 cm — No data.

Ap

0-37 cm — Slightly moist; yellowish brown (10YR 5/4) silt loam (28% clay, 20% sand) with 10% sub-angular boulders, 3% fine and medium sub-angular gravels; slightly sticky; moderately plastic; peds weak and friable; few krotovina; strongly pedal; profuse fine to medium polyhedral peds; few indistinct discontinuous clay coatings on ped faces; many microfine and extremely fine, common very fine, few fine and medium roots; distinct smooth boundary.

Bt1

37-55 cm — Slightly moist; brownish yellow (10YR 6/6) silty clay (36 clay, 25% sand) with 25% boulders, 4% coarse and 12% fine and medium sub-angular gravels; slightly sticky; slightly plastic; peds weak and friable; common krotovina; moderate pedality; many fine polyhedral peds; common distinct discontinuous clay coatings on ped faces; common microfine and extremely fine, few very fine roots; distinct smooth boundary.

Bt2

55-80 cm — Slightly moist; yellowish brown (10YR 5/6) silty clay (37% clay, 26% sand) with 2% fine to medium sub-angular gravels; common extremely fine to very fine faint to distinct mottles; slightly sticky; slightly plastic; peds slightly firm and semi-deformable; apedal massive; common distinct discontinuous clay coatings on ped faces; few microfine and extremely fine roots.

BC

80-110 cm — Slightly moist; brown (10YR 5/3) silt loam; slightly sticky; many very fine and fine prominent reddish yellow (7.5YR 6/6) mottles; slightly plastic; peds weak and friable.

C

110-200 cm — Slightly moist; brown (10YR 5/3) silt loam; common extremely fine to very fine distinct brownish yellow (10YR 6/6) mottles; non-sticky; non-plastic; peds weak and friable.

Parent material: Porphyritic andesite colluvium.

Drainage class: Well drained.

Soil classification:

- NZSC: Acidic Firm Brown Soils; Ms; Z/C; m/s.
- Soil Taxonomy: Ultic Hapludalf, clayey-skeletal, mixed, mesic.

Pedon 14

Soil-landscape unit: I

Site data:

- Location:
    - map reference: NZMS 260 D45 132569
    - word description:
- Elevation: 425 m.
- Geomorphic position: profile on a 22° linear slope with a 80° aspect contained within the upper back slope of a hill slope in hill country.
- Erosion/Deposition: n/a.
- Vegetation: Assorted grass species and forbs.

Soil data:

Ap

0-15 cm — Dark yellowish brown (10YR 3/4) loamy silt (18% clay, 25% sand) with 40% medium to coarse sub-angular gravels; moderately sticky; slightly plastic; peds weak and friable; strongly pedal; profuse fine to medium polyhedral peds; many microfine and extremely fine, few very fine roots; distinct smooth boundary.

CR

15-30 cm — No data.

R

30-on cm No data.

Parent material: Moderately weathered greywacke colluvium and residuum.

Drainage class: Well drained.

Soil classification:

- NZSC: Acidic Rocky Recent Soils; Ml; Ss; K; r/m.
- Soil Taxonomy: Typic Udorthents, loamy-skeletal, mixed, mesic, shallow.