TUAPAKA SOIL SURVEY

An exercise in classification and
detailed mapping in New Zealand hill country.

A thesis presented in partial fulfilment
of the requirements for the degree of
Master of Philosophy
in
Soil Science
at
Massey University.

Brian McLaughlin
1983

ABSTRACT

The Tuapaka hill block is set in a regional geological and physiographic context.

Classification and mapping concepts and soil survey techniques are critically examined.

A soil inventory of the study area is concluded through the erection of a local soil classification and depicted in a soil map at scale 1:5000, using concepts and techniques that accommodate hill country conditions.

Selected soil parameters related to soil genesis are examined for important soils.

Conclusions pertaining to pedogenic processes operating in the study area and classification and mapping concepts are discussed.

The local soil classification is correlated with the New Zealand Zonal Soil Classification and Soil Taxonomy.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to the following who have assisted me in preparing this study:-

Drs. J.A. Pollok and V.E. Neall for their encouragement and help in supervising my study;

Drs. J.W. Kirkman, R.B. Stewart, Michael Marden, Ph.D. student and others in the Soil Science Department for their assistance in various parts of the study;

Ronald de Rose, M.Sc. student for his friendship and help, and Miss Jacqui McEwan, technician, for her assistance with draughting;

Mr. A.L. Howard, manager of Tua Paka No. 3 Sheep Farm;

Mr. J.R. Clouston of Massey Photographic Unit for his practical help;

Mrs. E.J. Baxter for her efficient and expert typing of the thesis.

Finally, I wish to thank my wife Jane and sons Feilim, Conor and Brian for their patience and forebearance throughout, and our family in Ireland for their unending support.

CONTENTS

Page

Page

Page

Page

Page

LIST OF FIGURES

Page

Page

LIST OF TABLES

CHAPTER 1. INTRODUCTION

1.1 Reasons for Study.

New Zealand hill country farming is a sector of the agricultural economy with great physical potential yet to be fully exploited, but beset with major short-run and long-term economic problems (Taylor and Mars, 1979). The application of new technology to the hill country in the 1950's and 1960's through aerial topdressing and pasture oversowing permitted the development of an intensive farming operation that gave spectacular results in terms of increased dry matter production and higher stocking rates compared with earlier more extensive systems of management. However, the era of rapid technological progress in hill country operations is under threat today through pressures that include debilitating inflation in the national economy, increasing transport and topdressing costs and uncertain market conditions.

The challenge then is to sustain and develop hill country farming through a greater efficiency of operation that will maintain a margin between the farmer's gross income and expenditure. Practical measures that can be taken to this end will include more efficient fertilizer programmes that are selective in application and tailored to local soil conditions and plant needs, increased stocking numbers per hectare and improved performance from existing stock numbers; any improvements in farm performance bringing concomitant advantages to the national economy.

The Tuapaka No. 3 Sheep Unit is owned and commercially operated by Massey University for sheep and beef cattle production. In addition it is available and utilized for agricultural research purposes by the Faculty of Agricultural and Horticultural Sciences at Massey University and by the D.S.I.R., results of which benefit the overall farming objectives of New Zealand agriculture.

The Tuapaka farm is positioned to give a lead at this time of transition and development in hill country farming. The practical problems experienced on Tuapaka are common to hill country farming throughout the country. They include problems of soil moisture and its effects on pasture composition and dry matter production, susceptibility to erosion through failure to adjust land use to local soil and geological conditions, the incidence of soil pests and parasites related to soil properties and the need for efficient fertilizer and liming programmes geared to soil and plant requirements.

The Tuapaka farm is currently being reorganised by dividing the terrace flats and hill block into two separate and independent production units. The flats area is being designated solely for beef production while the hill block will continue to be operated as a sheep production unit. In the reorganisation of the hill block it is planned that paddocks will be subdivided with electric fencing into 3 ha grazing blocks. This will permit 70 day and 110 day rotations for hoggets and ewes respectively through the winter.

1.2 Objectives of Study.

The provision of a detailed inventory of the soil resource of the Hill Block of the Tuapaka farm was an important objective of the study. This was designed to provide an information base that could facilitate the research activities and commercial development of the farm.

Beyond this essentially practical objective, the study was designed to examine the technical problems encountered in conducting a detailed soil survey on hill country. The effectiveness of survey techniques and mapping and classification concepts in current usage were critically examined as to how applicable they are to hill country terrain.

It is important for hill country farmers to be provided with accurate information about the soils on their properties. Existing national soil surveys at scales of 1:254,000 or even 1:63,360 or 1:50,000 cannot provide the necessary level of predictability of local soil conditions and it is unrealistic to attempt detailed soil survey for all hill farms. Clearly then some effective method of soil information transfer is required.

It is suggested that carefully selected and specifically designed detailed soil surveys could be used to supplement the more general soil surveys to this end. The general surveys would provide a regional framework of soils. The detailed survey could then be designed to focus on selected areas, as windows displaying more precisely the relationship between soil-forming factors and processes and resultant soil properties. The results of such detailed surveys of selected areas would then be capable of transfer and extrapolation to larger areas covered by more general surveys with great economy of survey effort.

As an example the Kairanga Count y soil map (Cowie, 1978) displays a recurring pattern of soils on the western flanks of the Tararua Ranges immediately to the south of the study area. An objective of the Tuapaka survey was to provide a more detailed understanding of this soil pattern, the results of which could be extrapolated for more precise appraisal of the soil resources of the western flanks in general.

The study was also viewed as a contribution to an understanding of soil genesis through insights obtained in characterizing the soils in the study area and mapping their distribution in detail. Indeed it was found impossible to map the area without a concurrent awareness of the processes of soil formation that were operative. Earlier work had established that there was a broad change in soil properties on the Hill Block that was apparently altitude-related. This important pedological change was deemed worthy of further investigation.

1.3 Description of Study Area.

1.3.1 Location of Tuapaka Farm.

The Tuapaka sheep farm is located in the Manawatu District of the North Island, New Zealand. It lies to the southeast of the Manawatu River and adjoining the Aokautere Drive at a position 13 km from Palmerston North, 7 km from Aokautere and 5 km from the Manawatu Gorge (Fig. 1). The farm boundaries meet the road at grid refs. T24/414928 and T24/428938. The farm extends south-eastwards into the rolling hill country on the northwest flanks of the Tararua Ranges to an upper boundary at grid refs. T24/427906 and T24/436918.

The Hill Block shares a common boundary with an adjoining property on the southwest and possesses a natural boundary, a deeply incised gully channel on the northeast side.

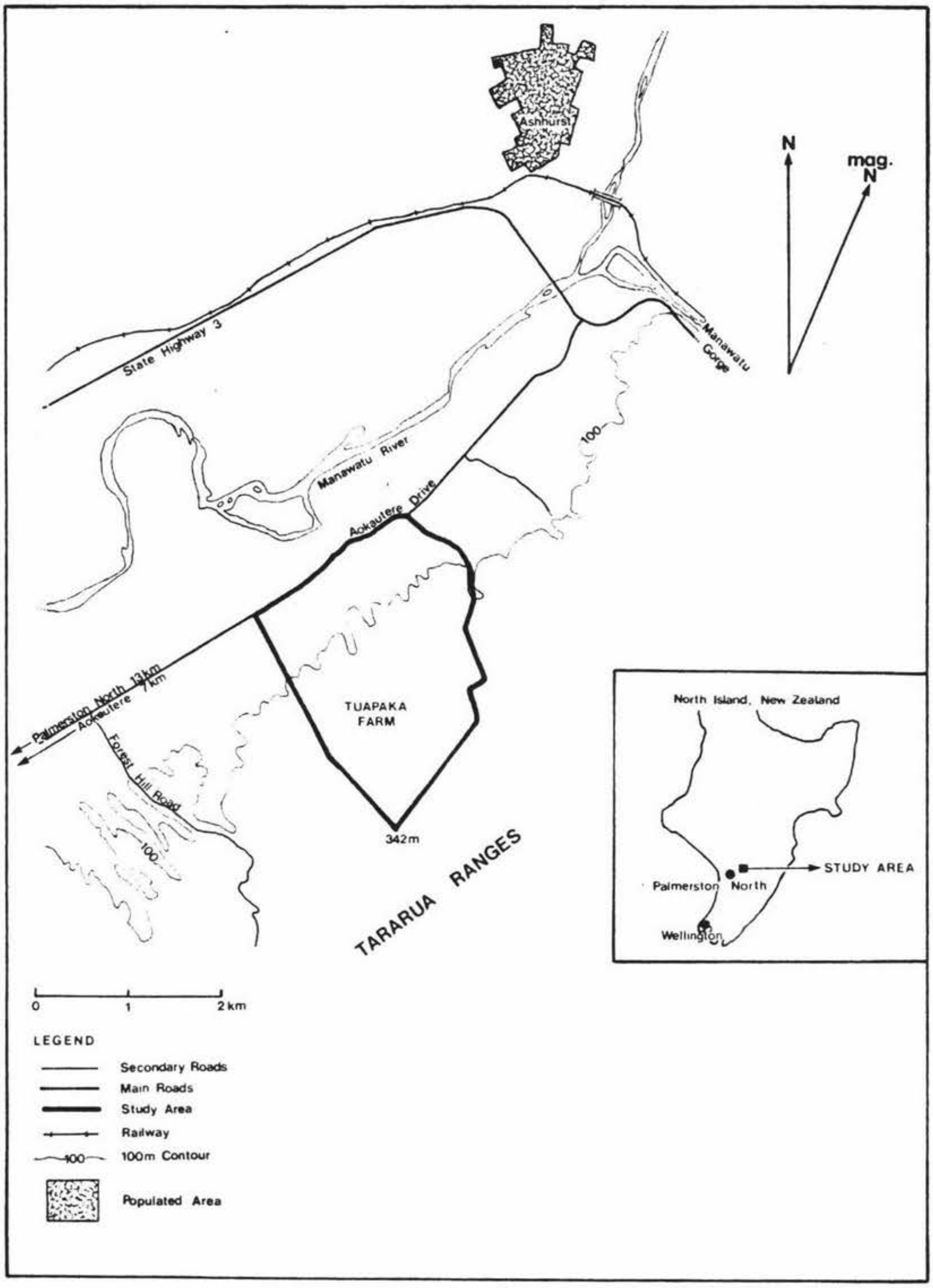
1.3.2 Relief of Tuapaka Farm.

The farm has two basic physiographic divisions, terrace flats and a hill block. The flats are gently undulating and lie approximately 60-80 m above sea level. They have an area of approximately 127 acres and extend in a strip approximately 65 m wide along the Aokautere Drive between the grid references already noted. This study is confined to the Hill Block which has an area of approximately 1073 acres. It rises abruptly from the flats to a succession of flat-topped spurs about 150 m above sea level along a line roughly parallel to the road. The land continues to rise gently from this level to 340 m, culminating in a gently undulating plateau surface at the back boundary of the farm. This surface continues to the crest of the Tararua Range.

1.3.3 Drainage of Study Area.

The Tuapaka Hill Block has three primary, fine textured, dendritic gully networks that drain northwest to the Manawatu River. The gullies rise in the vicinity of the back boundary of the property at c. 340 m and their main channels descend in a number of steep-sided valleys incised into the basement greywacke. Their first order channels are

Figure 1. Location Map.



interrupted by nick points that may relate to periods of uplift. They are fed by minor tributary channels, some of which flow across the surface of the basement greywacke.

In addition to these primary gully networks are three secondary gully networks that rise at ca. 220 m. They also have steep-sided valleys and drain northwest to the Manawatu River.

1.3.4 Vegetation in Study Area.

1.3.4.1 Past.

Prior to colonisation and vegetation clearance in the late 19th and early 20th centuries the coastal lowlands and the northwest Tararuas were covered with a blanket of forest. The most extensive forest type was podocarp-hardwood forest with totara, matai, miro, kahikatea and rimu representing the podocarps and northern rata, kamahi, tawa, pukatea, white and black maire among the hardwoods (Esler, 1978). A second forest type, found only near Aokautere, consisting of black beech, is floristically distinct from all other forests in the area. The forest extended about 1.6 km south and about 3.2 km north of the Forest Hill Road between 90 m and 270 m of elevation (Esler, 1978). This species favours dry, infertile sites (Franklin, 1967). These two forest types occurred in the study area. The northwest area of the Hill Block fell within the stand of black beech, while the remaining Hill Block area was covered in podocarp-hardwood forest.

The Tuapaka farm was cleared by burning in the early 20th century, following logging of the larger marketable species (Franklin, 1967).

1.3.4.2 Present.

Grass swards on hill country farms, taken in general, vary considerably in botanical composition, according to soil fertility (natural or induced artificially), the class of stock and the method of management (Levy, 1970). The Hill Block at Tuapaka is covered in pasture with a predominance of browntop and oversown white clover. Other grass species present include perennial ryegrass, danthonia and crested dogstail. Pasture composition may change under the new system of subdivision and grazing management envisaged for the block. Some steep-sided, rocky gullies contain manuka and gorse (Bargh, 1976).

1.3.5 Erosion in Study Area.

The Hill Block is in a disturbed state because the original vegetation has been removed and replaced with pasture, farm tracks have been cut, some cultivation has been carried out, and various animals' grazing effects have been imposed (Bargh, 1976).

Bargh has noted sheet erosion and soil slip erosion occurring on steep slopes of his study catchment, together with slight gully erosion. He reported that the wettest months tended to give rise to the highest loss of suspended sediments in streamflow. At times significantly higher sediment concentrations were recorded for a given flow rate in the wetter than in the drier months. Accelerated streambank erosion was cited as a major source of stream sediment.

The sheet and rill erosion recorded by Bargh in the area was largely due to exceptional circumstances pertaining to the upper area of his catchment. The area had been cropped and was bare due to heavy grazing of a forage crop. Storm events in July and August of that year carried off about 40% of the stream's annual sediment load. Since then the area has been grassed and sediment loads presumably reduced.

1.3.6 Existing Soils Information on Study Area.

The soils of the Study Area have been classified and mapped by Cowie, (1978) at a scale of 1:63,360. This map shows yellow-grey earth - yellow brown earth intergrades of the Shannon silt loam and Tuapaka hill soils on the lower slopes of the Study Area giving way to yellow-brown earths of the Ramiha series at higher elevations. A limited area of yellow-brown earths of the Korokoro hill soils is also included at higher altitudes.

CHAPTER 2. PHYSIOGRAPHIC BACKGROUND TO THE STUDY

2.1 Brief Geological History.

New Zealand is located on the southwestern margins of the Pacific Basin where two lithospheric plates of the earth are in contact - the Indian plate to the west and Pacific to the east. The contact between both plates is complex and in places involves numerous sub-parallel faults which in the North Island also bound a zone of active volcanism in the Taupo-Rotorua graben (Cole & Lewis, 1981). Here magma from subduction of the Pacific plate beneath the Indian plate has risen to the surface, where it forms part of the arc of volcanoes that border the Pacific Ocean. Relative movements of the two plates often results in movement along largely transcurrent faults, accompanied by earthquakes.

The area of present day New Zealand has been subjected to major crustal movement that has resulted in a shift in its position relative to neighbouring landmasses. In the course of this motion, elongated sections of the earth's crust have subsided and gradually accumulated great thicknesses of sediment. Such structures called geosynclines have received sediments from surrounding landmasses which after an extended period are so denuded of material as to be incapable of further supply. Each of these depositional phases is normally followed by tectonic uplift when the rocks of the geosyncline are subjected to orogenesis with attendant folding, faulting, induration and metamorphism.

In the New Zealand region deposition took place in a large geosyncline (the New Zealand Geosyncline) during Permian-Jurassic time, offshore from a landmass that now comprises East Australia and Antarctica. Quartzo-feldspathic detritus, largely from a granitic provenance, probably represented by Marie Byrd Land in Antarctica, accumulated in the Geosyncline to become indurated to greywacke, the most common basement rock of New Zealand. During the Rangitata Orogeny in early Cretaceous times, the greywacke was uplifted to form the ancestral New Zealand landmass. Subsequent to uplift, this landmass underwent a long period of denudation and was almost entirely submerged by a marine transgression which culminated in the Oligocene. Towards the upper Tertiary great thicknesses of marine sediments were deposited in localized troughs as ridges of crust were uplifted between localized basins of sedimentation. This culminated in the Kaikoura Orogeny which began about two million years ago, since when (Quaternary time) most of New Zealand's mountain ranges have been elevated and the New Zealand landmass took on an outline similar to the present day. The greywacke rocks elevated were rent by numerous faults producing a series of horsts that form the major relief of the country. Volcanic activity in the North Island accompanied the orogenic movements of the Kaikoura Orogeny.

Accompanying this tectonism and volcanism were widespread climate fluctuations which are classed in a sequence of glacial and interglacial periods termed the Pleistocene. About 14 Ka. B.P. the climate ameliorated and the period since the last glacial is termed the post-glacial or Aranuian stage in New Zealand.

The rocks deposited during the Pleistocene can be divided into an older group, (Nukumaruan and Castlecliffian strata), deposited in continuity with Pliocene rocks and a younger group formed in a physiographic environment rather similar to that of the present day (Hawera Series). In the North Island, rocks of the older group were deposited in sedimentary basins in the Wanganui, Hawkes Bay and Wairarapa areas. The Hawera Series consists of surficial deposits that are concordant with the present-day landscape. As a result of uplift of the land many of these features are now high above the level at which they were formed.

2.2 Physiography of the Manawatu.

The Manawatu District has two major physiographic elements, the axial ranges which dominate and bound it to the east and the coastal lowlands extending from the ranges to the sea in the west.

The axial ranges are bisected into the Ruahine and Tararua Ranges by the Manawatu Gorge, a deep-walled canyon approximately 244 m to 304 m deep, cut transversely through the axial ranges by the Manawatu River. The Manawatu Saddle at an elevation of approximately 300 m, immediately north of the Gorge, is the site of the lowest sag in the crest of the axial ranges. North and south of this point the Ruahines and Tararuas rise to more than 1500 m at their highest points.

The coastal lowlands contain three physiographic units, the river terraces, the alluvial plains and the coastal sand country. The Manawatu River meanders widely across these lowlands to the sea. The study area lies to the east of the Manawatu River 5 km downstream of the Manawatu Gorge on the northern section of the Tararua Range.

2.3 Lithology of the Ruahine-Tararua Axial Ranges.

The Ruahine-Tararua axial ranges have been regarded as a horst (Kingma, 1957, 1959), formed during the Kaikoura Orogeny. It is composed of Mesozoic relatively unfossiliferous greywacke together with argillites and associated spillites and chert (Rich, 1959). These rocks are strongly indurated and highly folded to the point where the folds are compact, upright and isoclinal. The beds vary in composition, strike, thickness and hardness, reflecting the complex conditions prevailing during sedimentation and the high degree of compression that has taken place since.

2.4 The Physiography of the Tararua Range.

2.4.1 General.

The Tararua Range is approximately 100 km long and 33 km across at its widest point. Over much of its area elevations range between 900 m and 1500 m. Summit height concordance shows that the Range as a whole is an elongated dome of uplift (Wellman, 1948). The Range is asymmetrical with highest elevations near the eastern side due to differential uplift resulting in tilting to the west (Mead, 1936).

2.4.2 Physiography of the Northern Tararua Subdivision.

The northern part of the Tararua Range, extending approximately 13 km south of the Manawatu Gorge to the Pahiatua Track, is the asymmetrical segment of a secondary domal structure at the northern end of the Tararua Range (Rich, 1959). It is an ancient erosion surface or peneplain warped into an asymmetrical arch (Ongley and Williamson, 1931), with a crest close to the central line and sufficiently preserved that its deformation can be recognized. The narrow, steep, southeast limb slopes at 30° to 35° and is broken by a major, nearly straight, high-angle fault. In contrast the northwest limb is broad and slopes gently at 7° - 10°. It dips beneath the covering strata which lap the flank of the Ranges and is modified by several small, high-angle faults. Rich (1959) located two small faults running along the northwest flank in this area. Each fault is approximately 1.7 km in length and dislocates both the undermass and overlying sediments. One of these, the Tuapaka Fault, runs through the study area and has a maximum vertical displacement of 25 m to 30 m.

This warped peneplain reaches an axial culmination at Tarakamuku Trig. at 544 m and descends to axial depressions in both the northeast and southwest. The north axial depression, here referred to as the Manawatu Depression, is in the vicinity of the Manawatu Gorge at about 300 m and the southern one is a sag at about 380 m through which the Pahiatua Track crosses the Range.

The northern Tararua segment is topographically distinct from the rugged, well-dissected parts of the ranges to the south and it is considered by some that this is due to protection from dissection afforded by a mantle of Tertiary sediment. This mantle has subsequently been removed to expose the greywacke basement rock (Heerdegen, 1972).

2.4.3 Plio-Pleistocene Sediments in the Northern Tararuas.

In the northern end of the Tararua Ranges rocks of Plio-Pleistocene age are found restricted to the western and eastern flanks (Rich, 1959). Here are found a series of wave-cut platforms backed by steep risers cut into the greywacke by marine erosion and veneered unconformably with sediments. Rich (1959) has identified four such areas in Plio-Pleistocene deposition in the northwest Tararuas which he correlates with Lower Waitotoran, Upper Waitotoran-Lower Nukumaruan, Upper Nukumaruan and Lower Castlecliffian.

Rich (1959) has defined the lower Castlecliffian deposits in the area as the Tuapaka formation. He mapped this as a sinuous band extending roughly 13 km southwest of the Manawatu Gorge along the west flank of the Tararua Range. It was named from exposures at the Tuapaka farm, where the most continuous outcrops of the formation occur. Stratigraphically overlying the lower Castlecliffian deposits are loess deposits of the Hawera Series.

2.4.4 The Tuapaka Formation.

2.4.4.1 Description

This formation has been described by Rich (1959) as consisting of poorly consolidated strata, comprising micaceous sands, thinly bedded to massive siltstones and rusty greywacke conglomerates. Characteristic features were widespread distribution of pumiceous materials, common occurrence of bands and lenses of conglomerates and rapid lithological variations both laterally and vertically. Only one lithological unit could be traced any appreciable distance, the Tuapaka conglomerate, traced 2.5 km along strike in the vicinity of the Tuapaka farm. In places an almost pure vitric tuff overlies the Tuapaka conglomerate. The contact between the uppermost sands of the Tuapaka formation and the underlying gravels was traced almost continuously along the foot of relict sea cliffs of lower Castlecliffian age south of the Tuapaka farm to the Forest Hill Road (Fig. 2). Prior to dissection the Tuapaka formation formed a wedge of sediments thinning against the Range to the foot of the relict sea cliffs. The formation thickened in the direction of dip. The erosion surface truncating the undermass is inclined more steeply than the Tuapaka formation.

2.4.4.2 Dating the Tuapaka Formation.

The extinction of many genera at the end of Nukumaruan time left an impoverished fauna in lower Castlecliffian times, but by upper Castlecliffian times this was reinforced by immigrant forms (Fleming, 1953). Fleming established the Okehuan substage of the Castlecliffian to denote early Castlecliffian deposits with impoverished marine faunas.

Molluscan evidence produced by Rich (1959) indicated that the Tuapaka formation was lower Castlecliffian in age. Characteristic forms present included *Amphidesma pliocenicum* and *Leucotina ambigua*. Also significant were *Xymere expansus*, characteristic of the lower Castlecliffian at Wanganui, that disappeared in mid-Castlecliffian times in the Rangitikei river sequence (Te Punga, 1952). Present also was the large *Maorimactra acuminella* which is also characteristic of lower Castlecliffian deposits (Fleming, 1953). Absent was the genus *Pector*, one of the most important immigrant forms of the upper or typical Castlecliffian (Fleming, 1953).

The fossil evidence suggests the withdrawal of the sea from the Manawatu Depression and the northern flanks of the Tararuas by mid-Castlecliffian times, although basinward marine sedimentation continued (Rich, 1959). Information from the Dannevirke subdivision confirms withdrawal of the sea from the Manawatu Depression by

Figure 2. A view south from Forest Hill Road of the relict sea cliffs rising to the skyline. The undulating surface in the foreground is a continuation of the marine bench mantled with sediments of the Tuapaka formation and loess, as observed at the Tuapaka Farm.

mid-Castlecliffian time (Lillie, 1953). By lower Castlecliffian times the outline of the northern Tararua Ranges was well established, as shown by the distribution of the Tuapaka formation and the relict marine cliffs cut along the western flanks. The Tuapaka formation sediments were probably laid down in shallow water of estuarine or littoral environments as evidenced by the fossil record, the relict cliffs, the wave-cut platform and cross-bedding of sediments.

2.4.5 Hawera Deposits.

Sedimentary strata of the Hawera age, except where covered by recent deposits, form the surface of the coastal lowlands of the Manawatu district. Surficial deposits include terrace gravels, alluvium and dune sand of late Pleistocene and Holocene age, together with solifluction debris of late Pleistocene age. Deposits such as these, with the exception of dune sand, adjoin the Tuapaka formation and form the flats of Tuapaka farm. However, they lie outside the area of this particular hill block study.

2.4.6 Loess.

2.4.6.1 Loess in New Zealand.

The term loess is of German origin (Löss) and comprises silt-sized particles predominantly 10-60μm in diameter that have been carried by the wind in suspension to accumulate as a mantle on the surrounding landscape. The term loess is used in New Zealand in a broader sense than in some parts of the world (Raeside, 1964). It is applied to any fine-textured deposit of eolian origin, other than sand dunes or tephra, irrespective of organic matter content, mineralogical composition, calcium carbonate content or degree of compaction (McCraw, 1975).

It is generally accepted that the bulk of the loess was derived from riverbeds during the cold periods of the Quaternary when vegetation cover was less than at present and erosional activity was at a maximum (Selby, 1976). However, not all loess deposits are of glacial origin. Silt-sized particles are blown off rivers in summer today to mantle the surrounding landscape but are usually of more restricted distribution. In the North Island loess occurs as a surface deposit in the Manawatu, Wairarapa, Hawkes Bay regions and elsewhere. It also occurs between volcanic ash beds (Pullar, Birrell and Heine, 1973).

2.4.6.2 Loess in the Manawatu.

New Zealand during the Otiran Glaciation experienced marked oscillations in mean temperatures from not more than 4.5 C below present (Soons, 1976) to temperatures very near, if not identical to those of the present (Burrows, 1978). The reductions in temperature experienced during the height of the Pleistocene glacials would have produced modest glaciation of the Tararuas (Willett, 1950). Actual glaciers were restricted to small areas near the summit of the Tararua Range (Adkin, 1912). The snow line was depressed causing a cold, dry climate with resultant physical weathering of rock and solifluction processes in periglacial areas. Solifluction deposits occur over much of the axial range of the southern part of the North Island (Cotton and Te Punga, 1955; Stevens, 1957 a, b, and Rich, 1959). In the northern Tararua Range Rich found deposits of greywacke congelifractate on slopes at elevations exceeding 200 m. The landscape would have been bare rock devoid of vegetation down to 600 m, below which sub-alpine vegetation would have extended to sea level (Fair, 1968).

In the Manawatu these fluctuations in climate during the waning phases of the last glaciation of the Pleistocene were of sufficient magnitude to induce changes in the regimes of the main rivers that allowed periodic aggradation of gravels and associated sediments in cooling phases and degradation of these in warmer, more humid conditions. This resulted in a series of aggradational terraces in the Manawatu River valley between the Manawatu Gorge and Palmerston North. They include the Forest Hill Terrace (possibly correlated with one of the Kumara 1 advances, or coeval with the Porewa terrace in the Rangitikei [80-70 Ka. B.P.]), the Milson terrace (possibly correlated with Kumara 2 - first advance or coeval with the Rata terrace in the Rangitikei [40-32 Ka. B.P.]), the Ashhurst terrace (possibly correlated with Kumara 2 - second advance or a Kumara 3 advance coeval with the Ohakea terrace in the Rangitikei [25-12 Ka. B.P.]) and the Raukawa terrace, the lowest and youngest aggradational surface found along the Manawatu River, of unknown age (Fair, 1968).

Coinciding with each period of gravel aggradation was a period of loess deposition in the Manawatu. Loess covers most of the terraces, rolling land and hill country of the Manawatu District. The bulk of the loess is considered to have been blown from the river beds by winds similar to the dominant winds today (McLintock, 1959). The loess becomes thinner and finer away from river beds where it is considered to have accumulated more slowly (Cowie, 1964 a).

The last major episode of deposition in the Manawatu occurred during the aggradation of gravels that now form the Ashhurst (Ohakea) terrace (Fair, 1968; Cowie, 1964 a). This episode is thought to have started about 25, Ka. B.P. and to have ended about 12, Ka. B.P. (Milne and Smalley, 1979). Loess from the Ohakea terrace is considered to be a principal parent material of soils throughout the Manawatu, including the study area.

Aggradational terraces older than the Milson terrace have experienced more than one episode of loessial deposition. These older loesses occur as strongly weathered clay soils in present-day profiles because after their deposition they are considered to have been subjected to long periods of continuous weathering with little or no loess accumulation (Cowie, 1964 a). The warming of the climate in post-glacial times, at around 12, Ka. .B.P., marked the end of actual loessial deposition and would have been accompanied by reforestation of the Tararuas.

The Manawatu has a well-defined and easily recognized datum plane provided by a volcanic marker bed, the Aokautere Ash. This ash was erupted from the Taupo region about 20, Ka. yr.B.P. and extended as a sheet over surfaces of different ages and heights throughout the district (Cowie, 1964 b). The shower banding within it is a distinctive characteristic. It is well preserved within thick deposits of the Ohakea loess (Cowie, 1964 b). This confirms that the loess was accumulating fairly rapidly around 20, Ka. .B.P. when the ash was erupted.

2.5 Erosive Phases in the Aranuian.

Grant (1981,a; 1981,b), has postulated five major erosion and intervening sedimentation phases to the north of the study area associated with climatic oscillations during Aranuian times.

The erosion periods recognized and their approximate chronology are as follows:

1.	Waihirere	c A.D. 1270 to c A.D. 1370.
2.	Matawhero	c A.D. 1530 to c A.D. 1620.
3.	Wakarara	c A.D. 1780 to c A.D. 1830 (?)
4.	Tamaki	c A.D. 1870 to c A.D. 1900.
5.	Waipawa	late 1940's to present.

He has inferred that the erosion phases resulted primarily from sustained increases in the frequency of major rainstorms, when gales devastated extensive forest areas. These events are recorded as having caused progressive stripping of the soil mantle in upland areas, resulting in a reduction in the volume and efficiency of soil moisture storage and an increase in the hydrological instability of drainage basins. These erosive phases in Aranuian time may also have been responsible for erosion episodes in the study area.

2.6 Climate.

2.6.1 Brief Outline of New Zealand Climate.

New Zealand lies in a temperate climatic zone in the path of prevailing westerly winds. The country is subject to rapid fluctuations of weather produced by a series of anticyclones and depressions which move continuously from west to east. The effects of latitude, marine influences and relief result in an insular climate, marked by an absence of extreme variations in temperature. Relief has an orographic effect on rainfall distribution.

2.6.2 The Manawatu Climate.

2.6.2.1 General

The Manawatu lies within the west Wellington climate district which is characterized by warm summers, mild winters and a seasonal distribution of rainfall with a summer drought. The prevailing winds are west to north-west, with frequent gales (Cowie, 1978).

2.6.2.2 Rainfall.

The average number of rain days per annum recorded at the Tiritea climatic station located on the lower slopes of the Tararuas, 9.5 km from the study area, for the years 1921-50 was 168 days of rain per annum and rainfall was fairly evenly distributed throughout the year. The driest month was March and the wettest month June. Droughts and dry spells occur in the area and they vary in severity according to relative humidity, temperature and wind frequency during the preceeding weeks (Cowie, 1978).

2.6.2.3 Wind.

The prevailing northwesterly and westerly winds (35.5% frequency at Milson Airport) have a high proportion of strong winds (14% over 24 km/hr) and this is typical of the Manawatu area. Calm conditions or winds of 5 km/hr or less occur for 31.5% of the year (Cowie, 1978).

2.6.2.4 Temperatures.

Mean monthly temperatures in Palmerston North range from 8°C in July to 17.5°C in February, and the annual average temperature is 12.6°C (Cowie, 1978).
These figures are higher than for the study area because of the lower elevation of the observations sites compared with the study area.

Figure 3. The uneven greywacke bedrock comes to the surface throughout the study area. This greywacke outcrop was observed on Physiographic Unit 3.

2.7 The Study Area.

2.7.1 Structure of the Study Area.

The Tuapaka hill block is located on the margin of the gently sloping northwest limb of the northern Tararua Range and has an undermass of uneven greywacke rock (Fig. 3). This surface plunges at an angle of 7°-9° beneath strata that lap the flanks of the Range at the lower boundary between hill block and river flats. The undulating bedrock surface at the upper boundary of the farm slopes gently to the crest of the Range and is part of the ancient Cretaceous peneplain surface warped into an asymmetrical dome by uplift.

The line of relict sea cliffs and undulating wave-cut platform identified by Rich (1959), along the western flanks of the northern Tararua Range extends through the study area. The relict sea cliffs have undergone severe dissection resulting in reduced slope and subdued appearance in most locations. A bench has been cut into the face of the relict sea cliffs at 260 m - 280 m and the relict cliffs rise above this feature to 300 m. This is considered to be the strand line at the height of marine transgression in the area.

Faulting during uplift of the ancient peneplain has resulted in a small, high-angle fault, named the Tuapaka fault by Rich (1959) that crosses the marine bench. The fault has a vertical displacement of approximately 30 m.

2.7.2 Stratigraphy of the Study Area.

Marine sediments of the Tuapaka formation rest unconformably on the marine bench. Prior to dissection, these strata had formed a wedge that thinned across the marine bench to terminate at the foot of the relict sea cliffs. The Tuapaka fault has dislocated these marine sediments and in addition they have been cliffed by the Manawatu River to form the steep scarp forming the boundary between hill block and river flats at the front of the farm (Fig. 4). Marine sediments are apparently absent from the ancient peneplain surface that extends above the relict sea cliffs to the back boundary of the farm.

Figure 4. View of the scarp slope separating the hill block from the river flats on the Tuapaka Farm. This is the lower boundary of the study area.

All the surfaces on the hill block have been blanketed by successive episodes of loessial deposition and the Aokautere Ash is observed interbedded in the youngest of the loess deposits. The cover beds in the study area have been subject to erosion and varying degrees of stripping.

R epresentation of the sequence of events that formed the present physiography of the study area is shown in Figure 5.

2.7.3 Physiographic Subdivision of the Study Area.

The deposition of bedrock surfaces and covering surficial deposits in the study area permits recognition of four physiographic divisions of the landscape, as depicted in Figs. 6 and 7.

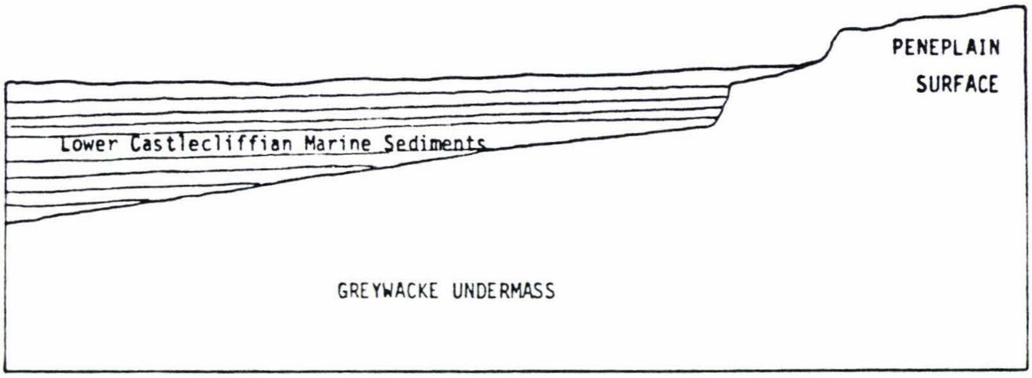
Physiographic Unit 1: This is the gently undulating plateau surface that slopes from around 280 m to 300 m up to around 340 m at the back boundary of the farm. This surface is identified as the ancient Cretaceous peneplain surface and has greywacke bedrock covered by colluvial material mantled with loess deposits.

Physiographic Unit 2: This surface forms the break in slope from 240 m to 280-300 m caused by the relict sea cliffs (Fig. 8). This zone has exposures of greywacke rock and colluvium, together with surficial loessial and slope wash materials that obscure the break in slope in some locations.

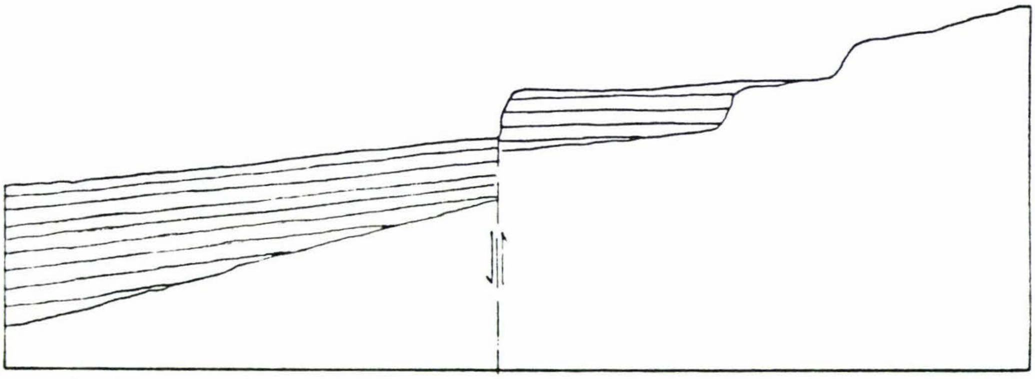
Physiographic Unit 3: This surface represents the upthrown section of the marine bench, extending from the foot of the relict sea cliffs at about 240 m to the Tuapaka fault at 200-220 m. The surface has greywacke bedrock mantled by dissected marine sediments of the Tuapaka formation (Fig. 9). These consist of deep sand and marine gravels (Fig. 10). The surface has been capped with loess.

Physiographic Unit 4: constitutes the downthrown section of the marine bench. It extends from the Tuapaka fault at about 170 m to a steep scarp slope at 150 m to 160 m that marks the lower boundary of the study area on the southwest side of the farm.

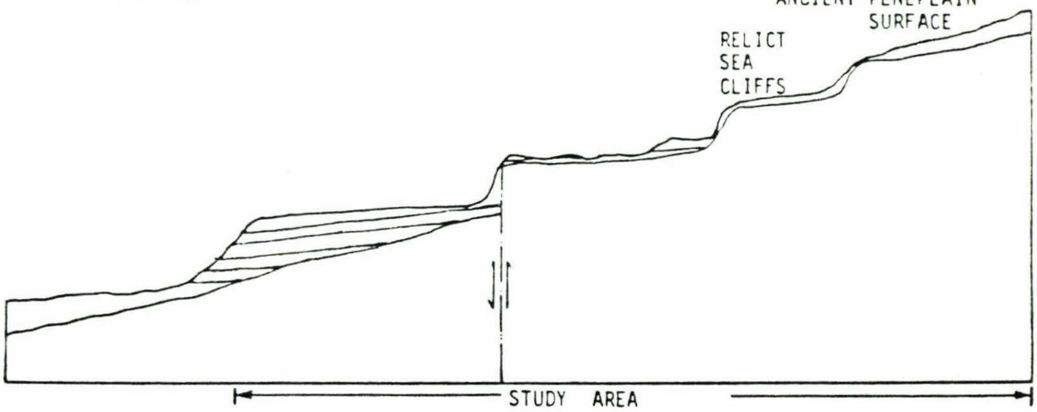
Figure 5. Diagrams illustrating the sequence of events in the formation of the present day physiography of the Tuapaka Farm.



a) Diagram showing ancient peneplain surface and marine bench mantled in sedimentary strata at the height of the Lower Castlecliffian marine incursion.



b) Diagram showing dislocation of marine bench and sedimentary strata by uplift. Note Tuapaka fault.



c) Diagram showing current physiography of Tuapaka farm showing former erosion of marine sediments and loess deposition. Note the marked stripping on the upthrown side of the Tuapaka fault and fluvial intrusion by Manawatu River to form a prominent cliff on the downthrown side of the Tuapaka fault where extensive river flats now occur.

Figure 6. Physiographic divisions of Tuapaka Farm - plan.

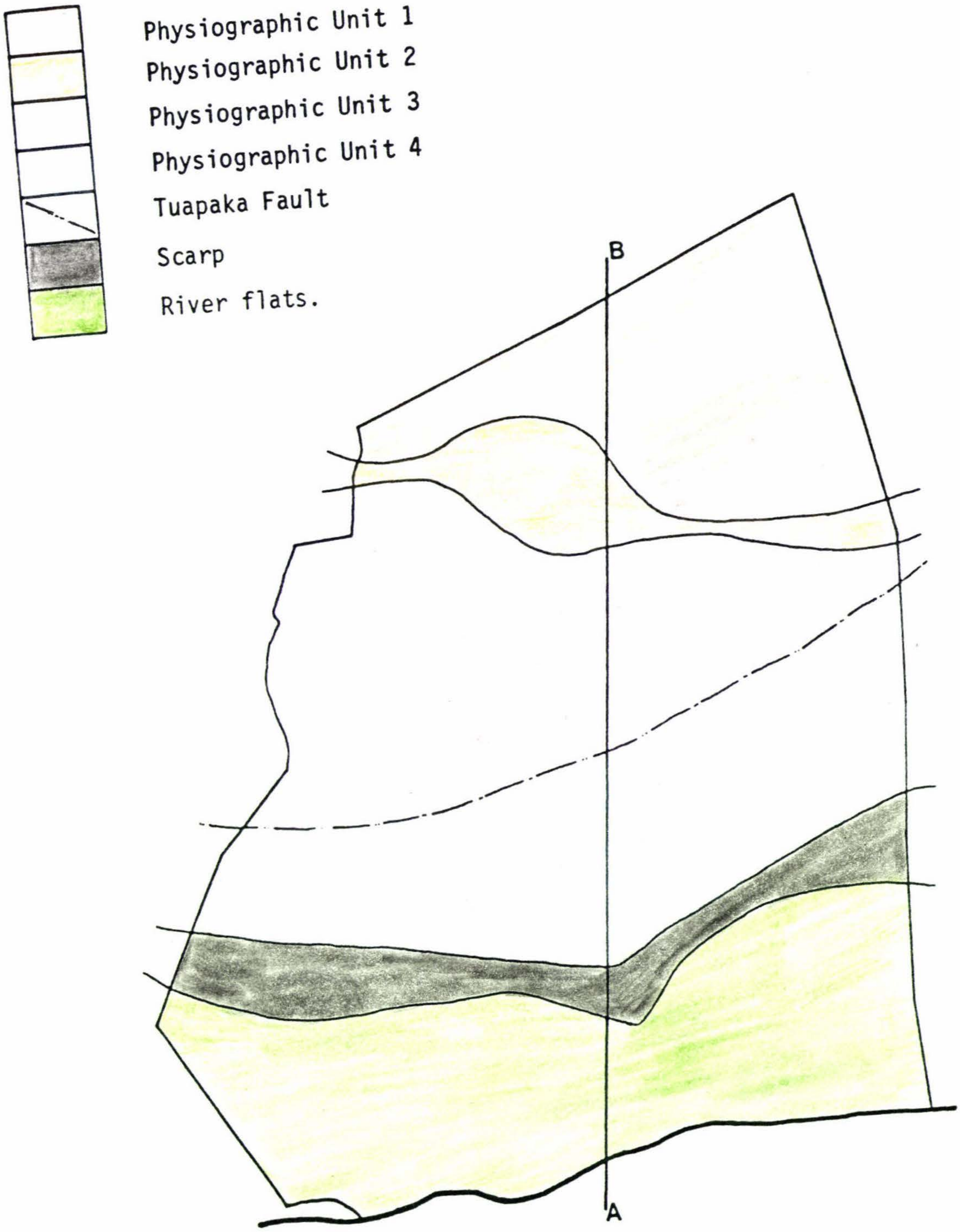
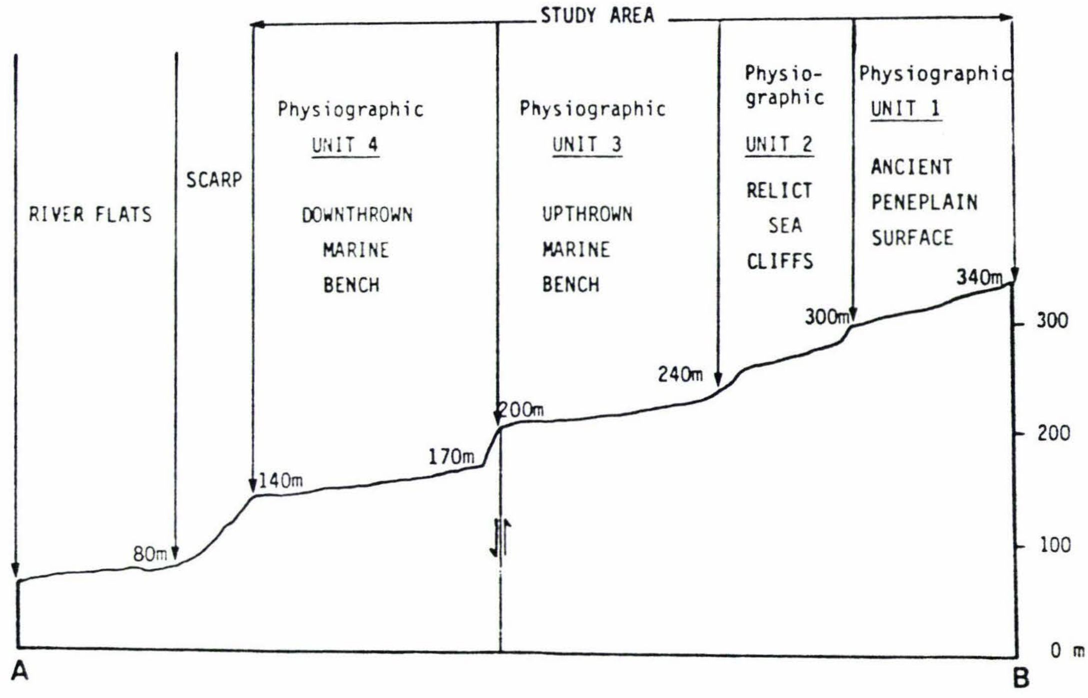


Figure 7. Idealized section across Tuapaka Farm, showing Physiographic Units.



The surface on the northeast side of the farm has experienced greater dissection and a sharp physiographic boundary between hill block and flats is now not present.

The surface has a wedge of marine sediments of the Tuapaka formation capped with loess, lying on the greywacke of the sloping marine bench. Marine sediments thicken to a maximum depth of more than 60 m thickness at the lower bondary of the study area.

2.7.4 The Local Climate at Tuapaka.

Changes in local climate on the hill block at Tuapaka with elevation include an increase in rainfall coupled with increased fog and mist cover, reductions in evapotranspiration and diurnal and annual ranges in temperature.

Average annual rainfall is estimated at around 1140 mm on the river flats of the Tuapaka farm, rising to around 1270 mm at the back boundary of the hill block (Cowie, 1978).

A water balance has been computed by Robinson (1975) and applied to the study area by Bargh (1976). This used average monthly 'Penman' values of potential evapotranspiration from Palmerston North and daily rainfall data from the Waipuna (Woodville) Climate Station 9 km from the study area. Agricultural drought (as defined by Rickard, 1960) occurred on an average of 49 days per year.

It was observed that the strong, prevailing northwest and westerly winds had a significant drying effect on the soils of the area, especially in summer.

Figure 8. A view across Physiographic Unit 3 to the relict sea cliffs of Physiographic Unit 2. These rise to Physiographic Unit 1 on the skyline.

Figure 9. A view of Physiographic Unit 3 in the foreground crossed by a deeply-incised gully channel. The exposures of greywacke bedrock in the gully channel indicate the depth of overlying sediments of the Tuapaka formation and loess cap mantling greywacke bedrock.

Figure 10. A cutting showing exposure of marine sands of the Tuapaka formation near the intersect of Physiographic Unit 3 with Physiographic Unit 2.

CHAPTER 3. CONCEPTUAL SCIENTIFIC FRAMEWORK: Literature Review and Examination of Concepts.

"The concept formed by the intellect is not that which is known but that by which the intellect knows the extra-mental object." *(Aquinas.)*

3.1 The Scientific Method.

The scientific method relies on the observation of a certain regularity in nature caused by internal principles which by their operation always produce the same phenomena. The effect is non-accidental and the task of the scientist is to uncover these internal principles (Gilson, 1950). The demand of science that nature shall be lawful and a unity, expresses itself in the simplicity found in her laws when we have them right. Phenomena which first appear different in kind are organized to reveal in the apparent disorder of nature a profound unity. The body of systematic, formulated knowledge, admitting to quantitative treatment is derived from observation, experiment and that unpredictable blend of speculation and insight called induction (Bronowski, 1977).

The development of all branches of science has always had a strong practical bias because of the struggle by man towards utilization of nature but the concurrent efforts for acquisition of abstract knowledge, the discovery of the laws of phenomena, are more significant. "If at the present time we are able to point to continuous progress in many branches of science, we should recognize that it is due primarily not to those who seek scientific knowledge merely for use but to those who have attempted to formulate the laws of nature." (Marbut, 1927).

3.2 Soil as an Organized Natural Body.

The recognition of soil as an object of study in itself and the creation of a body of effort directed towards the investigation of the soil as a definite branch of natural philosophy is due primarily to the insight and work of Dokuchaiev in Russia from 1870 onwards.

Dokuchaiev (1886) defined soils as "the layers of material lying on the surface of the earth, or near it, which have been changed by natural processes under the influence of water, air and living and dead organic matter". This was a revolutionary genetic concept of soils as independent natural bodies, each with a unique morphology resulting from a unique combination of state factors (soil forming factors), an idea to be further developed much later on in America by Jenny (1941, 1961, 1980).

Dokuchaiev's approach was continued by Glinka and others of the Russian school as well as by various Europeans including Ramann in Germany. Shaler in America had a similar perception but genetic ideas were slow to catch on in that country until the advent of Marbut's translation of Glinka's "Die Typen der Bodenbildung" under the title of "The Great Soil Groups of the World and their Development" in 1927.

An additional important early contribution to the concept of soils as organized natural bodies came through the work of Müller (1887) who recognized the genetic relationship between eluvial and illuvial horizons in the podzol profile. From his work came the general realisation that the sequence and relationships between horizons and their degree of expression reflect the entire history of pedogenesis in each soil.

We thus arrive at the position where investigations need not be confined merely to the description of the external and internal characteristics of the soil, but can strive to interpret the many processes giving rise to its origin, development and decay. As Robinson (1949) has it, "The domain of Pedology can only be defined by the natural limits of enquiry."

The view that pedology should be regarded as an independent branch of study and treated as a pure science does not imply any depreciation of the practical significance of the subject. To quote Robinson (1949) again, "The study of the genesis and constitution of the soil and the development of a philosophical system of classification will yield, as corollaries, practical results that could hardly be obtained by direct research." Indeed it is one of the declared aims of this study to demonstrate the practical utility of the scientific approach to the study of the soil on the Tuapaka property.

3.3 The Soil-Definitions.

The soil mantle is present over nearly all land areas as a thin surface film. It can be viewed as "the one great formation in which the organic and inorganic kingdoms meet and derives its distinctive character from this union" (Coffey, 1912). The term "Pedosphere" was coined and defined by De Sigmond (1938) as "the outer layer of the earth's land surface in and on which organic life exists in contrast to the lifeless lithosphere which is the outer mineral crust of the earth". The soil then is the outermost part of the regolith and its upper and lateral boundaries are clear, where land meets air and water respectively, but the lower boundary is often obscure with no distinct break setting it apart from the remainder of the regolith.

The classical view, in accordance with a genetic perspective, considers the lower boundary between soil and regolith to be where the external and internal characteristics of weathering geological material have not been modified by soil-making processes acting upon it (Marbut, 1927). This view is echoed by Robinson's (1949) observation that "an adequate conception of the soil can be obtained only from a study of soil strata down to the parent material."

The U.S. Soil Taxonomy (Soil Survey Staff, 1975) acknowledges that there are circumstances where the lower boundary of the soil must either be set arbitrarily at 1 or 2 metres, or else at the lower limit of biological activity or of the common rooting of native perennial plants - again a matter of 1 or 2 metres. This may serve for most practical purposes provided that we are mindful of the fact that the roots of native perennial plants may extend beyond 2 metres and also of Robinson's (1949) belief that "to restrict the study of the soil to the upper layers in which plant roots ordinarily fulfill their activities would be to exclude horizons which clearly fall within the sphere of pedogenic processes". Furthermore, pedology must study materials beneath the pedosphere as these have a strong influence on the soil and its properties, management and stability (Cutler, 1977).

3.4 Soil Classification.

3.4.1 Objectives.

The scientific study of the soil requires the erection of a classification system to organize information and ideas about soil variation in the pedosphere so that meaningful predictions may be made therefrom. Unfortunately, however, there is no general agreement as to the precise objectives and basis for soil classification. Kubiena (1953) maintains that any such classification should represent the essential order in nature itself. Kovda et al (1967) consider that the function of classification is to determine and reflect the main stages in the origin and development of soils. Robinson (1950) expresses the view that the purpose of soil classification is to ensure that soils will be thrown into the clearest possible relationship to each other. As against these more fundamental views of the purpose of soil classification, it is stated in Soil Survey Technical Monograph No. 14 (Avery, 1980) that soil classification is required to organize information and ideas about soil variation in ways that seem logical and useful for particular purposes. In similar vein, Riecken (1963) maintains that a soil classification should permit the extension of knowledge in the use, management, productivity and conservation of different soils. Soil Taxonomy (Soil Survey Staff, 1975) caps this off by declaring that classifications are contrivences of men to suit their purposes.

Given these conflicting views on the nature of classification in general and soil classification in particular, we may take refuge in Hallsworth's (1965) belief that "...perhaps the overriding reason (for a classification, soil classification included) however is the mental satisfaction that follows the logical organization of knowledge in a coherent and mutually consistent scheme."

3.4.2 Basis of Classification.

Soil classifications are natural or technical in character. A natural classification system is based on the properties of the objects classified. Technical classifications have limited objectives and a special bias dictated by their particular use or management objective and are arranged in an interpretative or capability type format.

3.4.2.1 Natural soil classifications.

3.4.2.1.1 Introduction:

Natural systems of soil classification were impossible until it was recognized that soils were independent, organized, natural bodies with distinctive morphologies. Systems devised vary widely in the weight they give to 'Idealism' and 'Empiricism' (Butler, 1980). Idealist systems posit a basic theory of soils and select differteriae for galleries of conceptual classes that result from soil genesis. Empiricist systems group soils as they are seen to appear in the field, without attempting to fit them to a theory of pedogenesis.

3.4.2.1.2 Idealist natural soil classifications:

The classical Russian and European tradition of classification, begetter of the New Zealand Genetic Classification, is avowedly Idealist. Soils are viewed as natural bodies tending to equilibrium with their environment. Classifications are devised through interpretation of soil process and the pedogenetic functions of the environment to express progressive approximations to the "essential order in nature itself" (Kubiena, 1953). The systems are provisory, change and modification resulting from advances in knowledge and understanding of pedogenesis. The classes in such a system are not contrived by man but "arise of their own accord, corresponding essentially to the natural phases of development. The arrangement (of the classes) is not governed by an arbitrary principle of division but by their mutual connection and interrelationship" (Kubiena, 1953). The classification then reflects the state of our knowledge - or ignorance as Glazovskaya (1966) has noted.

The U.S.D.A. classification, Soil Taxonomy (Soil

Survey Staff, 1975), was designed to overcome the perceived weaknesses in the earlier Idealist systems. It rejects the classical bias for defining soil classes in terms of soil forming factors external to the soil itself and the extreme emphasis on virgin soils. The history of soil genesis in any soil is complex and often a matter of inference rather than direct observation and experiment. Consequently it was considered that classifications based on inferred causes of present soil characteristics were subject to large risks (Coffey, 1912; Marbut, 1922). Furthermore it was considered that earlier classifications gave inadequate recognition of dynamic soil changes in response to the cultural changes created by man.

The system devised therefore emphasized soil characteristics themselves, on the principle that the use of morphology and composition of the profile as criteria for differentiating classes seemed to present the smallest risk of error (Simonson, 1962). The system may be regarded as Idealist as theories of soil genesis lie behind the choice of differentiating criteria down to the subgroup level in the system.

These criteria are diagnostic horizons and properties and are recognized as marks in the soil of differences in the degree and kind of the dominant sets of soil forming processes that have gone on. The diagnostic properties can be evaluated in the field, or inferred from field examination and by comparison with bench mark soils sampled for laboratory analysis. It is professed that the increased precision of the system is reflected in this ability to supply quantitative statements on characteristics of the soil. The system is termed taxonomic as its purpose is "to understand, as fully as existing knowledge permits, the relationship between soils and also between soils and the factors responsible for their character."

The classical and U.S. taxonomic systems of classification assume that all soil characteristics are interrelated, that soil morphology is created by pedogenic processes determined by factors of environment and that there is a high degree of 'orderliness' and a low level of 'noise' in the pedosphere (Butler, 1980). They assume that though soils have many properties, some are associated in apparently causal relationships and it is assumed that individual soils agreeing in the common possession of a few differentiae will also agree in the possession of other associated properties. These assumed relations and consequent groupings are the means used to make predictions of soil behaviour.

3.4.2.1.3 Empirical natural soil classifications.

The Factual Key for the Recognition of Australian Soils (Northcote, 1979) is the chosen example of an empirical system of soil classification. This system has no *a priori* philosophical base in terms of soil genesis and lacks a gallery of foundation conceptual classes. It was issued in the form of a key based on simply defined soil-profile characteristics that can readily be determined in the field. These allow unambiguous sorting of soils and are chosen because they are simple, objective and do not involve assumptions of their genetic importance through an interpretation of pedogenesis. The system is explicitly designed to avoid the assumption of 'orderliness' in the pedosphere and consequently the relationship of differentiae and grouped associated properties is unknown. However, such an inferred association of properties is a mark of a successful classification.

3.4.2.2 <u>Technical Classifications</u>

These systems are based on a few properties significant for their objectives and need only be homogeneous in these differentiae. Classifications pertaining to soil performance in the pre-scientific era as detailed by Simonson (1968) were technical in nature. Many modern New Zealand examples are to be found in the interpretive maps and suitability ratings for specific activities such as pastoral farming (N.Z. Soil Bureau, 1968b) or exotic forestry (Mew et al, 1975; Mew, 1980). Cline (1949) has observed that only classes in the lowest category of a natural system provide units that are sufficiently homogeneous in the specific properties for which technical groupings are made. While technical classifications are valuable for the specific purposes for which they are made, they cannot claim to provide a wide data base or to have the general predictive power of natural classifications. The very fact that in New Zealand interpretive maps are derived from natural genetically based soil surveys bears this out.

3.5 The Soil Individual: Natural or Artificial?

3.5.1 Introduction.

The concept of the soil individual as an object to be classified, is necessarily antecedent to a natural soil classification. The continuous nature of the pedosphere and the absence of discrete soil individuals has given rise to a fundamental difference of view on the nature of the soil individual. There are those with Simonson (1968) who consider the soil individual to be a natural entity, while others such as Knox (1965) regard it as a contrived human construct.

3.5.2 The Natural Soil Individual.

Scientists who advocate the existence of natural soil individuals view the soil continuum as a mosaic or patchwork consisting of many different polypedons which constitute the soil individual (Simonson, 1968; Van Wembeke, 1966). Each individual is defined by an ensemble of properties that are actually observed to occur. "The ensemble of properties is given and does with certain variations occur in nature" (Robinson, 1950). The mosaic of unlike soil individuals in the soil continuum is a consequence of the local domination of the influence of a limited number of state factors (Schelling, 1970; Stephens, 1947). Unlike soil individuals are linked to each other in the soil continuum through boundary zones of soils with transitional properties. The phenomena of transitional soils is due to "the entirely passive, non-particulate, response by soil to environmental factors and the absence of particular responses which depend on inherent genetic structure, as occurs in plants and animals" (Robinson, 1950).

The natural soil individual is defined by properties peculiar to itself. Its existence is not considered incompatible with transitional soils. The soil individual in this sense is equated with the soil series at the lowest level of a natural soil classification.

3.5.3 The Artificial Soil Individual.

The view that the soil individual is artificial and a contrived human construct is advocated by Cline (1949), Knox (1965), Butler (1980) and others. They consider that natural individuals can exist only as members of a particulate universe and must be discrete and independent of the observer. It is their view that in a continuous universe there are no natural individuals. The sampling unit, the profile or pedon, is considered as representing the artificial soil individual at a spot location and the soil series is regarded as "an abstract field, a nucleus of differentiae to which sampling units are related within a permitted frequency distribution" (Cline, 1949). According to this school, the differentiae chosen to define the soil series and their permitted variation are determined by the objectives of the classification.

The pragmatic view put forward in the U.S. Soil Taxonomy reflects that as the soil individual is fashioned by environmental pedogenic processes, marked breaks will be observed in soil properties with abrupt changes in environmental agencies, while soil properties merge from site to site where environmental agencies change slowly. In the first case little subjective judgement is required to define the soil individual, while in the latter case the amount of human interference to define the individual increases, approximating the condition of natural and artificial individuals respectively.

3.6 The Pedon and Polypedon.

3.6.1 Introduction.

In recent decades emphasis has been placed on the three-dimensional nature of the soil. It represents a volume mantling the surface of the earth. This has resulted in the introduction of the concepts of the pedon and polypedon.

3.6.2 The Pedon.

The soil profile has long been recognized as the natural unit of study of the soil (Robinson, 1949) and has been defined as a vertical cut through the soil, exploring its various horizons. As such it is essentially two-dimensional. It has now been replaced (at least conceptually) by the pedon as the basic soil sampling unit. The pedon (Soil Survey Staff, 1975) refers to a three-dimensional volume of soil large enough, but no larger, in lateral dimensions and depth to permit the study of horizon shapes and relations. The area of the pedon ranges from 1 to 10 square metres, depending on the nature and variability of horizons. The inferred lower limit of the pedon is the somewhat vague limit between the soil and the "not soil" below. The pedon is thus a unit of arbitrary size, although the limits are adjustable in an endeavour to accommodate the variability in horizon differentiation found in nature. An important point emphasised by Avery (1973) is that soil classification units group pedons according to their similarity whereas soil mapping units must group them according to their contiguity.

3.6.3 The Polypedon.

The polypedon is a three-dimensional segment of the landscape made up of a group of contiguous pedons, similar in the nature and sequence of horizons and with a range of characteristics, no wider collectively than that permitted for a single soil series. The polypedon is bounded on all sides by "not soil" or by pedons of unlike character in respect of one or more characteristics diagnostic for a soil series. Boundary criteria are thus prescribed and determined by the limits of a soil series.

According to Simonson, (1968), the polypedon is the soil individual, the real thing encountered in the field. It has specific and definite features regardless of geographic occurrence. The polypedon relates bodies of soil represented on maps to classification units.

3.7 The Soil Series.

3.7.1 Introduction.

The "soil series" was originally introduced by the U.S. Soil Survey before knowledge and acceptance of Dokuchaiev's genetic ideas had taken root in that country. In 1898, under the direction of founding director Whitney, the U.S. Soil Survey had commenced mapping soils in terms of textural classes called "soil types". The soil type was defined according to the texture of an arbitrary "soil section", either 3 feet or 6 feet deep. The soil series was then introduced in 1903 as a grouping of all soil types of similar provenance.

Glinka introduced Dokuchaiev's genetic ideas to Europe through publication of his book 'Die Typen der Bodenbilding' in 1914. This book was translated by Marbut in the U.S. in 1921 and the Russian genetic ideas were applied to develop an entirely new genetic concept of the soil series. Marbut advocated the grouping of soils on characteristics that were tangible, determinable by a study of the profile, direct observation and experiment. He succeeded in changing the concept of the soil in the U.S. from that of weathered rock material to that of an independent natural body.

3.7.2 Definition.

The Marbut (1921) soil series criteria state that in order to belong to a given soil series, soils must be essentially alike with respect to:-

- the number of horizons
- the sequence of horizons (order within the profile)
- the thickness of horizons
- the colour of horizons
- the texture of horizons (except the topsoil)
- the structure of horizons
- the chemical composition of horizons
- the geology of the parent material.

G.W. Robinson (1949) added the further requirement that soils should be formed "under similar conditions of development" (i.e. under a similar set of soil forming factors).

Simonson (1968) echoes this in defining soil series as "classes of soils with limited ranges in morphology and composition and with the same history of horizon differentiation". The current New Zealand definition (Palmer et al., 1981) updates the soil series criteria by giving due recognition to the inherent soil climate as follows:

"a soil series is a grouping of soils which have similar profiles, similar temperature and moisture regimes and are derived from the same or similar parent materials."

The soil series is used in the Soil Survey of England and Wales and is the lowest grouping in their natural classification. It denotes, however, a profile class with particular lithological characteristics within a broader grouping based primarily on character and arrangement of horizons. The main criteria for differentiating soil series within subgroups of mineral soils are:

- the dominant particle size class between specified depth limits, normally the upper 80 cm
- the presence and nature of texturally contrasting layers
- the origin of the parent material
- the mineralogy or related characteristics of the soil material. (Avery, 1973).

This concept of a soil series may be considered as something of a throwback to the initial U.S. Soil Survey's pre-genetic definition of 1903.

3.7.3 Discussion.

The soil series grouping used in the United States and New Zealand is an abstract conceptual unit, the lowest category in the classification system (pedogenic legend as distinct from physiographic legend).

Soil series are not defined on a narrow range of all properties. Emphasis is given to genetic horizons and these tend to provide classes with limited ranges of main properties. The differentiae used must be observable or capable of being inferred with reasonable assurance and have some significance to the nature and degree of expression of horizons (Simonson, 1964). The same author asserts that every polypedon belonging to a particular soil series is essentially uniform below the depth of ploughing in differentiating characteristics and arrangement of genetic horizons. Greater variability is permitted in the properties of surface horizons than in deeper ones, it being acknowledged that that part of the soil below the depth of ploughing is less readily subject to change.

A weakness of the Marbut and related criteria is that they do not specify precisely how alike or similar soils must be in order to belong to a particular soil series.

Soil Taxonomy (Soil Survey Staff, 1975) attempts to overcome this deficiency by carefully defining the range of variability allowable in soil properties at the series level. Certainly this range must fall within that permitted for the soil family, the next category up in the classification system. However at both family and series level emphasis is placed on inherent, observable properties likely "to influence use and behaviour". While emphasis on such properties is understandable in soil categories likely to be of greatest use at the local level, the prior selection of utilitarian properties to the possible exclusion of others, tends to make the soil series less natural and divorce it to that extent from the higher categories above the family in the system.

3.8 The Soil Survey.

3.8.1 Introduction.

Soil survey can make a fundamental contribution to our understanding of the origin and development of soils and of the relationships that exist between different kinds of soils. In addition it provides an essential link in the practical application of scientific knowledge to agricultural, horticultural, forestry and other technological uses of the soil. However, despite its importance, it has yet to develop a completely sound theoretical and procedural framework. In consequence soil surveys tend to be carried out in a very practical and somewhat idiosynchratic manner.

As Butler (1980) has it, the soil surveyor stands in the midst of his problem. He must take up and manipulate those concepts that are attuned to the purpose of the survey and the landscape for which they are intended. He is concerned to classify and map real things, defined in terms of classes for the ranges of soil properties that exist.

The success of a given survey may be assessed on the extent to which the variability of soil properties within mapping units is less than the variability between mapping units (Beckett and Burrough, 1971). Several parameters have been used to measure the degree of success achieved (Webster and Beckett, 1968). Application of these parameters will permit more accurate statements on soil properties and potential use than has previously been the case and thus "...assist the land user to maximize returns and minimize risks by adopting land management or land use policy to local soil conditions." (Bie and Beckett, 1971).

3.8.2 Types of Soil Survey.

In keeping with the distinction between natural and technical soil classifications made earlier (3.4.2) soil surveys tend to fall into two main categories, what Beckett and Burrough (1971) have termed "general purpose" (or "unfocussed") soil surveys on the one hand, and "single property" (or "focussed") on the other.

General purpose soil surveys are part of a general stocktaking of a natural resource and should be designed as far as possible to provide for all foreseeable land uses. Most soil surveys produced are of this kind as these can provide an information base from which information for many interpretive purposes may be derived.

By contrast single property soil surveys are designed to resolve some problem in relation to a specific land use. In such surveys the soil classes are defined on specific ranges of one, or a small number of properties. The class limits are plotted on a map as "isolines" and the map's capacity to predict soil conditions between these depends on the variance of the soil in the specified property (or properties).

The soil survey of Tuapaka hill block falls within the general purpose category, as this preserves the greatest predictive value for a variety of land uses and enables the soil classes to be erected within a natural classification system.

3.8.3 'Orderliness' and 'Pedogenic Noise'.

A classification and mapping exercise has an implicit assumption of 'orderliness' in the soil population and a low level of 'pedogenic noise'. Butler (1980) sums up the assumption of 'orderliness' as follows:

a) The individual soil entities belonging to each class are more or less continuous, giving rise to a run of soil, so that most classes can be mapped in mapping units that are coherent and not too impure.
b) A reasonable proportion of the boundaries to be drawn possess external expression to guide their delineation.
c) The definitive properties of the classes are either themselves relevant to land uses being considered or else are associated with useful or relevant properties.
d) The relevant properties are in fact relevant and between them account for most of the management problems that give rise to the survey.

'Pedogenic noise' refers to the amount of disorder in the soil system. It thus operates against the concept of 'orderliness'. It is argued that the permanent soil characteristics in any organized natural body of soil, including its specific system of layers and horizons, result from the interaction of the processes of pedogenesis and geogenesis, where geogenesis refers to processes giving rise to the specific distribution of parent material within the total system. Pedogenesis superimposes its marks on the products of geogenesis to create the organised natural body of soil. It is implicit in the concept of orderliness that there are runs of soil without high incidences of significant short-range horizontal or vertical variations in parent materials due to variations in the processes of geogenesis. In addition geomorphic processes associated with the erosional history of an area may remove, obscure or disorder the organised natural bodies formed by pedogenesis. Significant short-range horizontal and vertical variations in parent materials due to geogenesis or interference with organised natural bodies of soil by geomorphic processes will generate 'pedogenic noise' and mitigate against 'orderliness' in the soil continuum. This will create problems in classification and mapping of the survey area.

A model has been proposed by Butler (1982) that provides a basis for formulation of hypotheses on the development and nature of soils and sediments in local landscapes subject to geomorphic and geogenetic processes. It is based on the concept of soil mantle or 'pedoderm' development on the surface of unconsolidated sedimentary bodies in the landscape through a diverse and intermittent history of events referred to as 'K cycles'. Each successive K cycle produces a pedoderm which is subject to stripping, truncation and burial by either of several sedimentary processes and soil development proceeds within these restraints. The model thus utilizes the measure of order finally prevailing in the soil mantle.

3.8.4 The Profile Class.

The soil surveyor faces a dilemma if he attempts at the beginning of his endeavours to fit his sampling units of local soils into an established regional or national system at the soil series level. As soil series are conceptual units designed to accommodate soils from a wide area, they may not satisfactorily fit local modes and survey requirements, (as specified in 3.8.1). Furthermore, studies have indicated that in detailed mapping a ceiling to the utility of series maps is achieved at map scales of 1:20,000 - 1:25,000, due to the imprecision of the series category (Beckett & Burrough, 1971).

The surveyor may instead adopt an empirical approach and examine the full range of soils in the survey area, from which he can formulate a gallery of profile classes which condense his full experience in the most comprehensive way (Butler, 1980).

The concept of profile form has been used by Northcote (1979) to express the overall visual impact of the physical soil properties in their intimate association with each other and within the framework of the solum. The profile is regarded as a physical system with physical properties capable of observation and recording. These may carry along other features and properties, physical, chemical or biological.

Using this concept pedons may be grouped through similarities in classification differentiae to erect profile classes. The profile class is then a many-faceted abstraction expressed by a central concept which specifies particular diagnostic features and properties common to the class. The uniformity of a soil property within a profile class is adequately measured by its variance. Beckett and Webster (1971) present medians of published values of variance of soil properties within profile classes or mapping units, defined or mapped according to accepted canons of soil survey. A profile class cannot be more uniform than its definition allows and actual profile classes will be less uniform than this to the extent that their definition and sampling have been less than perfect (Bie and Beckett, 1971).

The principal criteria of success for a local classification is that it should provide a list of profile classes that are complete and stable, producing satisfactory polypedons for use in soil mapping (see 3.6.3). The profile classes generated must provide groupings that match the visible discontinuities of the landscape and soil class boundaries should where possible match landscape boundaries.

Representative pedons selected for each profile class may be subjected to laboratory analysis for chemical and physical characteristics considered relevant. These results may be extrapolated in some measure to the class as a whole to provide a more comprehensive characterization of the profile class.

3.8.5 The Selection of Differentiae.

The differentiae used to characterize the organized natural bodies in the field are primarily morphological and may be selected for example from the range contained in the formalized soil descriptions of the U.S. Soil Survey Manual (Soil Survey Staff, 1951) and the N.Z. Soil Survey Method (N.Z. Soil Bureau, 1962). Pedogenic phenomena which have a high frequency in the survey area and consequently are important will strongly influence the character and selection of differentiae. Experience may allow the choice of more useful and selective criteria that make profile class definitions mutually exclusive.

Differentiae selected will record the morphological properties of the pedon and should be measurable as this reduces the subjective element and improves definition of profile classes. Detailed profile drawings and site descriptions should be included with each profile description as an aid to classification and soil boundary delineation.

In a limited area profile classes may be identified on less than the full range of properties. The properties used in these cases are "keying properties" and may be selected to separate members of a class from those of all other classes (Butler, 1980). The keying property or properties should be unambiguous and uniquely associated with other definite and useful characteristics.

3.8.6 The Soil Map.

The soil inventory of the survey area is represented pictorially in the form of a soil map. The soil and landscape are divided up into a number of mapping units each containing a consistent pattern of soils. The soil map thus provides information on the distribution of the different kinds of soils in the area.

Bie and Beckett (1971) insist that the quality of a soil map depends on its utility for practical purposes and that it should be judged by this standard. A map's utility depends on how accurately it predicts the kind of soil occurring at any point in the survey area and also upon how well properties of interest to land use are correlated with the properties used to define profile classes (Beckett and Bie, 1976).

The soil map cannot predict the profile class at a particular site more confidently than the definitions of its mapping units will allow. In practice it will do worse than this to the extent that mapping units of necessity contain "impurities" and the "aids" for the recognition of any particular soil are less than perfect.

3.8.7 Scale of the Soil Map.

The scale of mapping used is determined by the objectives of the survey and the predictive power required for the soil map. These two factors are closely interrelated.

In New Zealand soil maps have been produced on many different scales. In 1948, N.H. Taylor published the first soil map covering the country as a whole on a scale of 1:2,000,000, It was based unashamedly on genetic principles, the units of mapping and classification employed being soil groups. Later, maps covering both North and South Islands on a scale of 1:1,000,000 were published (N.Z. Soil Bureau, 1968a). For many years the most comprehensive source of information on the soils of the North Island was that contained in the Soil Bureau Bulletin 5, "General Survey of the Soils of the North Island, New Zealand", on a scale of 1:253,440 (N.Z. Soil Bureau, 1954). This was later matched by a similar volume, with maps on the same scale, for the South Island - Soil Bureau Bulletin 27 (N.Z. Soil Bureau, 1968b). Both these surveys utilised a mapping unit peculiar to New Zealand, the soil set. The soil set comprised a rather loose bundle of soil types, named after the principal soil type, as the soil type was then understood.

A more detailed map of the soils of the Downs and Plains, Canterbury and North Otago, New Zealand, on a scale of 1:126,720 was published in 1967, using the soil type as mapping unit (Kear et al, 1967). Over the years a useful range of maps covering individual counties has been produced on a scale of 1:63,360, notable local examples being Soil Bureau Bulletin 33, "Soils and Agriculture of Kairanga County" (Cowie, 1978), and N.Z. Soil Survey Report 30, "Soils of Manawatu

County, North Island, New Zealand" (Cowie and Rijkse, 1977), again using the soil type as mapping unit. Some important areas, employing a refined version of the same mapping unit, have been mapped at a scale of 1:15,840, an outstanding example being Soil Bureau Bulletin 20, "Soils and Agriculture of Gisborne Plains" (Pullar, 1962).

The first detailed soil map using the metric scale of 1:50,000 was that of Palmer et al (1981) for Egmont County. Mapping units used were the soil series and soil association. The first authentic use of the soil association under New Zealand conditions had been made earlier by Cowie et al (1967) in Soil Bureau Bulletin 29, "Soils of the Manawatu-Rangitikei Sand Country". A limited number of very detailed soil surveys of experimental areas have been made at scales ranging from 1:10,000 to 1:3000.

In general terms maps at a scale of 1:253,440 and above fall into the reconnaisance category, while those of scales of 1:126,720 and below are classed as detailed soil maps. Detailed soil maps enable the soil pattern to be seen in relation to individual farm boundaries.

The mapping scale employed exercises control over the degree of simplification of the soil continuum represented on the soil maps and the kind of mapping unit employed. As the scale of mapping is increased, so smaller areas of soil are able to be represented on mapping sheets and the "purer" the mapping units become. Likewise the predictive power of the map as discussed earlier (3.8.6) is increased. There is, however, a cartographic limitation on the delineation of mapping units which determines that the smallest plan area that can effectively be shown on a map is about 5 mm x 5 mm (25 mm^2) (Buringh et al, 1962).

3.8.8 Choice of Sampling Sites.

Prediction of soil conditions can be no better than the sampling procedures employed (Ragg and Henderson, 1980). Sampling sites may be chosen by free traversing of the landscape or by the use of a square grid system. The free method is superior where soil boundaries have fairly clear external expression and definitely superior at smaller scales of mapping. At larger scales, grid and free survey are nearly comparable (Beckett and Burrough, 1971).

In the free method of site selection, the choice of sampling sites is not random but deliberate and systematic, guided by the disposition and internal topographic character of the landscape bodies. Profile sites are selected within 'landscape bodies' to sample the variation in soil pattern associated with changes in relief and drainage characteristics.

Transects parallel or at right-angles to slope have been employed within the free method of site selection. Transects parallel to slope have been employed where there are no conspicuous micro relief differences and where there was no substantial change in macro relief. Transects at right-angles to slope have been employed where there have been macro and micro relief features of potential influence on soil conditions (Ball and Williams, 1968).

In all cases the surveyor works from higher to lower parts of the landscape allowing the soil pattern to unfold before him. This allows him to build up models of the soil landscape patterns in his immediate locality and to make predictions which he will test later by visiting adjacent areas (Cutler, 1977). The minimum spacing of soil observations during mapping is achieved to the degree that soil differences are associated to external landscape differences and the surveyor will need to sample more sites where variability is greater in order to achieve similar levels of precision in his estimates (Ragg and Henderson, 1980).

The grid method superimposes a square grid with the desired number of sampling sites onto a map of the survey area, as an organized grid of random origin. The random sites located by the intersection of the grid lines on the map are located and sampled. Boundaries on grid maps may be drawn midway between grid points for profiles of different profile classes (Beckett and Burrough, 1971) or may be located as outlined in 3.8.9.

3.8.9 Soil Boundary Delineation.

It has been observed that soil classification and mapping units must fit the landscape. This idea was formulated in the Netherlands into a physiographic approach to mapping (de Bakker, 1970). In this the grouping of soils into mapping units is derived directly from the features of the landscape and the classification scheme devised must provide satisfactory polypedons for this purpose. The surveyor therefore delineates his mapping units where possible on observed discontinuities in the landscape. We may also include surficial materials and soil water regimes in boundary delineation. This is a requirement of 'orderliness' in the soil continuum.

However there are many instances where changes in soil forming factors are obscured making delineation difficult. The absence of external expression of soil boundaries can result in 'inclusions' of different soils within mapping units, dependent on mapping scale. Ease of recognition of mapping units and reliability of soil boundaries go together (Ragg and Henderson, 1980). The drawing of a soil boundary in an area where there are no landscape discontinuities and where soil properties are integrading between profile classes can be carried out by augering for 'keying properties' and extrapolated between bores. Boundaries for mapping units using a grid system of sampling site selection may be drawn midway between sampling sites for profiles of different profile classes (Beckett and Burrough, 1971). However such a grid system would be impracticable on a broken terrain such as the Tuapaka hill block.

3.8.10 Soil Mapping Units.

Polypedons are the basic units grouped to construct mapping units. Mapping units accommodate the existing distribution of polypedons in the landscape and are defined by Schelling (1970) as delineated soil bodies. Mapping units represent real entities, actual areas of ground defined in terms of one or more taxonomic units together with inclusions of possible other classes (Simonson, 1968). Mapping units are named after the profile class or soil series names of the dominant constituent polypedon or polypedons.

Mapping units may be simple or complex. The simple mapping unit approaches the ideal of a pure mapping unit defined in terms of polypedons representing a single profile class or soil series only. However, if only because of the problem of scale, it is inevitable that minor inclusions of other profile classes will be present as impurities. Whenever possible the impurities are named and their amounts and distribution are specified in the text accompanying the map.

Complex mapping units are more heterogeneous than simple mapping units and contain an intricate pattern of polypedons belonging to two or more profile classes which either cannot be mapped separately at the scale of mapping used or which are not because of the excessive demand on resources required to separate them. Such complexes are named after the two principal profile classes or soil series present, the most extensive being cited first.

Of the two mapping units commonly employed to accommodate this situation, the soil complex leaves the two or more constituent profile classes unresolved in terms of distribution, whereas the soil association (Ellis, 1932; Cowie et al, 1967; Palmer et al, 1981) relates their distribution in a repetitive and predictable way to drainage as determined by relief.

3.8.11 Purity of Mapping Units.

The concept of purity in mapping units is related to the ratio of alike to unlike constituent polypedons. The purity of mapping units possible in constructing any soil map will depend on three factors:

a) the scale of mapping and related intensity of sampling,
b) the degree of variation in soil properties under the influence of variations in state factors,
c) the incidence and degree of disruption to orderliness in the soil continuum through geogenetic and geomorphic processes.

Purities achieved are highest where the soil bodies mapped are most coherent (Beckett and Burrough, 1971). Variation within mapping units ultimately determines a map's utility, since lack of purity reduces the predictive power of the map and is related to poor correlation between mapping units and plant response.

Bie and Beckett (1971) have tabulated a set of aids to prediction within impure mapping units that can be included in a soil survey memoir for map users.

3.8.12 The Map Legend.

The map legend is an explanatory tabulation that goes with the soil survey. In New Zealand it has become customary to provide two soil legends, one physiographic and the other pedological or taxonomic. In the former the soils are arranged in terms of their occurrence in the landscape so that particular soils can be related to particular landscape forms, eg. soils of the terraces, soils of laharic terrain and so on. In the pedological legend the soils are placed within a definite taxonomic system so that interrelationships between them and predictions about their properties and behaviour can be made with confidence.

3.8.13 The Memoir.

It has been customary for the soil map to be accompanied by a memoir. The memoir fills out the soil map by stating the objects and methodology of the survey, giving an account of the soil forming factors and processes at work in the survey area, providing essential physical, chemical and mineralogical analyses and commenting on land-use potential, erosion and other practical matters. In New Zealand such memoirs have been given the title of Soil Bureau Bulletins and given a number, eg. Soil Bureau Bulletin 33, "Soils and Agriculture of Kairanga County."

The production of such bulletins is time-consuming and in order to make soil survey information available more quickly, recourse has been made in this country in recent years to the production of a series of Soil Survey Reports, eg. N.Z. Soil Survey Report 30, "Soils of Manawatu County, North Island, New Zealand." Such reports carry the completed map and map legends. In addition an extended legend is provided which summarises for each soil class the relevant soil forming factors, typifying profile description, carrying capacity and land use potential, "natural" nutrient status and response to fertilizers and lime, and susceptibility to erosion. The extended legend is thus a very valuable shorthand version of information that would otherwise be elaborated upon in the memoir or bulletin.

CHAPTER 4. METHODOLOGY OF THE SOIL SURVEY.

4.1 Scope of the Survey.

The study was concerned to classify and map the soil pattern on the rolling northwest tending slopes of the Tararua Range within the Hill Block of the Tuapaka farm. The survey excluded consideration of soils in the gully systems of the survey area. These had for the most part steepland soils of limited value to production.

The objectives of the study prescribed the design of an appropriate large-scale soil survey. The soil information derived from the survey was to be used in formulating a specifically local soil classification and a soil map of high predictive power. The complexity of the soil pattern and landscape encountered demanded high survey effort using survey techniques specially adapted to local hill country conditions.

4.2 Choice of Scale.

The scale chosen for the mapping exercise had to be apposite to the predictive power demanded by the objectives of the study and commensurate with the intensity of sampling envisaged in the execution of the survey. Furthermore it was required to accommodate the farm area on a map sheet of convenient and manageable proportions. In specific terms, the scale selected had to be capable of representing soil variations within 3 ha management units and of providing specific soil information for siting edaphic trial plots for research purposes.

A scale map that would permit such predictive power required a mapping scale capable of representing the local soil continuum in simple, single stage mapping units or compound mapping units supplemented by clear and consistent aids for elucidating the components of the compound units.

The mapping scale of 1:5000 was selected as meeting survey specifications and it permitted the farm area to be represented on a map sheet of dimensions 75 cm x 60 cm.

4.3 Preliminary Site Investigations.

A stereoscopic examination of the area was carried out using a mirror stereoscope and black-and-white panchromatic stereo photographs and a reconnaissance survey of the Hill Block was undertaken on foot. This was done with a view to interpreting the landscape and identifying 'landscape units' with associated 'soil landscape bodies', to permit planned, selective sampling of the survey area and soil boundary delineation.

Familiarity with the topography gained by these exercises established areas of identifiable 'landscape bodies' and 'soil landscape units' in the survey area. These areas were, however, limited in extent and the investigation did not permit explicit definition of coherent landscape bodies over considerable areas of the Hill Block. The dissevering effect on the topography of the deeply-incised gulleys and the fragmenting effect of lesser surface drainage channels hindered recognition of a coherent topographic pattern.

In summary, irregularities in topography belied any simple recognition and delineation of 'soil landscape bodies'. The 'Physiographic Approach' to mapping was not considered operative in these circumstances.

4.4 The Base Map.

4.4.1 General.

Experience gained through encounter with the survey area during the reconnaissance survey made clear the need for a large-scale base map for use in the planning and execution of the soil survey.

A base map at a scale of approx. 1:5000 depicting paddock boundaries in relation to relief and drainage was produced. This permitted the planned selection of sampling sites and their precise location in the field.

It was used to record actual sampling site positions together with information gathered on incidence of erosion, slopes and stratigraphy in the survey area. The use of a base map at this scale also facilitated soil boundary delineation, interpretation of the soil-landscape and allowed direct transference of information to the final soil map.

4.4.2 Preparation of Base Map.

The base map was prepared using a stereo air photograph of the farm and the 1:25,000 scale topographic map, ref. NZMS 270, Sheet No. T24A, which included the Tua Paka property. The latter, on the new metric grid, was obtained by courtesy of Lands and Survey Department, Wellington. It displayed a contour interval of 20 m.

The stereo air photograph was enlarged photographically by New Zealand Aerial Mapping, Hastings, to a scale of approx. 1:5000 and the farm perimeter boundaries, internal paddock boundaries, drainage systems and access roads were traced from it onto a separate map sheet.

The area of the farm on the 1:25,000 topographic map was photographed and enlarged to a scale of approx. 1:5000 by New Zealand Aerial Mapping. The enlarged negative obtained displayed the contours at 20 m intervals together with spot heights, paddock boundaries and the main drainage systems. In like manner these features were traced onto another map sheet.

The two tracings obtained were superimposed one on the other and the final base map containing all above-mentioned material was drawn. This last operation required great care in matching up paddock boundaries and drainage channels on each of the sheets. A copy of the base map produced is contained in the pocket at the back of this thesis.

4.4.3 Accuracy of Base Map.

A base map constructed in this manner was used to record sampling sites in the survey area, together with information on erosion and stratigraphy. An equivalent map with paddock boundaries removed so as to more clearly reveal the landscape pattern was used for the initial selection of sampling sites.

It was recognized that the base maps produced were subject to inaccuracies. The photographic enlargement process resulted in some areal distortion of the survey area. It also resulted in thickening of the contours on the negative of the topographic map used. In this case the contours on the final base map were drawn in carefully with a fine pen along the mid-position of the thick contour lines of the photographic enlargement.

The accuracy of the base map was examined in various ways. The position of paddock boundaries in relation to topographic features such as interfluves were observed in the field and compared with the position depicted on the base map. The position of spot heights in the field were compared with their positions on the base map. In addition a scaled topographic map was obtained that depicted a major catchment in the Hill Block (Sheet Reference No. N.Z. A.M. 401/1). This map had been prepared by N.Z. Aerial Mapping for a previous hydrological and sedimentation study (Bargh, 1976). It accurately represented the relative positions of paddock boundaries, drainage channels, contour heights and an access road within the catchment. The relative positions of these features were measured and compared with the positions of the same features on the base map.

The results of these checks established that the base map was sufficiently accurate and suitable for the purposes of planning and execution of the survey.

4.5 Sampling Sites.

4.5.1 Method of Sampling Site Selection.

The areas of gently rolling topography to be mapped remained subsequent to dissection of the Hill Block by gully channels. These areas were depicted by the contour lines across the base map as a succession of spur-shaped configurations with the characteristic bending of contour lines downslope.

A first step in the selection of sampling sites was the linking up of the 'toes' of these spur-shaped configurations at each elevation. They were linked across the base map by lines that may be defined as 'generalized contour lines' or 'isolines' at each 20 m of elevation. These 'isolines' simplified the contour of the survey area by eliminating the distractive effect of gully channels and represented the relief as it would have been in the absence of dissection.

Sampling sites were selected and positioned along these 'isolines' where they coincided with the spur-shaped configurations on the base map.

These sampling sites were later supplemented by additional sites, considered necessary through encounter on the ground with local topographic variations.

A copy of the base map with 'isolines' drawn, as described above, is contained in the pocket at the back of this thesis.

4.5.2 Discussion.

The procedure of sampling site selection adopted may be viewed as a modified grid system supplemented by limited free survey. It accommodated the topographic reality of the survey area, by utilizing the coherent topographic pattern where it existed while at the same time coping with local irregularities in the landscape.

It enabled intensive sampling of the plateau and interfluve areas that are of greatest significance to production. It allowed examination of interfluves along a transect where local disturbance of the soil cover had not occurred. Familiarity with details of local terrain gained during its implementation permitted free survey of selected sites in areas of topographic complexity. The procedure permitted an altitudinal control of sampling that was very important in detecting subtle changes in soil conditions with elevation.

Thorough sampling of the survey area was accomplished through the inspection of seventy-four sampling sites. Sixty-six of these were selected through the modified grid system outlined above; these were supplemented by a further eight chosen by free sampling. Additional sampling sites of soils classed as Halcombe hill soils were inspected but these are not included in this study.

4.6 Recording the Soil Information.

Profile pits were dug at each of the sampling sites selected and information derived from them was recorded using provisional profile description forms obtained from the Soil Bureau and a field notebook. The forms were used to record standard soil site and profile data while a field sketch, notes on unusual site conditions, the extent and kind of erosion and stratigraphic observations were recorded in the field notebook.

A 35 mm colour photograph was taken of each profile. Photographs were also taken of significant landscape features observed during field work. Tests for the presence of allophane were carried out for all horizons of all profiles using 1 mol NaF and phenolphthalein papers (Fieldesand Perrott, 1966).

Later the photographs of the soil profiles and the field data were transcribed onto permanent cards specially designed to facilitate profile appraisal and classification.

The completed cards provide a soil inventory of the survey area. A simple reference system was devised that allowed easy matching of each card in the soil inventory with its sampling site on the base map. Two reference numbers separated by a slash were used. The first number referred to the paddock as numbered on the base map. The second number referred to the sampling site. Thus, for example, the profile card reference number 7/67 referred to sampling site number 67, located in paddock 7.

The FAO/UNESCO nomenclature for soil horizon designations was used and soil colours were expressed using Munsell Colour Charts. Northcote's (1979) Value/Chroma rating groups, for use with Munsell Colour Charts were used in the text.

4.7 The Soil Map.

The soil map was drawn on a print obtained from a 1:5000 photographic negative of the Tua Paka farm obtained from N.Z. Aerial Mapping. This negative had been enlarged with a minimum of areal distortion. The production of a distortion-free photographic negative required the provision of accurate point-to-point measurements on the ground at an appropriate series of altitudes on the Hill Block. These measurements were obtained at altitudes 120 m, 220 m and 300 m using a Citation C.I. 450 Reducing Infrared distancer. Assistance from the Aokautere Science Centre (MWD) with these measurements is gratefully acknowledged. The positions of measurement pairs and their distances apart at each altitude were carefully marked on the standard stereo air photograph covering the farm. This was forwarded to N.Z. Aerial Mapping and the enlargement satisfactorily produced.

The prints obtained using this negative clearly displayed detailed topographic and drainage features in the survey area and enabled mapping units to be delineated with precision.

CHAPTER 5. RESULTS OF STUDY.

5.1 Local Soil Classification.

5.1.1 Introduction.

A natural classification of the soils of the study area was erected by grouping the profile descriptions obtained during the course of the soil survey. Profile Classes were erected that had a central concept of diagnostic features and properties common to their class. Further groupings of Profile Classes gave six Profile Groups. The criteria used to group Profile Classes into Profile Groups were selected to demonstrate meaningful relationships between Profile Classes and have been specified in each case.

In the spirit of Northcote's "Profile Form" (Northcote, 1979) concept, the initial Profile Class groupings were made on the overall visual impact of readily discernable features, supplemented by specific properties easily assessed in the field.

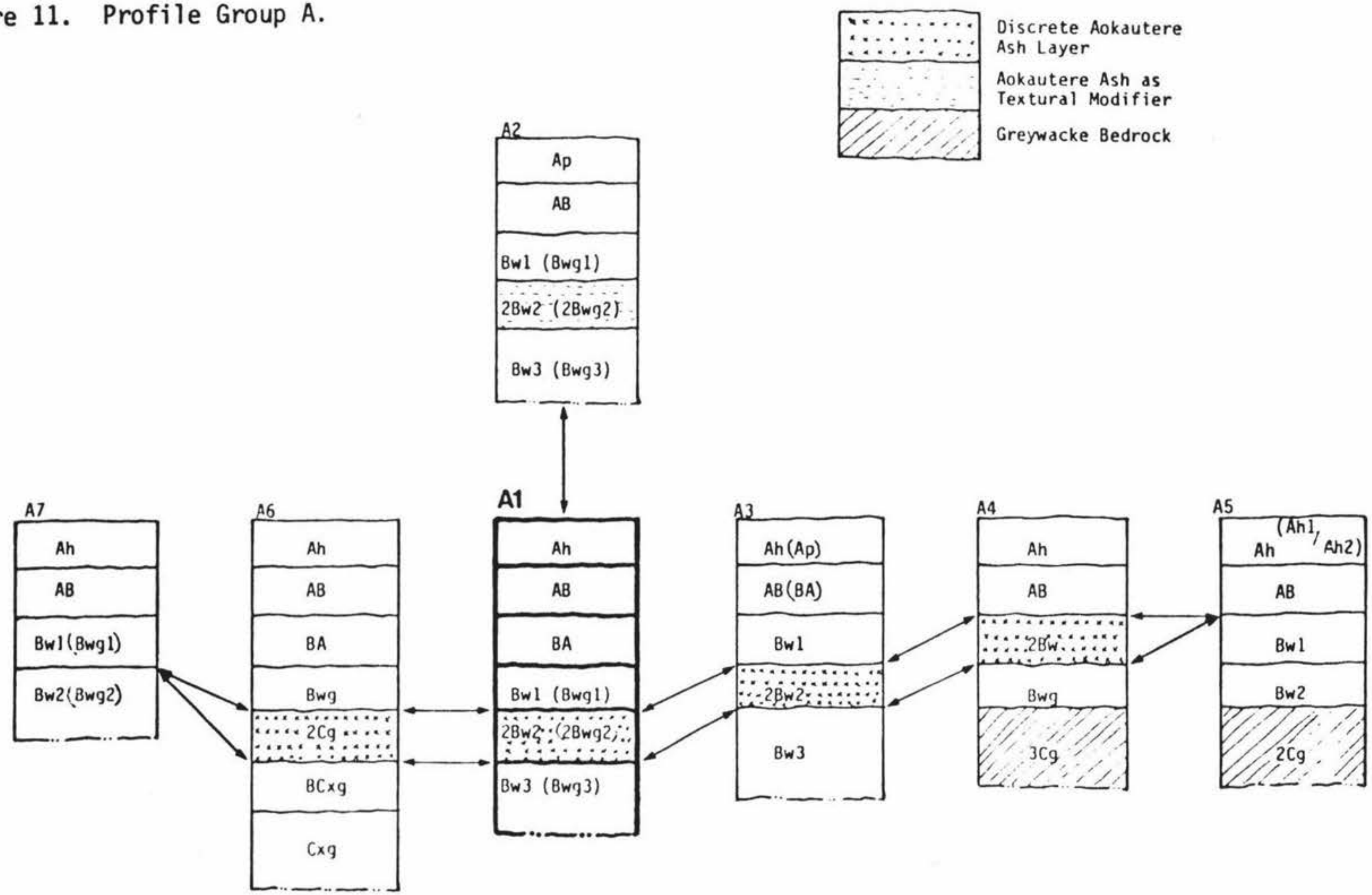
5.1.2 Profile Group A - Introduction.

Profile Group A contains 7 Profile Classes with many diagnostic features held in common, but differentiated by important morphological variations. These are occasioned by the presence and nature of the Aokautere Ash layer and variations in the depth of the loess cap over greywacke bedrock. The morphological variations and the relationship between Profile Classes in Profile Group A are illustrated in Fig. 11.

5.1.3 Diagnostic Features for Profile Group A.

1. Soils of this Profile Group are formed out of loess with possible admixtures of andesitic and rhyolitic ash.
2. The soil matrix has the characteristic feel of an allophane rich clay. Samples treated with sodium fluoride (1 mol) on phenolphthalein papers gave positive reactions of varying strengths between horizons of all profiles in the Profile Group.
3. Textures change down the profiles from silt loams in the upper 40 cm of the profile to silty clay loams in the subsoils.
4. Topsoils generally have a very distinctive fine and medium nutty breaking to fine crumb structure in the upper 40 cm of the profile, overlying a blocky structured subsoil that becomes more massive with depth.
5. Transitional horizons from topsoils to subsoils are marked by worm mixing and dark worm casts in a lighter matrix and are a noted common feature in these zones.
6. Horizon colours show trends of increasing values and falling chromas down the profile.
7. There is evidence of mobilization of iron down the profile and the subsoils contain pinhead or small hard iron concretions, together with incipient placic horizons in some instances. Concretions, incipient placic horizons and mottling are associated with increasing impedance to drainage from increasingly massive subsoils.
8. Mottling, although variable in its occurrence, is not a

Figure 11. Profile Group A.



prominent morphological feature.

9. Cutans are often a feature on the blocky peds in the subsoil and in fine, relict root channels.

10. There is considerable textural variation in horizons containing the Aokautere Ash. In many instances the texture of the Aokautere Ash layer grades from sandy loam at the base of the horizon to silty clay loam at the upper boundary with the overlying horizon. In some cases Aokautere Ash is detected only as a textural modifier in a silty clay loam matrix and in other locations it is entirely absent.

5.1.3.1 Profile Class A1.

Diagnostic Features:

1. The soil has the general diagnostic features for the Profile Group but is differentiated by a discrete Aokautere Ash layer in the lower soil profile at > 80 cm.

2. The characteristic horizon sequence is as follows:-
   O (Turf mat present in some cases)
   Ap (or Ah)
   AB
   BA
   Bw1 (possibly Bwg1)
   2Bw2 (Aokautere Ash, possibly 2Bwg2)
   Bw3 (possibly Bwg3).

3. The soil has a possible turf mat of organic matter.

4. The Ah (Ap) topsoil is underlain by two deep transitional AB and BA horizons, differentiated by colour and the degree or worm mixing exhibited.

5. The subsoil has two Bw (or Bwg) horizons (Bw1 and Bw3 or Bwg1 and Bwg3 respectively) with a discrete interbedded 2Bw2 (or 2Bwg2) Aokautere Ash layer. In some instances the Bw horizon above the ash is considered to have differentiated into two distinct Bw horizons.

6. Site conditions have resulted in seasonal waterlogging in some cases, causing mottling of the subsoil in these locations and Bwg horizon designations are appropriate in these circumstances.

7. Texturally the 2Bw2 Aokautere Ash horizon grades from sandy loam at its base to silty clay loam in the overlying Bw1 (or Bwg) horizon.

Profile 18 is nominated as typical of Profile Class A1 and is shown in Fig. 12. The full pedological description of the A1 Taxonomic Unit is given in Appendix 1.

Figure 12. Profile Class A1 (Profile 65/18).

Site slope: 12^{o}. Elevation: approx. 300 m.
Topography: undulating crest of sloping interfluve.
Drainage: Well drained.

cm

O +9 - 0

Dark brown (10yr 3/4) silt loam; strongly developed medium and fine nutty structure; soft; profuse fine roots; distinct smooth boundary.

Ah 0 - 14

Brown (7.5yr 4/3) silt loam; strongly developed, medium and fine nutty structure; firm; abundant to many fine roots; indistinct, irregular boundary. NaF reaction positive.

AB 14 - 24

Brown (7.5yr 4/3) and yellowish-brown (10yr 5/6) silt loam; strongly developed medium and fine nutty structure; firm; many fine roots; horizon or worm mixing; indistinct, irregular boundary. NaF reaction positive.

BA 24 - 58

Dull yellowish-brown (10yr 5/4) going to dull brown (7.5yr 5/4) silty clay loam; fine, faint orange (7.5yr 6/6) and greyish-olive (5y 5/2, 6/2) mottles; moderately developed, very coarse breaking to coarse blocky structure; stiff; many fine roots; distinct smooth boundary. NaF reaction positive.

Bw1 58 - (74 to 86)

Dull yellowish-brown (10yr 5/4) to yellowish-brown (2.5y 5/4) silty clay loam; profuse, coarse, faint and distinct bright-brown (7.5yr 5/6) mottles; moderately developed, very coarse breaking to coarse blocky structure; very stiff; many to few fine roots; distinct smooth boundary.

2Bw2 (74 to 86) - (97 to 105)

Dull yellow (2.5y 6/4) sandy loam; moderately developed coarse blocky structure; very stiff; distinct, sharp boundary. NaF reaction positive.

Bw3 >(97 - 105)

Dull yellow (2.5y 6/4) silty clay loam; moderately developed medium blocky breaking to fine blocky structure. NaF reaction positive.

* Each black or white division on depth-measuring tape represents 10 cm.


18

5.1.3.2 Profile Class A2.

Diagnostic Features.

1. The soil has the general diagnostic features of the Profile Group but is differentiated by the presence of Aokautere Ash as a textural modifier in a lower silty clay loam horizon of the profile.

2. The characteristic horizon sequence is as follows:-
   Ap
   AB
   Bw1
   2Bw2 (possibly 2Bwg1)
   Bw3 (possibly Bwg2).

3. The Ap horizon is underlain by a transitional AB horizon that shows considerable mixing by worms.

4. The subsoil has Bw1 and Bw3 (or Bwg2) horizons with an interbedded 2Bw2 horizon of Aokautere Ash. The 2Bw2 (or 2Bwg1) horizon differs from that of Profile Class A1 as the ash is not present as a discrete morphological feature but is detected by manual textural assessment in the field and reaction to sodium fluoride tests.

5. Site conditions have resulted in seasonal waterlogging in some cases, causing mottling of the subsoil in these locations and Bwg horizon designations are appropriate in these circumstances.

Profile 3 is nominated as typical of Profile Class A2 and is shown in Fig. 13. The full pedological description of the A2 taxonomic unit is given in Appendix 2.

Figure 13. Profile Class A2 (Profile 64/3)

Site slope: 5^{o}. Elevation: approx. 320 m.
Topography: flat, gently rolling surface.
Drainage: Well drained.

cm

Ap 0 - 24

Dark brown (10yr 3/4) silt loam; moderately developed, medium nutty structure with fine crumb structure around roots; stiff; profuse-abundant fine roots; distinct, smooth boundary. NaF reaction positive.

AB 24 - 42

Brown (10yr 4/4) and dark brown (10yr 3/4) silt loam; moderately developed, coarse breaking to medium and fine nutty structure; very stiff; many fine roots and some old bush roots; horizon of worm mixing; distinct, smooth boundary. NaF reaction positive.

Bw1 42 - 62

Dull yellowish-brown (10yr 5/4) and some dark brown (10yr 3/3) silty clay loam; moderately developed coarse, breaking to medium and fine blocky structure. NaF reaction positive.

2Bw2 62 - 120

Dull yellow-orange (10yr 6/4) sandy clay loam; moderately developed coarse breaking to fine blocky structure, becoming more massive with depth; very stiff; few fine roots; distinct, smooth boundary. NaF reaction positive.

Bw3 >120.

Dull yellow-orange (10yr 6/4) silty clay loam; moderately developed coarse blocky structure; very stiff; old bush roots. NaF reaction positive.


3

5.1.3.3 Profile Class A3.

Diagnostic Features.

1. The soil has the general diagnostic features for the Profile Group but is differentiated by a discrete Aokautere Ash layer in the lower soil profile at < 80 cm.

2. The characteristic horizon sequence is as follows:-

   Ap (Ah)
   AB or BA
   Bw1
   2Bw2 (Aokautere Ash)
   Bw3.

3. The Ap (Ah) horizon of the soil is underlain by an AB or BA transitional horizon that shows mixing by worms. The degree of worm mixing determines the choice of AB or BA horizon designation.

4. The subsoil has Bw1 and Bw3 horizons with an interbedded 2Bw2 Aokautere Ash horizon.

5. The position of the Aokautere Ash layer higher in the profile than is the case for Profile Class A1 has resulted in a foreshortened upper profile, as compared with Profile Class A1.

Profile 9 is nominated as typical of Profile Class A3 and is shown in Fig. 14. The full pedological description of the A3 taxonomic unit is given in Appendix 3.

Figure 14. Profile Class A3 (Profile 64/9).

Slope: 0^{o}. Elevation: 300 m.
Topography: flat surface.
Drainage: well drained.

cm
Ap 0 - 18

Dull yellowish-brown (10yr 5/4) silt loam; strongly developed medium and fine nutty structure; very stiff; abundant to profuse fine roots; indistinct, smooth boundary. NaF reaction positive.

AB 18 - 40

Yellowish-brown (10yr 5/6) and brown (10yr 4/4) silt loam; strongly developed, medium nutty structure; very stiff; many fine roots; horizon of worm mixing; indistinct, smooth boundary. NaF reaction positive.

Bw1 40 - 66

Yellowish-brown (10yr 5/8) and bright yellowish-brown (10yr 6/8) silt loam; moderately developed coarse blocky breaking to fine crumb structure; stiff; many fine roots; indistinct, smooth boundary. NaF reaction positive.

2Bw2 66 - 80

Yellowish-brown (10yr 5/8) and bright yellowish-brown (10yr 6/8) sandy loam; massive to blocky structure; very stiff; distinct sharp boundary. NaF reaction positive.

Bw3

Dull yellow-orange (10yr 6/4) silty clay loam; massive structure; stiff; few fine roots, old bush roots. NaF reaction positive.

5.1.3.4 Profile Class A4.

Diagnostic Features.

1. The Profile Class has diagnostic features for the Profile Group but is differentiated by a discrete Aokautere Ash layer yet higher up in the soil profile and greywacke bedrock at the base of the profile pit at < 120 cm.

2. The characteristic horizon sequence is as follows:-

   Ah
   AB
   2Bw (Aokautere Ash)
   Bwg
   3Cg (weathering greywacke bedrock).

3. The Ah (Ap) horizon of the soil is underlain by a transitional AB horizon that shows considerable mixing by worms.

4. The 2Bw horizon of Aokautere Ash directly underlies the AB transition horizon. Thus a reduction in loess cover over Aokautere Ash has resulted in the elimination of the Bw horizon present above the Ash layer in Profile Class A2.

5. The subsoil has a Bwg horizon lying on weathering greywacke rock, designated as 3Cg horizon. The presence of greywacke bedrock at the base of the profile is considered to have caused impedence to drainage and seasonal waterlogging resulting in faint mottling in the Bwg horizon.

Profile 11 is nominated to represent Profile Class A4 and is shown in Fig. 15. The full pedological description of the profile is given in Appendix 4.

Figure 15. Profile Class A4 (Profile 60/11)

Site slope: 0^{0}. Elevation: approx. 320 m.
Topography: flat interfluve.
Drainage: moderately well drained.

cm

Ah 0 - 23

Dark brown (10yr 3/4) silt loam; moderately developed, fine and medium nutty structure; soft; abundant fine roots; distinct, wavy boundary. NaF reaction positive.

AB 23 - 39

Brown (10yr 4/6) and dark brown (10yr 3/4) silt loam; weakly developed medium crumb structure; stiff; abundant fine roots; horizon of worm mixing; diffuse, discontinuous boundary. NaF reaction positive.

2Bwl 39 - 66

Yellowish-brown (10yr 5/6) sandy clay loam, with patches of greyish-olive (7.5y 6/2); massive to coarse blocky structure; stiff; many fine roots; indistinct, discontinuous boundary. NaF reaction positive.

Bwg 66 - 106

Dull yellow-orange (10yr 7/3) silty clay loam; weakly developed, coarse blocky-polyhedral structure; stiff to very stiff; very few fine or no roots; NaF reaction positive.

3Cg >106

Weathering greywacke with a bright yellowish-brown (10yr 7/6) silty clay matrix; distinct, fine abundant yellow-orange (7.5yr 7/8) mottles in matrix.

5.1.3.5 Profile Class A5.

Diagnostic Features.

1. The soil has diagnostic features for the Profile Group and has greywacke bedrock at the base of the profile pit at < 120 cm. This Profile Class is differentiated from Profile Class A4 by the absence of Aokautere Ash from the profile.

2. The characteristic sequence of horizons is as follows:-

   Ah (or Ah1
   over Ah2)
   AB
   Bw1
   Bw2
   2Cg (weathering greywacke bedrock).

3. The Ah horizon is differentiated on matrix colour and structure into an Ah1 and Ah2 horizon. There is an underlying transitional AB horizon that shows considerable mixing by worms.

4. The subsoil is made up of Bw1 and Bw2 horizons overlying the 2Cg horizon of weathering greywacke bedrock.

5. The Aokautere Ash is not present as a discrete horizon or as a textural modifier.

Profile 16 is nominated to represent Profile Class A5 and is shown in Fig. 16. The full pedological description of the profile is given in Appendix 5.

Figure 16. Profile Class A5 (Profile 63/16).

Site slope: 0°. Elevation: approx. 340 m.
Topography: summit of flat-topped hillock.
Drainage: moderately well drained.

cm

Ah1 0 - 8

Dull yellowish-brown (10yr 4/3) silt loam; moderately developed, very fine nutty structure; firm; abundant fine roots; distinct, smooth boundary. NaF reaction negative.

Ah2 8 - 22

Dull yellowish-brown (10yr 5/4) silt loam; moderately developed, fine and medium nutty structure; very stiff; abundant fine roots; distinct, smooth boundary. NaF reaction negative.

AB 22 - 38

Dull yellowish-brown (10yr 5/4) and yellowish-brown (10yr 5/6) silt loam; moderately developed, medium nutty structure; very stiff; abundant fine roots; distinct, smooth boundary. NaF reaction positive.

Bw1 38 - 60

Yellowish-brown (10yr 5/8) silty clay loam, many, coarse, faint reddish-brown (5yr 4/6) mottles; moderately developed, coarse blocky breaking to fine granular structure; very stiff; indistinct smooth boundary. NaF reaction positive.

Bw2 60 - 102

Yellowish-brown (10yr 5/8) silty clay loam; abundant, medium and coarse, faint reddish-brown (5yr 4/6), bright brown (7.5yr 5/6 & 5/8) mottles; moderately developed coarse blocky breaking to medium and fine crumb structure; very stiff; few fine roots; distinct, smooth boundary. NaF reaction negative.

2Cg >102

Weathering greywacke with yellowish-brown (10yr 5/8) silty clay matrix.


16

5.1.3.6 Profile Class A6.

Diagnostic Features.

1. This Profile Class has the diagnostic features for the Profile Group and a discrete Aokautere Ash layer. It is differentiated by a fragipan-like morphology below the Aokautere Ash layer.

2. The characteristic horizon sequence is as follows:-

   Ah
   AB
   BA
   Bwg
   2Cg (Aokautere Ash)
   BCxg }
   over } (fragipan-like morphology).
   Cxg }

3. The Ah horizon of the soil overlies transitional AB and BA horizon, differentiated by decreasing incidence of worm mixing, an increasing clay fraction and a change from medium to medium and coarse nutty structure with depth.

4. The subsoil has a Bwg horizon and interbedded Aokautere Ash in a 2Cg horizon overlying BCxg and Cxg horizons.

5. It is noted that there is a textural gradation in the lower Bwg to the boundary with the 2Cg Ash layer. The texture changes from silty clay loam through sandy clay loam to sandy loam in the Aokautere Ash layer.

6. The BCxg and Cxg horizons have characteristic fragipan features and are strongly mottled.

Profile 7 is nominated to represent the Profile Class A6 and is shown in Fig. 17. The full pedological description of the profile is given in Appendix 6.

Figure 17. Profile Class A6 (Profile 69/7).

Site slope: 4^{o}. Elevation: approx. 240 m.
Topography: flat, an interfluve at foot of relict sea cliffs.
Drainage: moderately well drained.

cm

Ah 0 - 10

Dark brown (7.5yr 3/3) silt loam; moderately developed, medium and coarse nutty structure; soft; abundant fine roots; indistinct, smooth boundary; NaF reaction positive.

AB 10 - 22

Brown (7.5yr 4/3) silt loam; few dull yellowish-brown (10yr 5/4) worm casts; moderately developed, medium nutty structure; very stiff; abundant fine roots; indistinct smooth boundary. NaF reaction positive.

BA 22 - 40

Dull yellowish-brown (10yr 4/3, 5/4) and yellowish-brown (10yr 5/6) silt loam; reddish-brown (5yr 4/8) worm casts; few, medium faint mottles in lower horizon, colours as Bwg; moderately developed, medium and coarse nutty structure; very stiff; many becoming few fine roots; NaF reaction positive.

Bwg 40 - 55

Dull yellowish-brown (10yr 4/3, 5/3) silty clay loam with bright brown (7.5yr 5/8) and reddish-brown and very dark reddish-brown (5yr 4/8, 2/4, 3/4) veins; abundant to profuse, medium, distinct mottles, colours as above; moderately developed, very coarse crumb structure; many going to few fine roots; sharp smooth boundary.

2Cg

Orange (7.5yr 6/8) sandy loam; profuse, coarse, distinct to prominent dull yellow-orange (10yr 6/4) mottles; massive structure; very stiff; sharp smooth boundary. NaF reaction positive.

BCx 71 - 90

Light greenish-grey (10Gy 8/1) silt loam; abundant to profuse bright brown (7.5yr 5/6) mottles; moderately developed coarse blocky structure; very stiff; indistinct irregular boundary. NaF reaction positive.

Cxg >90

Light greenish-grey (10Gy 8/1) silty clay loam; abundant to profuse, coarse prominent bright brown (7.5yr 5/8) and orange (7.5yr 6/8) mottles; massive-columnar structure; very stiff. NaF reaction negative.

5.1.3.7 Profile Class A7.

Diagnostic Features.

1. The Profile Class has diagnostic features for the Profile Group but Aokautere Ash is absent either as a discrete layer or textural modifier. This Profile Class is differentiated from Profile Class A5 by the absence of greywacke bedrock at the base of the profile.

2. The characteristic horizon sequence is as follows:-
   O (Turf mat present in some cases)
   Ah
   AB

   Bwg1 (or Bw1)

   Bwg2 (or Bw2).

3. The soil has a possible turf mat.

4. The Ah horizon overlies a transitional AB horizon that has considerable worm mixing.

5. The subsoil has differentiated into two B horizons and horizon designation varies from Bw to Bwg according to the incidence and degree of mottling.

Profile 67 is nominated as typical of Profile Class A7 and is shown in Fig. 18. The full pedological description of the A7 taxonomic unit is given in Appendix 7.

Figure 18. Profile Class A7 (Profile 54/67).

Site slope: 0^{o}. Elevation: 280 m.
Topography: undulating interfluve surface.
Drainage: well drained.

cm

Ah 0 - (37 - 42)

Brownish-black (10yr 3/2) silt loam; moderately to strongly developed coarse nutty structure; stiff; abundant fine roots; worm mixing in lower horizon results in bright yellowish-brown (10yr 7/6) casts; NaF reaction positive; diffuse, discontinuous boundary.

Bw1 42 - 63

Light yellow (2.5y 7/4) silt loam to silty clay loam; abundant, medium, faint yellowish-brown (10yr 5/8) mottles; moderately developed, medium and coarse blocky-polyhedral structure; very stiff; many to few fine roots; distinct, smooth boundary. NaF reaction positive.

Bw2 63 - >130

Bright yellowish-brown (10yr 6/6) silty clay loam; spots of light grey (7.5y 7/2); weakly developed, coarse and very coarse blocky structure; stiff; few roots. NaF reaction positive.

5.1.3.8 Summary of Differentiating Diagnostic Features within Profile Group A.

In addition to diagnostic features held in common and used to group them, the Profile Classes of Profile Group A have the following differentiating diagnostic features:

Profile Class A1 has a discrete Aokautere Ash layer in the lower soil profile at a depth greater than 80 cm.

Profile Class A2 has Aokautere Ash as a textural modifier only in a lower silty clay loam horizon.

Profile Class A3 has a discrete Aokautere Ash layer in the lower soil profile at a depth less than 80 cm.

Profile Class A4 has a discrete Aokautere Ash layer and greywacke bedrock at the base of the profile pit at less than 120 cm.

Profile Class A5 does not contain Aokautere Ash in the profile, either as a discrete layer or textural modifier. Greywacke bedrock is present at the base of the profile pit at less than 120 cm.

Profile Class A6 has a discrete Aokautere Ash layer and a fragipan morphology below the Aokautere Ash layer.

Profile Class A7 does not contain Aokautere Ash in the profile, either as a discrete layer or textural modifier. Greywacke bedrock and a fragipan were also absent in this Profile Class.

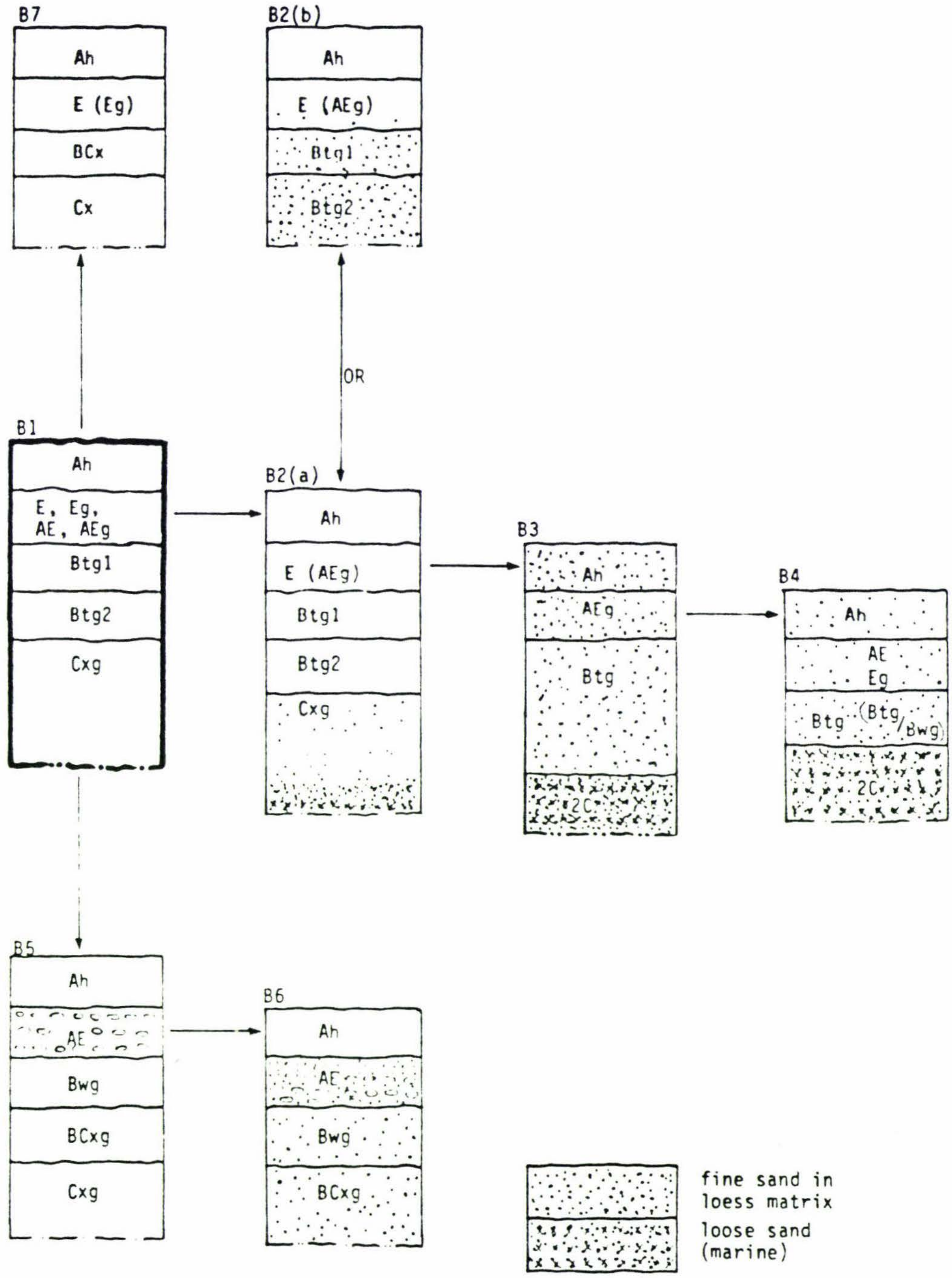
5.1.4 Profile Group B - Introduction.

Profile Group B contains 7 Profile Classes exhibiting eluvial horizons in their profiles.

Profile Classes B1 to B4 display an erosional sequence associated with a reduction in depth of loess over marine sands and a corresponding increasing importance of fine sand in the profile. Profile Classes B5 and B6 show a similar erosional sequence for soils that have redeposited marine gravels in their upper profiles. Profile Class B7 is a truncated hill associate of B1.

The relationships between Profile Classes in Profile Group B are illustrated in Fig. 19.

Figure 19. Profile Group B.



5.1.4.1 Profile Class B1

Diagnostic Features.

1. The soil is formed out of deep loess and has the following characteristic sequence of horizons in the profile:-

    Ah

    E, Eg, AE, AEg,

    Btg1

    Btg2

    Cxg

2. The eluvial horizon is designated E, Eg, AE or AEg. The AE designation is given to the eluvial horizon where material from the Ah horizon is present due to worm mixing. The 'g' suffix was given to those horizons where mottling was observed.

3. Textures change down the profile from silt loam in the Ah and E horizons to silty clay loam in the Btg1 and Btg2 horizons and become silt loam again in the Cxg horizon.

4. Matrix colours in the Ah and eluvial horizons are characterized by medium and high values and low to medium chromas. The Btg1, Btg2 and Cxg horizons are strongly mottles with medium to high values and high chroma strong brown colours and high value, low to medium chroma pale grey colours, forming into veins in the Cxg horizon.

5. The structure in the upper Ah and E horizons is granular or crumb changing to blocky in the Btg1 and Btg2 horizons and massive coarse, columnar in the Cxg horizon.

6. Concretions are present in all horizons above the Cxg horizon. The Ah and eluvial horizons have pinhead concretions while concretions are a prominent feature in lower Btg1 and Btg2 horizons, and appear to be forming out of mottles.

7. Cutans were observed on the peds of the Btg2 and Cxg horizons.

8. There is considerable variation in the thicknesses of all horizons in the Profile Class.

Profile 50 is nominated as typical of this Profile Class and is shown in Fig. 20. The full pedological description of the B1 taxonomic unit is given in Appendix 8.

Figure 20. Profile Class B1 (Profile 74/50.

Site slope: 6^{o}. Elevation: approx. 150 m.
Topography: gently undulating terrace surface.
Drainage: imperfectly drained.

cm
Ah 0 - 7

Dull yellowish-brown (10yr 5/3) with shades of greenish-grey (7gy 6/1) silt loam; moderately developed, medium and coarse crumb structure; soft; many fine roots; distinct wavy boundary.

Eg 7 - 31

Greyish-yellow (2.5y 7/2), light grey (5y 7/2) and light yellow (2.5y 7/3, 7/4) silt loam; many to abundant, fine to medium, faint to prominent orange (7.5yr 6/8) mottles; weakly developed, fine crumb becoming moderately developed, coarse blocky structure; stiff; many fine roots; indistinct, discontinuous boundary.

Btg1 31 - 56

Light grey (5y 7/2) silty clay loam; abundant, medium and coarse, prominent orange (7.5yr 6/8) mottles; cutans on peds; moderately developed, coarse blocky structure; stiff; few fine roots; indistinct, discontinuous boundary.

Btg2 56 - 85

Light grey (5y 7/1, 7/2) silty clay loam; abundant, medium and coarse, prominent orange (7.5yr 6/8) mottles; cutans on peds; moderately developed, coarse blocky structure; stiff; profuse small and large dark reddish-brown (5yr 3/4) concretions; indistinct-smooth boundary.

Cxg

Silt loam, colours as above. Massive-columnar structure; very stiff.

* Each black or white division on depth-measuring tape represents 10 cm.

5.1.4.2 Profile Class B2

Diagnostic Features.

1. This soil is formed from deep loess but has an admixture of fine sand that becomes significant in the profile below 70 cm.

2. The profile has the following characteristic sequence of horizons:-

   Ah
   Eg or AEg
   Btg1

   Btg2
   or Btg2 only
   Cxg

3. In some profiles the Btg2 and Cxg horizons are replaced by a deep Btg2 horizon. This variation is related to the absence of a fragipan.

4. The eluvial horizon was designated Eg or AEg in accordance with the degree of worm mixing of the Ah and E horizons that had occurred and the incidence of mottling.

5. The texture of the Ah and E horizons is silt loam becoming silty clay loam in the Btg1 horizon. The subsoil shows considerable textural variation due to the amount of fine sand in the soil matrix. Where the fine sand component is low, Btg2 and Cxg horizons are present and the texture is silty clay loam becoming silt loam with depth. Subsoils containing a high fine sand content do not exhibit fragipan characteristics and textures change to f. sandy clay loam and f. sandy loam with increasing depth.

6. Matrix colours in the Ah and eluvial horizons are characterized by medium and high values and low to medium chromas. Mottling is a prominent feature of this soil

below the eluvial horizon with high to medium value and high chroma strong brown mottles and high value, low to medium chroma pale grey colours in the Btg1 and Btg2 and Cxg horizons. The pale grey soil is forming into grey veins in the Cxg horizon.

7. Structures change from crumb and nutty in the Ah horizon to blocky in the E horizon. The Btg1 and Btg2 horizons have a blocky structure changing to massive or columnar in the Cxg horizon.

8. These soils have pinhead and fine concretions in the lower Ah, eluvial and Btg1 and Btg2 horizons, with mottles developing into coarser concretions in the Btg1, Btg2 and Cxg horizons. Soils without the fragipan display only pinhead concretions in the Ah horizon.

9. Cutans are marked features on peds of soils with a high fine sand component in the subsoil, and where the fragipan is not present.

10. There is considerable variation in the thicknesses of all horizons in the Profile Class.

Profile 8 is nominated as typical of the Profile Class and is shown in Fig. 21. The full pedological description of the B2 taxonomic unit is given in Appendix 9.

Figure 21. Profile Class B2 (Profile 69/8).

Site slope: 2^{o}. Elevation: approx 220 m.
Topography: very gently undulating narrow interfluve.
Drainage: imperfectly drained.

cm

Ah 0 - 11

Dark brown (7.5yr 3/4) silt loam; moderately developed, medium crumb structure; soft; many, fine roots; distinct, smooth boundary.

AE 11 - 26

Dull yellowish-brown (10yr 5/3, 5/4) silt loam; moderately developed, very coarse breaking to medium crumb structure; firm; many, fine roots; few orange (7.5yr 6/8) spots; considerable worm mixing; indistinct wavy boundary.

Btg1 26 - 55

Dull yellow (2.5y 6/3) silt loam to silty clay loam; many, fine, faint, bright yellowish-brown (10yr 6/6, 6/8), bright brown (7.5yr 5/8) and dull yellow-orange (10yr 7/3, 7/4) mottles; moderately developed, very coarse breaking to coarse blocky structure; cutans on peds; stiff; many to few fine roots; diffuse, irregular boundary.

Btg2 55 - 97

Greyish-yellow (2.5y 7/2) silty clay loam; profuse, medium and coarse, prominent bright yellowish-brown (10yr 6/8) mottles; cutans on peds; weakly developed, very coarse blocky structure; very stiff; distinct, irregular boundary.

Cxg >97

Light grey (10y 7/1) silt loam matrix and bright yellowish-brown (10yr 6/8) mottles. Columnar structure, grey formed into veins; sand a significant component in texture at 144 cm.


8

5.1.4.3 Profile Class B3.

Diagnostic Features.

1. This Profile Class is formed from loess with fine sand texturally significant in the lower part of the profile extending to 70 cm from the surface.

2. The profile has the fo-lowing characteristic sequence of horizons:-

   Ah

   AEg

   Btg.

3. The eluvial horizon is designated AEg on colour and has resulted from worm mixing of the Ah and E horizons and the incidence of mottling.

4. Textures change down the profile from loam in the Ah horizon to f. sandy clay loam grading to sandy loam in the AEg and sandy clay loam in the Btg horizon. Fine sand is present as a 2C horizon at ca. 150 cm.

5. Structures change from crumb in the Ah horizon to blocky-polyhedral and blocky in the AEg and Btg horizons respectively.

6. Concretions are present in the AEg horizon.

7. Cutans were observed on the peds of the Btg horizon.

8. Matrix colours in the Ah and AEg horizons are characterized by medium to high value and low to medium chromas. The AEg horizon has distinct mottles, becoming prominent in the Btg horizon. The mottles are medium to high value and high chroma strong brown in colour and in Btg horizon these are set in a high value, low and medium chroma pale

grey matrix.

Profile 41 is nominated as typical of the Profile Class and is shown in Fig. 22. The full pedological description of the B3 taxonomic unit is given in Appendix 10.

Figure 22. Profile Class B3 (Profile 71/41).

Site slope: 0^{o}. Elevation: 200 m.
Topography: gently undulating interfluve.
Drainage: imperfectly drained.

cm

Ah 0 - 22

Dull yellowish-brown (10yr 5/3) and dark brown (10yr 3/3) loam; weakly to moderately developed, fine, medium and coarse crumb structure; soft going to firm; many fine roots; indistinct, smooth boundary.

AEg 22 - 50

Light grey (10yr 7/1) and greyish-yellow-brown (10yr 6/2) fine sandy clay loam to sandy loam; many to abundant fine, distinct to prominent bright yellow-brown (10yr 6/8), orange (7.5yr 6/8), bright reddish-brown (5yr 5/8) and reddish-brown (5yr 4/8) mottles; moderately developed, very coarse blocky structure; firm; many fine roots; indistinct irregular boundary.

Btg 50 - >95

Light grey (5y 7/1) fine sandy clay loam; abundant, medium and coarse, prominent orange (7.5yr 6/8) mottles; dull yellowish-brown (10yr 5/4) and dull yellow-orange (10yr 6/3) cutans on peds; moderately developed, very coarse blocky structure; stiff; many to few fine roots.

2C sand horizon at approximately 150 cm.


4

5.1.4.4 Profile Class B4.

Diagnostic Features.

1. This Profile Class has formed out of loess and has a 2C sand horizon at the base of the profile at < 120 cm. The 2C horizon has a loamy sand or sandy texture of fine/medium grade. There is a considerable fine sand component in the upper profile.

2. The Profile Class has the following characteristic sequence of horizons:-
   Ah
   AE
   Eg
   Btg (possible differentiation into Btg/Bwg)
   2C.

3. The Profile Class has an upper AE and lower Eg differentiated on the degree of worm mixing. The lower Eg was given the 'g' suffix on the incidence of mottling observed.

4. The Profile Class generally has a Btg horizon overlying a 2C horizon but in some instances the subsoil is differentiated into an upper Btg and lower Bwg overlying the 2C horizon.

5. There is a textural gradation down the profile from silt loam grading to loam in the Ah and eluvial horizons to silty clay loam grading to f. sandy loam in the Btg horizon and sandy loam in the upper 2C going to loose f. sand with depth.

6. Structures change from granular or crumb in the Ah and eluvial horizons to blocky in the Btg horizons. The 2C horizon was single grained.

7. Pinhead and large concretions were observed throughout

the eluvial horizon. Mottles in the Btg horizon were tending to form into soft concretions.

8. An incipient thin iron pan was observed at the junction of the textural break with the 2C horizon in some profiles.

9. Cutans were observed on the peds of the Btg horizon.

10. Worm mixing is concentrated in the eluvial horizon with a few old worm casts in the Bwg and upper 2C horizons.

11. There is considerable variation in the thicknesses of horizons in this Profile Class.

12. There is a general trend in matrix colours from medium value, low to medium chromas in the Ah horizon to strongly mottled Eg, Btg and 2C horizons with medium to high value, high chroma strong brown mottles in a matrix of low to medium chroma pale grey colours. The 2C horizon shows the pale grey material forming into veins.

13. Some pebbles and fragments of rotting rock were observed in the Btg horizon.

Profile 1 is nominated as typical of the Profile Class and is shown in Fig. 23. The full pedological description of the B4 taxonomic unit is given in Appendix 11.

Figure 23. Profile Class B4 (Profile 67/1).

Site slope: 14°. Elevation: approx. 240 m.
Topography: undulating surface at foot of relict sea cliffs.
Drainage: imperfectly drained.

cm

Ah 0 - 15

Greyish-brown (7.5yr 4/2) silt loam; moderately developed, very coarse and coarse breaking to medium and fine crumb structure; firm; many fine roots; distinct, wavy boundary.

AE 15 - 30

Greyish-brown (7.5yr 4/2) and light yellow (5y 7/3, 2.5y 7/3) silt loam grading to loam; moderately developed, very coarse to medium and fine nutty structure; stiff; many fine roots; indistinct, wavy boundary.

Eg 30 - 44

Light yellow (2.5y 7/3) silt loam grading to loam; abundant to many, medium and distinct bright brown (7.5yr 5/8) orange (7.5yr 6/8) and greyish-brown (7.5yr 5/2) mottles; moderately developed, very coarse to fine nutty structure; stiff; many fine roots; indistinct, irregular boundary.

Btg 44 - 68

Dull yellow (2.5y 6/3) and light yellow (2.5y 7/3) silty clay loam becoming fine sandy loam; abundant, medium, prominent bright brown (7.5yr 5/8), orange (7.5yr 6/8) and yellowish-brown (7.5yr 5/3) mottles; cutans on peds; moderately developed, coarse and very coarse blocky structure; stiff; many fine roots; distinct to sharp, wavy boundary.

Bwg 68 - 82

Light brownish-grey (7.5yr 7/2) fine sandy loam; abundant, medium, prominent dull yellow-orange (10yr 7/3), dark brown (7.5yr 3/4), bright reddish-brown (5y 5/8) and orange (5yr 6/8) mottles; weakly developed, coarse blocky structure; stiff to very stiff; few fine roots; sharp and wavy boundary.

2C >82

Bright yellowish-brown (10yr 6/8) fine sandy loam going to loose sand; dull reddish-brown (5yr 4/9) worm casts; single grain structure; very stiff; some dull orange (5yr 6/4) cutans.

5.1.4.5 Profile Class B5.

Diagnostic Features.

This Profile Class contains soils that are similar to those of Profile Class B1 but have redeposited marine gravels in the upper profile. Variations in diagnostic features from Profile Class B1 are noted below:

1. The Profile Class has the following characteristic sequence of horizons in the profile:-
   Ah
   AE
   Bwg
   BCxg
   Cxg.

2. The redeposited marine gravels are contained in the AE horizon. These are more numerous in the upper than lower part of the horizon. Accordingly the texture is stony silt loam. There is fine mottling in the lower half of this horizon.

3. Clay eluviation has not occurred in soils of this Profile Class to the same degree as experienced in Profile Class B1. Cutans were not observed in this soil.

4. Structural trends are similar to Profile Class B1 except a crumb or nutty structure in the upper AE horizon changes to blocky in the lower AE horizon.

5. Concretions are absent in the Ah and AE horizons and present in the lower Bwg, BCxg and Cxg horizons.

6. There are fragments of rotting rock in the BCxg horizon.

Profile 38 is nominated to represent the Profile Class and is shown in Fig. 24. The full pedological description of the profile is given in Appendix 12.

Figure 24. Profile Class B5 (Profile 37/38).

Site slope: 17^{o}. Elevation: approx. 160 m.
Topography: sloping narrow interfluve.
Drainage: imperfectly drained.

cm

Ah 0 - 11

Greyish-brown (7.5yr 4/2) silt loam; weakly developed, fine and medium crumb structure; stiff; abundant fine roots; distinct wavy boundary.

AE 11 - 45

Greyish-brown (10yr 5/2) and greyish-yellow-brown (10yr 6/2) stony silt loam; abundant faint bright brown (7.5yr 5/8) and greyish-olive (5y 6/2) mottles near base of horizon; weakly developed, medium nutty structure becoming medium and coarse blocky in the lower half of the horizon; stiff to very stiff; many fine roots; diffuse smooth boundary.

Bwg 45 - 79

Greyish-yellow (2.5y 6/2) and greyish-yellow-brown (10yr 6/2) silty clay loam; abundant, fine, medium and coarse, prominent bright brown (7.5yr 5/8) and greenish-grey (10Gy 6/1) mottles; moderately developed coarse and very coarse blocky structure; many fine roots down peds.

BCxg 75 - 105

Light grey (10y 7/1 and 5y 7/1) silty clay loam; abundant, coarse, prominent mottles, colours as above plus greenish-grey (10Gy 7/1); spots on peds.

5.1.4.6 Profile Class B6.

Diagnostic Features.

This Profile Class is associated with Profile Class B5 in an erosional sequence. The soils of this class are similar to B5 in having redeposited marine gravels in their upper profiles but are similar to B3 in having a significant fine sand component present in the matrix above 70 cm.

1. The characteristic horizon sequence is as follows:-
   Ah
   AE
   Bwg
   BCxg.

2. The AE horizon has redeposited marine gravels and considerable worm mixing with the Ah horizon.

3. Textures change down the profile from silt loam in the Ah to stony loam in the AE horizon and f. sandy clay loam in the Bwg horizon. The BCxg horizon contains f. sandy clay loam becoming f. sandy loam with depth.

4. Structure changes from nutty-crumb in the Ah and AE horizons to blocky in the Bwg and blocky giving way to massive with depth in the BCxg horizon. Fragipan formation in this soil may have been related to exceptially well-drained site position.

5. Pinhead concretions are present in the lower AE horizon and Bwg horizon. The BCxg horizon has incipient concretions forming out of mottles.

6. Cutans were not present in this soil.

7. Matrix colours change from low value, medium to high chromas in the Ah horizon to medium value, low to medium chromas in the AB and BA horizons. The Bwg and BCxg

horizons have mottles with medium to high values and high chromas strong brown colours and high value, low to medium chromas in pale grey colours.

8. A few small rounded stones were found in the Bwg horizon.

Profile 55 is nominated to represent the Profile Class and is shown in Fig. 25. The full pedological description of the profile is given in Appendix 13.

Figure 25. Profile Class B6 (Profile 70/55).

Site slope: 18^{0}. Elevation: approx. 160 m.
Topography: very undulating narrow interfluve.
Drainage: imperfectly drained.

cm

Ah 0 - 10

Greyish-brown (7.5yr 4/2) silt loam; moderately developed, medium and coarse nutty and crumb structure; soft; many fine roots; distinct irrecular boundary.

AE 10 - 22

Dark brown (10yr 3/3) stony loam; dull yellow-orange (10yr 7/2) and grey yellow (10yr 6/2) brown worm casts; weakly developed, coarse and very coarse, crumb structure; very stiff; many fine roots; indistinct, irregular boundary.

Bwg 21 - 51

Greyish-yellow-brown (10yr 6/2) fine sandy clay loam; bright reddish-brown (7.5yr 5/8) and orange (7.5yr 6/8) mottles, abundant, fine and medium, distinct; weakly developed, coarse blocky structure; very stiff; many fine roots; diffuse, smooth boundary.

BCxg 55 - 90

Light grey (5y 7/2) fine sandy loam with shades of light bluish-grey (5B 7/1); abundant coarse prominent orange (7.5yr 6/8) to bright brown (7.5yr 5/8) mottles; weakly developed, blocky going to massive structure; very stiff; few fine roots.

5.1.4.7 Profile Class B7.

Diagnostic Features.

This Profile Class is a hill associate of Profile Class B1. It has a foreshortened profile and the Btg1 horizon of Profile Class B1 is absent. The Btg2 horizon of Profile Class B1 was designated a BCxg horizon in this soil. Variations in morphology from Profile Class B1 are noted below:

1. The soil has the following characteristic horizon sequence in the profile:

   Ah
   E Eg
   BCxg
   Cxg

2. Mottling in the profile is similar to Profile Class B1, excepting the eluvial horizon. The eluvial horizon was differentiated into Eg or E horizons, depending on the incidence of mottling.

3. Evidence of worm mixing is confined to the lower Ah horizon.

4. Structure in the Ah horizon is crumb to nutty becoming blocky-polyhedral in the E (or Eg) horizon. The BCxg horizon is blocky-columnar becoming massive columnar in the Cxg horizon.

5. Cutans are not observed in this soil.

Profile 22 is nominated as typical of the Profile Class and is shown in Fig. 26. The full pedological description of the B6 taxonomic unit is given in Appendix 14.

Figure 26. Profile Class B7 (Profile 58/22).

Site slope: 10 - 14°. Elevation: approx. 280 m.
Topography: undulating sloping interfluve on relict sea cliffs.
Drainage: imperfectly drained.

cm

Ah 0 - 28

Dark brown (7.5yr 3/4) silt loam; dull yellowish-brown (10yr 5/3), dull yellow-orange (10yr 6/3, 6/4) and light yellow (2.5y 7/3) worm mixing in lower Ah horizon; moderately developed, medium crumb structure going to coarse nutty structure; soft to firm; many fine roots; indistinct, discontinuous boundary.

Eg 28 - 46

Light yellow (2.5y 7/3) and light grey (10yr 7/1) silty clay loam; many, fine and medium distinct mottles, bright reddish-brown (10yr 5/8) and brownish-grey (5yr 5/1) mottles; weakly to moderately developed, medium blocky-polyhedral structure; stiff; many fine roots; distinct, wavy boundary.

BCxg >46

Light brownish-grey (7.5yr 7/1) silty clay loam; profuse coarse bright brown (5yr 5/8) mottles; few fine roots in upper 10 cm; very coarse blocky going to massive-columnar structure.


22

5.1.4.8 Summary of Differentiating Diagnostic Features within Profile Group B.

Profile Class B1 - Soils formed in deep loess with an eluvial horizon.

Profile Class B2 - Soils formed in deep loess, fine sand fraction significant in the profile at >70 cm.

Profile Class B3 - Soils formed in deep loess, fine sand fraction significant in the profile at <70 cm.

Profile Class B4 - Soils formed in loess with an eluvial horizon and a 2C fine sand horizon at the base of the profile.

Profile Class B5 - Soils are as specified for Profile Class B1 but with redeposited marine gravels in the eluvial horizon.

Profile Class B6 - Soils are as specified for Profile Class B5 but with a fine sand fraction present at <70 cm.

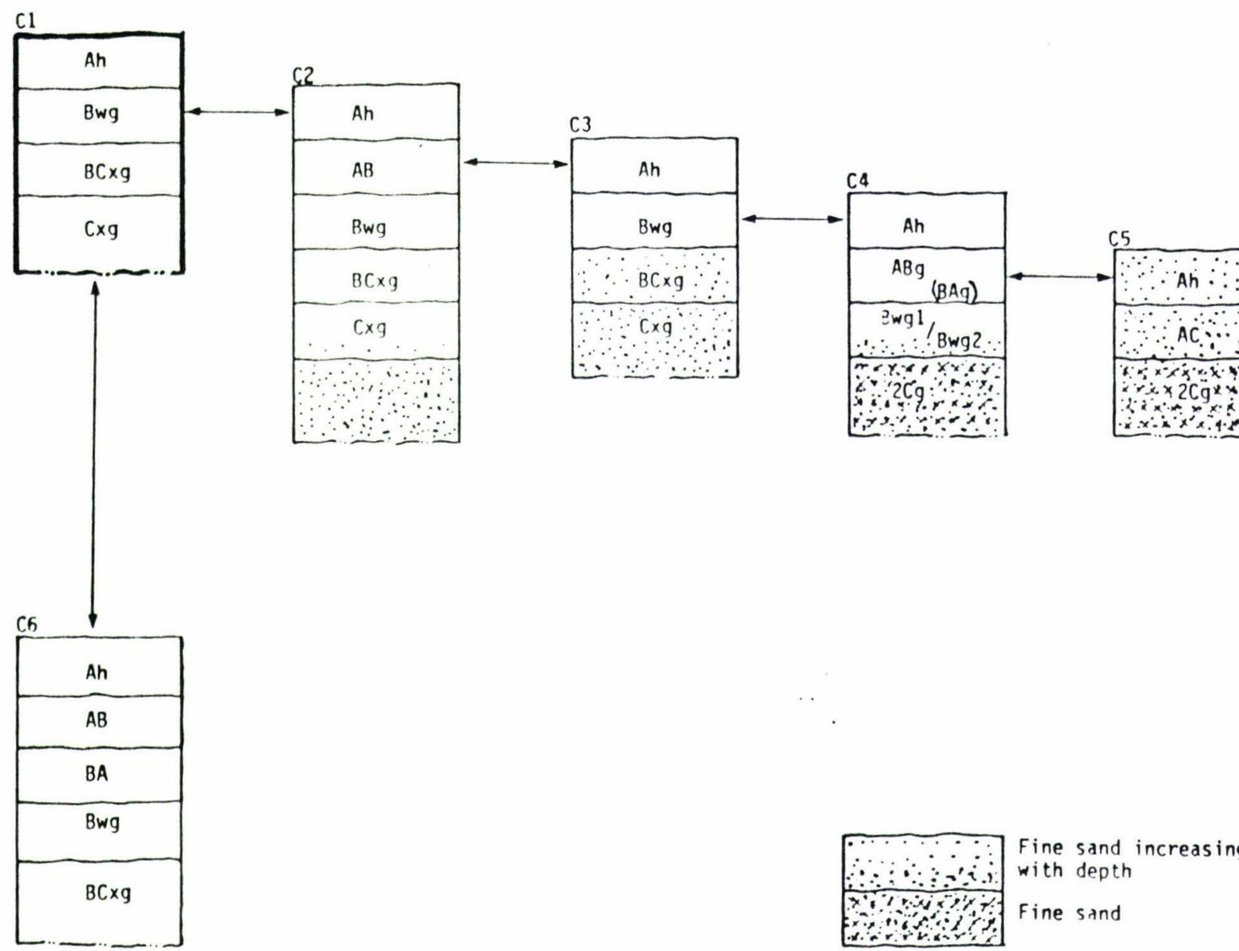
Profile Class B7 - Hill associate of Profile Class B1, having a foreshortened profile.

5.1.5 Profile Group C - Introduction.

Profile Group C contains 6 Profile Classes. Profile Classes C1 to C5 exhibit an erosional sequence similar to that which obtained in Profile Classes B1 to B4. Profile Class C6 is an overthickened variant of C1 resulting from slope wash or surface creep.

These Profile Classes do not display eluvial horizons and the lack of this feature differentiates them from Profile Classes of Profile Group B. The relationships between Profile Classes of Group C are illustrated in Fig. 27.

Figure 27. Profile Group C.



5.1.5.1 Profile Class C1.

Diagnostic Features.

1. The soils in this Profile Class are formed out of deep loess and have the following characteristic sequence of horizons in the profile:-

    Ah
    Bwg
    BCxg
    Cxg

2. Textures change down the profile from silt loam in the Ah to silty clay loam in the Bwg and BCx. Textures change again in the Cxg horizon from silty clay loam to silt loam.

3. This soil has faint mottling in the Ah horizon and prominent mottling in the Bwg, BCxg and Cxg horizons.

4. Structures range from crumb to nutty in the Ah to blocky-polyhedral in the Bwg and blocky-polyhedral tending to columnar in the BCxg horizon. Structure in the Cxg horizon is blocky-polyhedral tending to massive columnar.

5. Concretions are present in all horizons. Pinhead concretions are located at the base of the Ah horizon in association with mottling and also in the Bwg horizon. Larger concretions associated with mottling are found in the Bwg, BCxg and Cxg horizons.

6. Cutans were observed on the peds of the Bwg, BCxg and Cxg horizons of some profiles in the Profile Class.

7. Worm mixing is a notable feature of the Ah horizon and was observed to be present to a limited extent in the Bwg horizon.

8. There is considerable variation in the thicknesses of

horizons in this Profile Class.

9. Matrix colours in the Ah horizon are characterized by medium and high values and low to medium chromas. The Bwg, BCxg and Cxg horizons are characterized by strong brown mottles with high values and chromas and pale grey matrix colours with high values and low to medium chromas, forming into veins.

10. Dark matrix material from the topsoil was observed down root channels, joining up with grey veins in the subsoil.

11. A few small pebbles were observed in the BCxg horizons and fragments of rotting rock were located in the Cxg horizons in some profiles.

Profile 70 is nominated as typical of the Profile Class and is shown in Fig. 28. The full pedological description of the C1 taxonomic unit is given in Appendix 15.

Figure 28. Profile Class C1 (Profile 50/70).

Site slope: 6^{o}. Elevation: approx. 220 m.
Topography: mound on broad interfluve.
Drainage: imperfectly drained.

cm

Ah 0 - 28

Dull yellow-brown (10yr 5/3) going to dull yellow-orange (10yr 6/3) at lower boundary, silt loam; abundant fine, faint orange (5yr 7/8) mottles in lower half of horizon; moderately to strongly developed, coarse and very coarse nutty crumb structure; firm; many fine roots; indistinct, smooth boundary.

Bwg 28 - (49 to 55)

Dull brown (7.5yr 5/3) and light yellow (2.5y 7/3) silty clay loam; abundant, medium, prominent orange (7.5yr 6/8) mottles; weakly developed, coarse blocky structure; firm; many fine roots; diffuse, discontinuous boundary.

BCx (49 to 55) - 75

Greyish-yellow (2.5y 7/2) and light grey (5y 7/2) silty clay loam; abundant, medium and coarse, prominent orange (7.5yr 5/8, 6/8) mottles; dull yellow-orange (10yr 6/3) veins in matrix; strongly developed, coarse blocky-polyhedral structure; firm; few fine roots down peds; distinct wavy boundary.

Cxg >75

Dull yellow (2.5y 6/3), greyish-yellow (2.5y 7/2) and dull yellow orange (10yr 6/3) silt loam; profuse, coarse, prominent orange (7.5yr 6/8) mottles; massive-columnar structure; very stiff.

* Each black or white division on depth-measuring tape represents 10 cm.

5.1.5.2 Profile Class C2.

Diagnostic Features.

1. Soils from this Profile Class are formed from deep loess with the fine sand fraction becoming significant in the profile below 70 cm.

2. The Profile Class has the following characteristic sequence of horizons:-
   Ah
   AB
   Bwg
   BCxg
   Cxg (possible).

3. This soil has a transitional AB horizon produced by worm mixing and movement of material from the Ah horizon down old bush root channels.

4. Textures change down the profile from silt loam in the Ah and AB to silty clay loam in the Bwg and BCxg horizons. The texture of the Cxg horizon, where present, is silt loam and all profiles have f. sandy clay loam textures at depth.

5. A shallow Cxg horizon is present only in some profiles and its presence is related to the depth to a significant fine sand fraction in the matrix. Profiles with a significant fine sand fraction present below the BCxg do not possess a Cxg horizon.

6. Matrix colours change from medium and high values and low to medium chromas in the Ah and E horizons to mottles of contrasting high to medium values strong brown colours and high value, low to medium chroma pale greys in the Bwg, BCxg and Cxg horizons. Fine mottling was observed in the AB horizon and is a prominent feature in the Bwg, BCxg and Cxg horizons.

7. Structures change from crumb-nutty in the Ah and AB horizons to blocky-polyhedral in the Bwg and BCxg horizons. The structure of the Cxg horizon is massive.

8. Cutans were observed on the peds of horizons Bwg, BCxg and Cxg in some profiles.

9. There is considerable variation in the thicknesses of all horizons in this Profile Class.

Profile 64 is nominated as typical of the Profile Class and is shown in Fig. 29. The full pedological description of the C2 taxonomic unit is given in Appendix 16.

Figure 29. Profile Class C2 (Profile 57/64).

Site slope: 0^{o}. Elevation: approx. 240 m.
Topography: summit of small mound on undulating erosion surface.
Drainage: imperfectly drained.

cm

Ah 0 - 30

Brown (7.5yr 4/3) silt loam; strongly developed, coarse nutty-crumb structure; firm; abundant fine roots; diffuse, discontinuous boundary.

AB 30 - 44

Dull yellow-brown (10yr 4/3) and bright yellow-brown (10yr 6/6) silt loam; moderately to strongly developed, coarse nutty structure; many, medium, faint to distinct dull yellow-orange (10yr 6/4) mottles; very stiff; dull yellowish-brown (10yr 5/3) worm casts in lower horizon; abundant fine roots; indistinct, irregular boundary.

Bwg 44 - 63

Dull yellow-orange (10yr 6/3, 6/4) silty clay loam; abundant to profuse, medium, prominent, bright brown (7.5yr 5/8) and orange (7.5yr 6/8) mottles; strongly developed, coarse and very coarse blocky-polyhedral structure; firm; many to few fine roots down peds; indistinct discontinuous boundary.

BCxg

Light grey to grey (5y 7/1, 6/1, 10y 7/1, 6/1) silty clay loam; abundant, medium and coarse, prominent, orange (7.5yr 6/8) mottles; strongly developed, coarse and very coarse blocky-polyhedral structure; fine sandy clay loam at >130 cm.

5.1.5.3 Profile Class C3.

Diagnostic Features.

1. Soils from this Profile Class have formed from loess with fine sand texturally significant in the lower part of the profile above 70 cm.

2. The Profile Class has the following characteristic sequence of horizons:-

   Ah
   Bwg
   BCxg
   Cxg.

3. Textures change down the profile from silt loam in the Ah and Bwg horizons to loam and fine sandy clay loam to fine sandy loam in the BCxg and Cxg horizons respectively.

4. In contrast to equivalent Profile Classes in Profile Group B, the Cxg fragipan horizon appears well developed in this soil.

5. Matrix colours change as in Profile Class C2. Mottling is a prominent feature in the Bwg, BCxg and Cxg horizons.

6. Structures change from crumb to nutty in the Ah horizon to blocky, columnar in the Bwg and BCxg horizons and massive, columnar in the Cxg horizon.

7. Pinhead concretions are prominent in the Cxg horizon.

8. Cutans were observed on the peds of the BCxg and Cxg horizons.

Profile 73 is nominated as typical of the Profile Class and is shown in Fig. 30. The full pedological description of the C3 taxonomic unit is given in Appendix 17.

Figure 30. Profile Class C3 (Profile 36/73).

Site slope: 0^{o}. Elevation: 160 m.
Topography: flat-topped broad interfluve.
Drainage: moderately well drained.

cm

Ah 0 - 25

Dull yellow-orange (10yr 6/3, 6/4) silt loam; greyish-yellow-brown (10yr 4/2) worm casts; moderately developed, medium, coarse and very coarse nutty-crumb structure; very stiff; abundant to many fine roots; distinct, wavy boundary.

Bwg 25 - 45

Dull yellow-orange (10yr 7/2 and 7/3) silt loam; abundant, fine becoming medium, faint becoming distinct bright yellow-brown and yellow-orange (10yr 6/8, 7/8) mottles; greyish-yellow-brown (10yr 5/2) worm casts; moderately developed, coarse and very coarse blocky-columnar structure; many fine roots down peds; indistinct, smooth boundary.

BCxg 45 - 65

Dull yellow (2.5y 6/3) loam; abundant, fine, medium and coarse orange (7.5yr 6/8) and bright reddish-brown (5yr 5/8) and orange (5yr 6/8) mottles; greyish-yellow-brown (10yr 5/2) worm casts; strongly developed, coarse and very coarse, blocky-columnar structure; few fine roots down peds; distinct, wavy boundary.

Cxg

Pale yellow (5y 8/3) fine sandy clay loam, going to fine sandy loam; abundant, medium and coarse, prominent bright yellowish-brown (10yr 6/8) going to bright brown-orange (7.5yr 5/8, 6/8) mottles; greyish-olive (5y 6/2) worm casts; massive-columnar structure; few fine roots down the peds.

5.1.5.4 Profile Class C4.

Diagnostic Features.

1. Soils from this Profile Class have formed out of loess and have a 2C sand horizon at the base of the profile at <120 cm. There is a considerable fine sand component in the upper profile.

2. Soils from this Profile Class have the following characteristic sequence of horizons:-

   Ah
   ABg or BAg
   Bwg1
   Bwg2
   2Cg.

3. The profile contains a transitional horizon that is designated ABg or BAg according to the degree of worm mixing and incorporation into the Ah horizon.

4. The Bwg horizon was differentiated into Bwg1 and Bwg2 horizons on criteria including textual change, reduction in chroma values in the matrix and incidence of concretions in the lower horizon.

5. Textures change from silt loam to loam in the Ah and AB/BA horizons to fine sandy clay loam in the Bwg1 horizon. The Bwg2 horizon has a fine sandy loam texture. The 2C horizon at the base of the profile has a loamy sand to loose sand texture.

6. Matrix colours change as in Profile Class C1. Mottling is a prominent feature in the AB/BA, Bwg1 and Bwg2 horizons.

7. Structure changes from crumb-nutty in the Ah to polyhedral in the AB/BA horizon. The structure of the Bwg1 and Bwg2 horizons is blocky, columnar becoming massive

at the base of the Bwg2 horizon. The 2C horizon has a massive structure.

8. A few small concretions were observed in the Ah horizon. The AB/BA transition horizon has many pinhead concretions and the Bwg2 has many concretions concentrated near the lower boundary with the 2C horizon.

9. An incipient placic horizon was observed in some profiles at the junction of the Bwg1 and Bwg2 horizons.

10. Cutans were observed on the peds of some profiles in the AB/BA, Bwg1 and Bwg2 horizons.

11. Worm mixing was observed in the Ah and AB/BA horizon but disappeared in the Bwg1 horizon.

Profile 28 is nominated as typical of the Profile Class and is shown in Fig. 31. The full pedological description of the C4 taxonomic unit is given in Appendix 18.

Figure 31. Profile Class C4 (Profile 52/28).

Site slope: 0^{o}. Elevation: approx. 240 m.
Topography: crest of hummock on broad interfluve.
Drainage: imperfectly drained.

cm

Ah 0 - 25

Dull yellowish-brown (10yr 4/3) silt loam; weakly to moderately developed, coarse going to fine crumb structure; firm; many fine roots; indistinct smooth boundary.

ABg 25 - 40

Dull yellowish-brown (10yr 4/3) and bright yellowish-brown (10yr 6/6) silt loam; many, medium, faint orange (7.5yr 6/8) mottles; weakly developed, coarse blocky-polyhedral structure; many fine roots; distinct, wavy boundary.

Bwg1 40 - 62

Yellow-orange (10yr 7/8) fine sandy clay loam; profuse prominent, coarse, bright yellowish-brown (10yr 6/8) and yellow-orange (10yr 7/8) mottles; strongly developed blocky-columnar structure; very stiff; fine roots in structural cracks in association with dark material from above; indistinct, smooth boundary.

Bwg2 62 - 92

Orange (7.5yr 6/8) fine sandy loam; profuse prominent coarse mottles, as above plus greyish-yellow (2.5y 7/2); weakly developed, blocky-columnar structure; very stiff; few fine roots, as above; distinct, wavy boundary.

2Cg >92

Yellow-orange (10yr 7/8) loamy sand to loose sand; massive structure (single grain); very stiff.

5.1.5.5 Profile Class C5.

Diagnostic Features.

1. Soils in this Profile Class are formed largely from fine sand with a loessial admixture. This Profile Class is at the end of the erosion sequence represented by Profile Group C.

2. The soil has the following characteristic sequence of horizons:-

   Ah
   AC
   2C.

3. The texture of the Ah and AC horizons is sandy loam merging to loamy sand in the 2C horizon. Augering located a sandy clay loam band in the subsoil at ca 100 cm.

4. Matrix colours change from low values, medium to high chromas in the Ah to medium to high values, high chromas in the 2C horizon. There are a few mottles in the upper AC horizon and upper 2C horizon above 60 cm and these become more abundant and distinct in the lower 2C horizon, accompanied by grey streaks.

5. Structures are crumb in the Ah and AC horizons, becoming single grain in the 2C horizon.

6. Concretions are located at the base of the profile at ca 90 cm, just above the sandy clay loam band at 100 cm.

7. The effects of worm mixing are evident in the AC horizon and worm casts were observed in the matrix of the 2C horizon.

Profile 56 is nominated as typical of the Profile Class and is shown in Fig. 32. The full pedological description of the C5 taxonomic unit is given in Appendix 19.

Figure 32. Profile Class C5 (Profile 47/56).

Site slope: 0^{o}. Elevation: approx 220 m.
Topography: summit of mound on undulating erosion surface of broad interfluve.
Drainage: somewhat excessively drained.

cm

Ah 0 - 39

Brown (7.5yr 4/3, 4/4) sandy loam; moderately developed, fine and medium crumb structure; firm; many fine roots; bright yellowish-brown (10yr 7/6) worm casts in lower horizon; diffuse, discontinuous boundary.

AC 39 - 46

Brown (7.5 yr 4/3, 4/4) and yellow-orange (10yr 7/8) sandy loam to loamy sand; zone of worm mixing; weakly developed, fine and medium crumb structure; many to few fine roots.

2C >46

Bright yellowish-brown (10yr 6/8) and yellow-orange (10yr 7/8) loamy sand with dull yellow-orange (10yr 7/2) worm casts; colours going to bright yellowish-brown (10yr 7/6) bright yellowish-brown (2.5y 7/6) and light yellow (2.5y 7/4) below 60 cm; few orange (7.5yr 6/8) going to bright brown (7.5yr 5/8) mottles, also bright yellowish-brown (10yr 6/8) banding in loamy sand matrix; single grain structure; clay pan at approx. 100 cm in light yellow (2.5y 7/4) matrix.


56

5.1.5.6 Profile Class C6.

Diagnostic Features.

This Profile Class is a hill associate of Profile Class C1. The upper horizons of the profile have been overdeepened through slopewash or surface creep of material from above.

1. Soils of this Profile Class have the following characteristic sequence of horizons in the profile:-

   Ah
   AB
   BA
   Bwg
   BCxg.

2. The Ah horizon overlies AB and BA transitional horizons that contain small rounded and angular stones up to 4 mm in diameter. These are few in the AB and more numerous in the BA horizon.

3. Textures change from silt loam in the Ah and AB horizons to silty clay loam in the BA, Bwg and BCxg horizons.

4. Matrix colours change from low value, medium to high chromas in the Ah to medium value, low to medium chromas in the AB and BA horizons. Mottling is confined to the Bwg and BCxg horizons. These have mottles of medium to high value, high chroma, strong brown colours with low to medium pale grey colours going to veins in the BCxg horizon.

5. Structure is crumb and nutty in the Ah, AB and BA horizons and blocky-polyhedral in the Bwg horizon, becoming massive in the BCx horizon.

6. There are few concretions in the BA horizon but these become numerous in the Bwg and BCx horizons. Hard, black concretions are a feature of the BCxg horizon.

7. Worm mixing is concentrated in the lower AB and in the BA horizon.

Profile 5 is niminated as typical of the Profile Class and is shown in Fig. 33. The full description of the C6 taxonomic unit is given in Appendix 20.

Figure 33. Profile Class C6 (Profile 60/5).

Site slope: 9^{o}. Elevation: 300 m.
Topography: undulating gently-sloping interfluve.
Drainage: imperfectly drained.

cm

Ah 0 - 12

Brown (7.5yr 4/4) silt loam; moderately developed, fine and medium crumb structure; soft; profuse to abundant roots; indistinct smooth boundary.

AB 12 - 32

Brown (7.5yr 4/3) silt loam; dull yellow-orange (10yr 6/4) casts from worm mixing; moderately developed, fine and medium nutty structure; very stiff; abundant to many fine roots; few angular stones, 4 cm in diameter; indistinct irregular boundary.

BA 32 - 48

Dark brown (10yr 3/4) silty clay loam; dull yellow-orange worm casts (10yr 6/4) more prominent near lower boundary; weakly developed, coarse, nutty structure; stiff; distinct, smooth boundary.

Bwg 48 - 75

Dull yellow-orange (10yr 6/4) and bright yellowish-brown (10yr 6/6) silty clay loam; abundant to profuse bright yellowish-brown (10yr 6/8) and dull yellow-orange (10yr 7/2) mottles; weakly developed, medium, blocky-polyhedral structure; stiff; few fine roots.

BCxg >75

Light grey (2.5y 7/1) silty clay loam; profuse, medium and coarse dull yellow-orange (10yr 7/2) mottles; massive-columnar structure with grey veins; very stiff; no roots.


5

5.1.5.7 Summary of Differentiating Diagnostic Features within Profile Group C.

Soils of Profile Class C1 have formed in deep loess and possess a Bwg horizon but lack an eluvial horizon.

Soils of Profile Class C2 have formed in deep loess, possess a Bwg horizon with fine sand significant in the profile below 70 cm.

Soils of Profile Class C3 have formed in loess, possess a Bwg horizon with fine sand significant in the profile above 70 cm.

Soils of Profile Class C4 have formed in loess with a 2C fine sand horizon at the base of the profile.

Soils of Profile Class C5 have formed in a shallow loess and sand topsoil over a 2C fine sand horizon.

Soils of Profile Class C6 are overdeepened hill associates of Profile Class C1.

5.1.6 Profile Group D - Introduction.

Profile Group D contains 3 Profile Classes, formed from loessial material overlying Castlecliffian marine sediments.

Profile Class D1 has topsoils formed from loess overlying subsoils derived from siltstone of the Tuapaka formation. Profile Classes D2 and D3 have topsoils formed from loess over subsoils formed from marine gravels of the Tuapaka formation. Profile Class D3 is essentially a shallow phase of Profile Class D2.

5.1.6.1 Profile Class D1.

Diagnostic Features.

1. Soils of this Profile Class have the following characteristic sequence of horizons:-

   Ahc
   Bg or Bwg
   2R.

2. The B horizons were designated Bg or Bwg on the amount of alteration that had occurred to the matrix material.

3. Textures are silt loam in the Ah and Bg horizons while Bwg horizons have silty clay loam textures.

4. There is mottling in the Ahc, Bg and Bwg horizons. Matrix colours of the Ahc horizon are predominantly of medium value and low to medium chromas. The Bg and Bwg horizons are characterized by mottles of medium to high value and high chroma brown and orange colours.

5. Ahc horizons of this Profile Class have crumb to nutty structures and the Bg or Bwg horizons have blocky structures.

6. The Ahc horizon has profuse pinhead concretions and concretions were observed in Bg or Bwg horizons, grading from small to coarse with depth.

7. There are cutans on the peds of the B horizon.

8. There is evidence of worm mixing throughout the profile.

9. There is considerable variation in the thicknesses of the Ahc and Bg or Bwg horizons in this Profile Class.

Profile 39 is nominated as typical of the Profile Class and is shown in Fig. 34. The full description of the D1 taxonomic unit is given in Appendix 21.

Figure 34. Profile Class D1 (Profile 37/39).

Site slope: 15^{o}. Elevation: approx. 140 m.
Topography: sloping narrow interfluve.
Drainage: imperfectly drained.

cm

Ahc 0 - 12

Greyish-brown (7.5yr 5/2) silt loam; weakly to moderately developed fine and medium crumb structure; firm; abundant fine roots; soft and hard bright reddish-brown (5yr 5/8) concretions concentrated at lower boundary; distinct, wavy boundary.

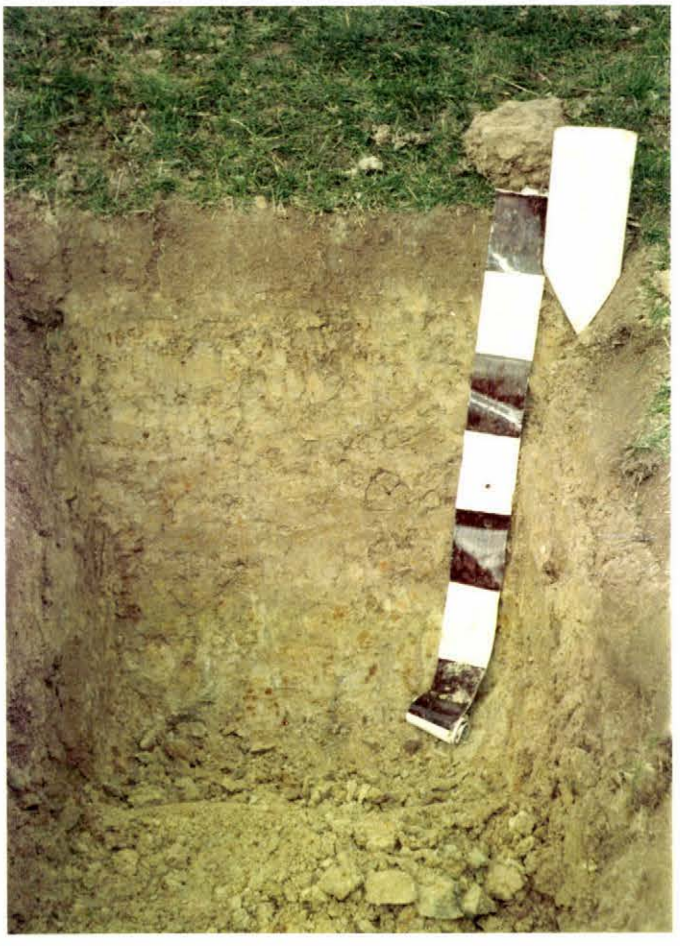
Bwg 12 - 51

Bright brown (7.5yr 5/8) to orange (7.5yr 6/8) and olive-yellow (5y 6/3) going to pale yellow (5y 8/3) (slightly stony possible) silty clay loam; many fine and medium mottles and pieces of rotting rock indistinguishable; strongly developed coarse and very coarse blocky structure; diffuse, irregular boundary.

R

Light grey (10y 8/2) siltstone with bright yellowish-brown (2.5y 6/8) and yellowish-brown (2.5y 5/6) colouration; dull yellow-orange (10yr 6/3) and greyish-yellow (2.5y 6/2) veins in siltstone; few roots in veins.

* Each black or white division on depth-measuring tape represents 10 cm.



5.1.6.2 Profile Class D2.

Diagnostic Features.

Soils of Profile Class D2 are formed from loessial material overlying undisturbed marine gravels of the Tuapaka formation. The topsoil is of sufficient depth to allow the development of B horizons.

1. Soils of the Profile Class have the following characteristic horizon sequence:-
    Ah
    Bw
    Bwg
    2Cg.

2. The Ah horizon overlies a B horizon that is differentiated into a Bw and Bwg horizon, lying on a 2Cg horizon of strongly weathered marine gravels.

3. Textures range from silt loam in the Ah to silt loam becoming loam with depth in the Bw horizon. The underlying Bwg horizon has a sandy clay loam texture and the marine gravels are bedded in a sandy loam matrix.

4. Matrix colours are medium value, low to medium chromas in the Ah horizon and merge through the Bw horizon with faint mottling to prominent high value, low to medium chroma mottles in the Bwg horizon.

5. Structure in the Ah horizon is blocky breaking to crumb and is predominantly crumb in the underlying Bw horizon. The Bwg horizon has a blocky-polyhedral structure.

6. Cutans were observed on the peds in the Bw horizon.

7. Worm mixing was noted in the Bw horizon.

8. There are a few rotting rounded pebbles in the Bw

horizon. The marine gravels from the 2Cg horizon extend upwards into the lower Bwg horizon.

Horizon 57 is nominated as typical of Profile Class D2 and is shown in Fig. 35. The full description of the D2 taxonomic unit is given in Appendix 22.

Figure 35. Profile Class D2 (Profile 47/57).

Site slope: 0^{o}. Elevation: >220 m.
Topography: undulating erosion surface on broad interfluve.
Drainage: imperfectly drained.

cm

Ah 0 - 19

Dull yellowish-brown (10yr 5/3) and dull yellow-orange (10yr 6/3) silt loam; moderately developed, very coarse breaking to medium and fine blocky to crumb structure; firm; many fine roots; indistinct irregular boundary.

Bw 19 - 35

Dull yellow-orange (10yr 6/3, 7/3) and light yellow (2.5y 7/3) silt loam to loam; many, fine, faint bright yellowish-brown (7.5yr 3/4) mottles, greyish yellow-brown (10yr 4/2, 5/2) worm casts; weakly to moderately developed, very coarse crumb structure; firm to stiff; many fine roots; indistinct, irregular boundary.

Bwg 35 - 56

Light yellow (2.5y 7/3) and dull yellow-orange (10yr 7/3) stony sandy clay loam; abundant, coarse, distinct, orange (7.5yr 6/8) and gright yellowish-brown (10yr 6/8) mottles; moderately developed, coarse blocky-polyhedral structure; firm; few fine roots; distinct, wavy boundary.

2Cg >56

Light yellow (2.5y 7/3) matrix of sandy loam and undisturbed weathering medium marine gravels; (very stony); stiff; no roots.


57

5.1.6.3 Profile Class D3.

Diagnostic Features.

Profile Class D3 is a shallow phase of Profile Class D2. It has a shallow topsoil derived from loess overlying undisturbed marine gravels of the Tuapaka formation. Variations in the profile that differentiate the Profile Class from Profile Class D2 are noted below:

1. The Profile Class has the following characteristic horizon sequence:
   Ah
   2C.

2. Textures in the Ah horizon vary from silt loam to loam and sandy loam. The 2C horizon has strongly weathered marine gravels bedded in a sandy, loamy sand or sandy loam matrix.

3. The Ah horizon has a crumb to nutty structure.

4. There are no cutans in the profile of this Profile Class.

5. Worm mixing and old bush roots were observed to have brought some material from the Ah horizon into the 2C horizon.

6. Matrix colours in the Ah horizon are of low value, medium to high chromas.

Profile 30 is nominated as typical of the Profile Class and is shown in Fig. 36. The full description of the D3 taxonomic unit is given in Appendix 23.

Figure 36. Profile Class D3 (Profile 52/30).

Site slope: 0^o. Elevation: approx. 200 m.
Topography: undulating surface sloping at 24^o to 27^o adjacent to Tuapaka Fault.
Drainage: well to excessively drained.

cm

Ah 0 - 20

Brown (10yr 4/4) loam; weakly developed, fine and medium crumb structure; firm to very stiff; abundant to many fine roots; distinct smooth boundary.

2C

Bright yellowish-brown (10yr 6/8) very stony loamy fine sand structure; few fine roots; undisturbed marine gravels, 18 to 20 cm in diameter.

5.1.7 Profile Group E - Introduction.

Profile Group E contains 7 Profile Classes, characterized by topsoils formed from loess over greywacke.

Soils of Profile Classes E1 and E2 have formed in a loessial material over greywacke colluvial material and exhibit eluvial horizons in their profiles. Profile Class E2 is a shallow or erosive phase of Profile Class E1.

Profile Class E3 has a similar profile form to Profile Class E1 but the eluvial horizon is absent.

Profile Classes E4 and E5 have loessial material over greywacke bedrock. Profile Class E5 is the erosive phase of Profile Class E4.

Profile Class E6 has loessial material over a subsoil of marine gravels redeposited in a silty matrix.

Profile Class E7 has loessial material over a subsoil formed from an unsorted mixture of angular greywacke stones, boulders and marine gravel resting on greywacke bedrock.

5.1.7.1 Profile Class E1.

Diagnostic Features.

1. Soils of this Profile Class have the following horizon sequence:-
   0 (possible)
   Ah
   Ec
   BCg
   Cg.

2. Concretions are a striking feature of the eluvial horizon and it was given an Ec designation. There are fine pinhead concretions in the upper Ec horizon going to numerous large concretions, (up to 2 cm), in the lower half of the horizon.

3. The Ah horizon has some small, angular and rounded greywacke gravels. These are not present in the Ec horizon. The BCg horizon has angular pieces of strongly weathered greywacke. The Cg horizon has large boulders of strongly weathered greywacke colluvium.

4. Textures change from silt loam in the Ah horizon to silty clay loam in the Ec horizon, becoming silty clay in the BCg horizon. There is a lot of fine gritty material in the Ah horizon. This is present but in much reduced amounts in the Ec horizon.

5. Matrix colours are medium value, low to medium chroma in the Ah and Ec horizons. The BCg horizon has prominent medium to high value, high chroma mottles in a pale yellow matrix.

6. Structure changes from fine crumb in the Ah to nutty in the Ec horizon and coarse blocky in the BCg horizon.

7. Worm mixing is pronounced in lower Ah and upper Ec horizons.

8. An O horizon resulting from a root mat may be present at the surface in soils of this Profile Class.

Profile 13 is nominated as typical of the Profile Class and is shown in Fig. 37. The full description of the E1 taxonomic unit is given in Appendix 24.

Figure 37. Profile Class E1 (Profile 56/13).

Site slope: 10^{o}. Elevation: approx. 280 m.
Topography: gently undulating broad interfluve.
Drainage: imperfectly drained.

cm

Ah 0 - 20

Brownish-grey (10yr 4/1) silt loam; weakly to moderately developed fine crumb structure; soft; profuse fine roots; indistinct, irregular boundary.

Ec 20 - 47

Dull yellow-orange (10yr 6/3) silty clay loam; moderately developed coarse, medium and fine nutty structure; stiff; many large concretions (up to 2 cm diameter) (10yr 1.7/1) and small soft concretions (7.5yr 6/8); many going to few fine roots; distinct, smooth boundary.

BCg 47 - 70

Pale yellow (5y 8/3) stony silty clay; abundant, medium, prominent orange (7.5yr 6/8) mottles; moderately developed, coarse blocky structure; firm.

Cg >70

Weathering greywacke orange (7.5yr 6/8) and black (5y 1.7/1) very bouldery silty clay; matrix light grey (5y 7/1).

* Each black or white division on depth-measuring tape represents 10 cm.


13

5.1.7.2 Profile Class E2.

Diagnostic Features.

This Profile Class may be regarded as a shallow phase of Profile Class E1. Important profile variations from Profile Class E1 are noted below:

1. The Profile Class has the following characteristic horizon sequence:-
   Ah
   E
   Bwg
   Cg.

2. Colluvial material underlying the topsoil has been deposited on previous colluvial material under influence of slope movement and these overlie an earlier phase of colluvial accumulation on bedrock greywacke.

3. The Ah horizon has many small pebbles, many smoothed and rounded.

4. The E horizon contains strongly weathered greywacke pebbles, angular stones and boulders.

5. The Bwg horizon has fewer stones and boulders than the overlying E horizon and these appear to be yet more strongly weathered than the greywacke material in the horizon above.

6. Large greywacke boulders in a matrix are located at the base of the profile and this was designated as the boundary between the Bwg horizon and the lower Cg horizon.

7. Textures of the matrix range from silt loam in the Ah to silt loam going to silt clay loam in the E horizon. The Bwg horizon has a silty clay matrix.

8. The matrix of the Ah horizon has low value and medium to high chroma colours, becoming colours of medium value, low to medium chroma in the E horizon. Mottling is a prominent feature of the Bwg horizon with high value, low to medium chroma mottles in a pale grey matrix, differentiating into veins with depth.

9. Concretions are present in the E and Bwg horizons though these are difficult to distinguish from strongly rotting rock.

10. There is evidence of worm mixing in the E horizon.

Profile 37 is nominated as typical of the Profile Class and is shown in Fig. 38. The full description of the E2 taxonomic unit is given in Appendix 25.

Figure 38. Profile Class E2 (Profile 69/37).

Site slope: 15^{o}. Elevation: approx. 260 m.
Topography: undulating sloping surface at location of relict sea cliffs.
Drainage: poorly to imperfectly drained.

cm

Ah 0 - 25

Brown (10yr 4/4) slightly stony silt loam; moderately developed fine and medium nutty structure; stiff; abundant fine roots; indistinct irregular boundary.

E 25 - 40

Greyish-yellow-brown (10yr 6/2) very bouldery silt loam to silty clay loam; brown (10yr 4/4) worm casts; weakly developed, fine and medium, nutty-crumb structure; firm; many fine roots; indistinct wavy boundary.

Bwg 44 - 85

Light grey (10yr 7/1) and dull yellow-orange (10yr 7/2) stony silty clay; profuse, coarse, prominent becoming abundant, coarser and distinct (with depth) orange (7.5yr 6/8) becoming yellow-orange (10yr 7/8) and orange (5yr 6/6, 6/8) mottles; massive structure; firm; few fine roots; diffuse, irregular boundary.

Cg >85

Light grey (2.5y 7/1) very bouldery silty clay; mottles as above; massive structure; very stiff; no roots.


37

5.1.7.3 Profile Class E3.

Diagnostic Features.

Soils in the Profile Class are similar to Profile Class E1 in that they are forming out of greywacke colluvium but lack an E horizon.

1. The soils of this Profile Class have the following characteristic sequence of horizons:-
   O (possible)
   Ah
   Bw or Bwg
   BCg
   Cg.

2. These soils may have a root mat designated an O horizon.

3. The B horizon is designated Bw or Bwg on the degree of mottling observed.

4. Small and large angular greywacke stones and boulders are found throughout the profile in a loessial matrix. There is a general trend from smaller pebbles in the upper profile going to larger boulders in the lower profile.

5. Matrix textures change from silt loam in the Ah horizon to silty clay loam in the Bw or Bwg horizons and silty clay in the BCg horizon.

6. Matrix colours are low value, medium to high chromas in the Ah horizon. There is variation in the prominence of mottling in the B horizon, as noted above. Mottling is a prominent feature of the BCg horizon and pale grey veins form in this horizon.

7. Structures range from crumb to nutty in the Ah horizon to blocky-polyhedral breaking to nutty in the Bwg horizon. The BCg horizon has a massive structure breaking

to blocky-polyhedral.

8. The soil has many concretions in the Ah, Bw/Bwg and BCg horizons. These are difficult to distinguish from strongly weathered rock fragments in the lower horizon.

9. Faint cutans were observed in the lower Bw/Bwg horizons of some soils in this Profile Class.

10. Worm mixing was observed to have taken place at the junction of the lower Ah and upper Bw/Bwg horizons and down bush root channels.

Profile 12 is nominated as typical of the Profile Class and is shown in Fig. 39. The full pedological description of the profile is given in Appendix 26.

Figure 39. Profile Class E3 (Profile 58/12).

Site slope: 12^{o}. Elevation: approx. 300 m.
Topography: hummocky topography on broad flat sloping surface.
Drainage: imperfectly drained.

cm

O 9+ - 0

Dark brown (10yr 3/3) silt loam; moderately developed medium crumb structure; soft; many fine roots; no visible boundary with Ah.

Ah 0 - (9 to 16)

Dull yellowish-brown (10yr 4/3) and brown (7.5yr 4/3) slightly stony silt loam; moderately developed, medium and coarse crumb structure; stiff to very stiff; many fine roots; distinct, wavy boundary.

Bwg (9 to 16) - (41 to 59)

Bright yellowish-brown (10yr 6/6) stony silty clay with brown (10yr 4/4) worm casts; many to abundant, madium, distinct, bright yellowish-brown (10yr 6/8) mottles; moderately developed, coarse blocky-polyhedral breaking to medium nutty structures; very stiff; some fine roots; indistinct irregular brounday.

BCg (41 to 52) - 73

Light brownish-grey (7.5yr 7/1) and light grey (10yr 7/1) bouldery silty clay; profuse to abundant, coarse to medium, prominent, orange (7.5yr 6/8) and dull yellow-orange (10yr 7/2) mottles; weakly coherent massive, breaking to blocky-polyhedral structure.


12

5.1.7.4 Profile Class E4.

Diagnostic Features.

This Profile Class has soils formed in a loess mantle, nesting on greywacke bedrock.

1. The Profile Class has the following characteristic sequence of horizons:-
   Ah
   Bwg
   BCg
   R.

2. The Ah and Bwg horizons do not contain stones in the loessial matrix though much fine gritty material was detected in the Ah horizon. Some few small rounded stones were observed in the BCg horizon.

3. The bedrock under the BCg horizon is strongly weathered greywacke that could not be penetrated with an auger.

4. Textures change from silt loams in the Ah lorizon to silty clay loam in the Bwg and silty clay in the BCg horizon.

5. Matrix colours change from medium value, low to medium chromas in the Ah horizon to higher chromas in the Bwg horizon. Mottling is present in the lower Ah horizon and is a notable feature of the Bwg and BCg horizons. The BCg horizon has medium to high value, high chroma mottles with a matrix of high value, low to medium chroma pale grey colours.

6. Structure changes from crumb in the Ah horizon to blocky in the Bwg and BCg horizons.

7. Cutans are present on the peds in the lower Bwg and upper BCg horizons.

8. There is considerable worm mixing in the lower Ah and upper Bwg horizons. Dark material from the Ah horizon is found down old bush root channels in the BCg horizons.

Profile 66 is nominated as typical of Profile Class E4 and is shown in Fig. 40. The full pedological description of the profile is given in Appendix 27.

Figure 40. Profile Class E4 (Profile 59/66).

Site slope: 0°. Elevation: approx. 300 m.
Topography: flat, gently undulating surface adjacent to deeply-incised gully channel.
Drainage: somewhat poorly drained.

cm

Ah 0 - 31

Dull yellowish-brown (10yr 5/3), bright yellowish-brown (10yr 6/6, 7/6) and dull brown (7.5yr 5/3) fine gravelly silt loam; many, fine, faint to distinct orange (7.5yr 6/8) mottles; moderately developed, coarse and very coarse crumb structure; firm; abundant fine roots; distinct, irregular boundary.

Bwg 31 - 56

Dull yellow (2.5y 6/4) silty clay loam; abundant to profuse, medium prominent orange (7.5yr 6/8) mottles; moderately to strongly developed, very coarse blocky structure; stiff; many fine roots; dull yellow (2.5y 6/3) cutans on peds; distinct, irregular boundary.

BCg 56 - 87

Light grey (5y 7/1 to 7.5y 8/1) stony silty clay; abundant, coarse, prominent bright brown (7.5yr 5/8) mottles; stiff; few fine roots; dull yellow (2.5y 6/3) cutans on peds; moderately developed, very coarse blocky structure; distinct, irregular boundary; rock fragments in matrix.

R >87

Strongly weathered greywacke boulders in light grey (7.5y 8/1) silty clay matrix.


66

5.1.7.5 Profile Class E5.

Diagnostic Features.

The soils of this Profile Class may be regarded as an erosive phase of Profile Class E4. They have formed in a shallow loess cover on greywacke bedrock.

1. Soils of this Profile Class have the following horizon sequence:-

   O
   Ah
   2Cg
   2R.

2. The soil has a root mat which overlies an Ah horizon that contains many angular greywacke stones, 2-6 cm in diameter. The 2Cg horizon is strongly weathered greywacke with loessial material present in cracks in the rock.

3. The Ah matrix is silt loam and the material in the cracks of the 2Cg horizon is silty clay loam in texture.

4. The Ah horizon has medium to high value, high chroma colours becoming medium value, low to medium chroma at its base. The material in the cracks of the 2Cg horizon appears to be mottled but it is difficult to distinguish mottling from colours due to strongly weathered rock particles.

5. The O and Ah horizons have a fine crumb and nutty structure.

6. Worm casts were observed in the cracks in the Cg horizon.

Profile 26 is nominated as typical of the Profile Class and is shown in Fig 41. The full pedological description of the profile is given in Appendix 28.

Figure 41. Profile Class E5 (Profile 65/26)

Site slope: 0^{o}. Elevation: 280 m.
Topography: hummocky, undulating interfluve.
Drainage: somewhat excessively drained.

cm

O +8 - 0

Dark brown (10yr 3/4) silt loam; moderately developed medium nutty and fine crumb structure; firm; abundant, fine roots; distinct smooth boundary.

Ah 0 - 22

Bright yellowish-brown (10yr 6/6) to dull yellow-orange (10yr 6/4) slightly stony silt loam; moderately developed coarse and medium nutty and fine crumb structure; very stiff; abundant fine roots; distinct, wavy boundary.

2Cg 30 - 57

Weathering rock plus brown (10yr 4/6) material with worm casts in cracks, silty clay loam (bouldery silty clay loam); abundant coarse, distinct orange (7.5yr 6/8) and dark reddish-brown (5yr 3/6) mottles; some fine roots in joints.

5.1.7.6 Profile Class E6.

Diagnostic Features.

Soils of this Profile Class have a topsoil derived from loessial material over a subsoil of marine gravels redeposited in a silty matrix.

1. Soils of the Profile Class have the following characteristic horizon sequence:-
   Ah
   E
   Bwg.

2. The Ah horizon is stone-free and overlies an E horizon that contains numerous fine rounded pebbles. The underlying Bwg horizon has many rotting rounded pebbles from 1-5 cm in diameter set in a silty matrix. Pebbles continued to be struch by the auger at 110 cm.

3. Textures change from silt loam in the Ah horizon to silt loam grading to silty clay loam in the E horizon. The Bwg horizon has a silty clay loam texture.

4. The Ah has a crumb structure that becomes nutty with depth before changing back to fine crumb in the E horizon. The Bwg horizon has a coarse blocky structure, becoming weakly coherent, massive with depth.

5. The Ah horizon has low value, medium to high chroma colours becoming medium value, low to medium chroma colours in the E horizon. There are abundant pinhead mottles in the Ah horizon and many, fine becoming medium, prominent, medium to high value, high chroma mottles in the Bwg horizon. The mottles are yellowish brown going to orange coloured with depth in a light grey matrix.

6. Worm mixing appears to have been active in the E horizon.

Profile 27 was representative of the Profile Class and is shown in Fig. 42. The full pedological description of the profile is given in Appendix 29.

Figure 42. Profile Class E6 (Profile 52/27).

Site slope: approx. 8^{o}. Elevation:
Topography: gently undulating broad interfluve.
Drainage: imperfectly drained.

cm

Ah 0 - 16

Dull yellowish-brown (10yr 4/3, 5/3) silt loam; abundant pinhead mottles (5yr 5/8); weakly developed fine and medium crumb structure; firm; many fine roots; indistinct irregular boundary.

E 16 - 26

Dull yellowish-brown (10yr 5/3) merging to dull yellow (2.5y 6/3) silt loam becoming silty clay loam; weakly developed very coarse nutty becoming fine crumb structure; stiff; many fine roots; indistinct, irregular boundary.

Bwg 26 - >110

Dull yellow (2.5y 6/4) slightly stony silty clay; many, fine becoming medium, prominent bright yellowish-brown (10yr 6/8) mottles; (matrix light grey (7.5y 7/1), mottles orange (7.5yr 6/8) with depth); weakly developed developed, coarse blocky structure, going to weakly coherent, massive structure with depth.

5.1.7.7 Profile Class E7.

Diagnostic Features.

Soils of this Profile Class have a topsoil derived from loessial material over a subsoil containing an unsorted mixture of angular greywacke stones, boulders and marine gravels in a silt loam to sandy loam matrix. It is considered that the subsoil was formed in material redeposited by erosion processes in two erosive phases, capped by loess.

1. The soils of the Profile Class have the following characteristic horizon sequence:-
   Ah
   2C
   3C
   R.

2. The Ah horizon has a silt loam texture derived from loessial material and is stone-free.

3. The 2C horizon has angular greywacke stones and boulders from a few centimeters to 32 cm major dimension, set in a silt loam to sandy loam matrix. The greywacke material is not noticeably rotted.

4. The 3C horizon has mixed angular greywacke stones and marine gravels ranging from 2 cm to 19 cm major dimension set in a silty to sandy loam matrix. This material appears to be more strongly weathered than that contained in the 2C horizon.

5. The R horizon is very strongly weathered greywacke basement rock.

6. Mottling is not present in the profile of this Class.

7. The Ah horizon has a crumb structure.

8. The matrix colour of the Ah horizon has low values, medium to high chromas, changing to colours of medium value, low, medium chromas in the 2C horizon.

Profile 2 is nominated as typical of the Profile Class and is shown in Fig. 43. The full pedological description of the profile is given in Appendix 30.

Figure 43. Profile Class E7 (Profile 67/2).

Site slope: 0°. Elevation: approx. 240 m.
Topography: flat to gently undulating broad interfluve surface.
Drainage: moderately well drained.

cm

Ah 0 - 12

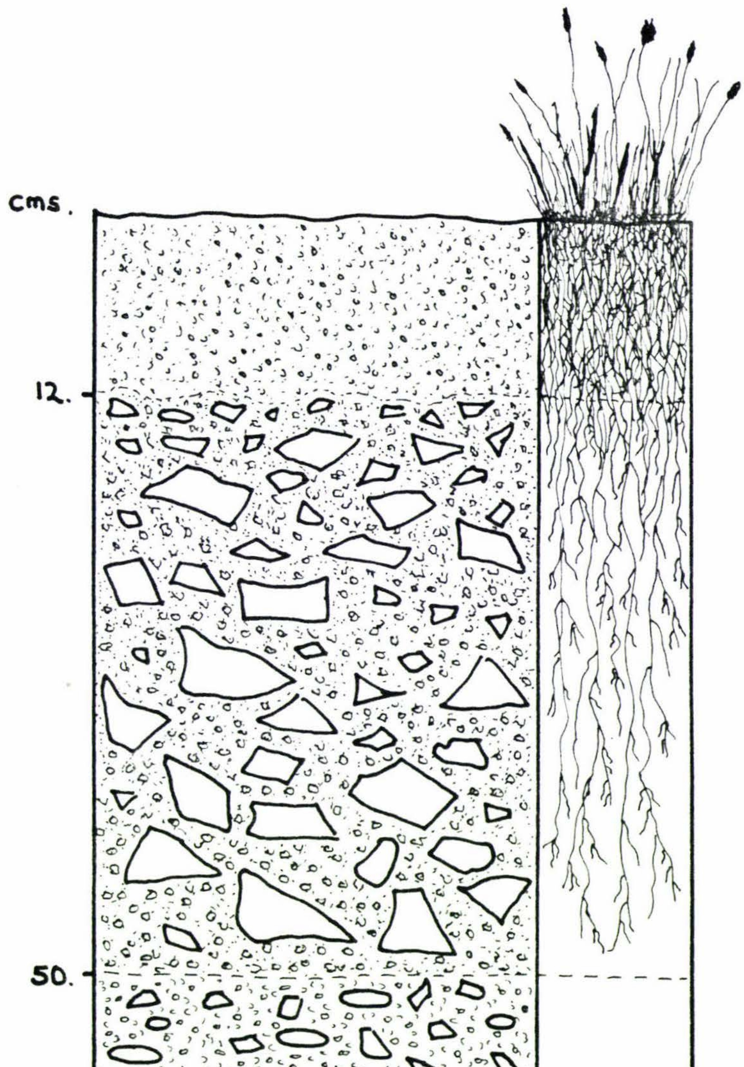
Dark brown (7.5yr 3/3) silt loam; weakly to moderately developed, fine medium and coarse crumb structure; firm; many fine roots; distinct smooth boundary.

2C 12 - 20

Dull yellowish-brown (5yr 5/4) and dull reddish-brown (2.5yr 5/4) bouldery silt loam to bouldery sandy loam; weakly to moderately developed, fine, medium and coarse crumb structure; very stiff; many fine roots.

3C >50

As above, very stony silt loam to sandy loam; strongly weathered greywacke stones.


cms.
12.
50.
65.

5.1.8 Profile Group F - Introduction.

This Profile Group contains 2 Profile Classes with the upper part of their profiles formed in slopewash material.

Profile Class F1 is formed from slopewash loessial material overlying loess on greywacke bedrock.

Profile Class F2 was formed from slopewash loessial material overlying deep loess.

5.1.8.1 Profile Class F1.

Diagnostic Features.

Soils from this Profile Class have formed from slopewash loessial material overlying loess on greywacke. The buried loess on greywacke in the subsoil may be regarded as a buried soil from Profile Class E4.

1. The characteristic sequence of horizons for soils in this Profile Class is as follows:-
   0
   Ah
   BAc
   2Bwc
   2BCg
   3R.

2. The Ah and BAc horizons are considered to have been formed from slopewash material deposited on existing loess of the 2Bwc horizon.

3. The soil has an O horizon due to the presence of a root mat.

4. There are many strongly weathered, angular stones in the upper part of the 2Bwc horizon. These are less common in lower 2Bwc.

5. The 2BCg horizon is a transition horizon to strongly weathered greywacke.

6. Textures in the Ah and BAc horizons are silt loam. This contrasts with sandy clay loam in the 2Bwc horizon and in the matrix of the 2BCg horizon. This sandy texture is due to the presence of fine rock particles in these horizons.

7. Rust staining is a prominent feature of the 2Bwc horizon

especially in the upper horizon. There is some faint mottling at its lower boundary with the 2BCg horizon. The matrix of the 2BCg horizon has prominent strong brown mottling.

8. Structures vary from nutty in the Ah and BA horizons to blocky in the 2Bwc horizon.

9. There are profuse pinhead concretions in the BAc horizon and many hard larger concretions in the 2Bwc horizon, concentrated in the lower area of the horizon.

10. Cutans were observed in the upper 2Bwc horizon.

11. Worm mixing is a notable feature of the Ah and BAc horizons and this process is incorporating the BAc horizon into the Ah horizon. Dark material from the Ah horizon is also carried down old root channels into the BAc horizon.

12. Matrix colours change from low value, medium to high chromas in the Ah and upper BAc horizons to medium to high value, high chromas in the lower BAc and 2Bwc horizons. The 2BCg horizon characteristically contains low value, medium to high chroma mottles set in a high value, low to medium chroma grey matrix.

Profile 24 is nominated as typical of the Profile Class and is shown in Fig. 44. The full pedological description of the profile is given in Appendix 31.

Figure 44. Profile Class F1 (Profile 57/24).

Site slope: 0^o. Elevation: 260 m.
Topography: flat to very gently undulating surface on interfluve at location of relict sea cliffs.
Drainage: imperfectly drained.

cm

O +9 - 0

Brown (7.5yr 4/3) silt loam; moderately developed medium and fine crumb and nutty structure; soft; profuse to abundant fine roots; distinct, smooth boundary.

Ah 0 - 15

Brown (10yr 4/3) and dull brown (10yr 5/4) silt loam; moderately developed, coarse, nutty structure; very stiff; profuse to abundant roots; distinct, smooth boundary.

BAc 15 - (37 to 43)

Reddish-brown (10yr 4/6), bright reddish-brown (10yr 5/6, 5/8), brown (7.5yr 4/3) and dull yellowish-brown (10yr 5/4) silty clay loam; moderately developed, medium and coarse nutty structure; profuse, pinhead bright reddish-brown (5yr 5/8) concretions; very stiff; many fine roots; indistinct, wavy boundary.

2Bwc 52 - 92

Bright brown (7.5yr 5/6), becoming orange (7.5yr 6/6) sandy clay loam (sandy texture from greywacke fragments in matrix); light yellow (2.5y 7/3) mottles, becoming bright brown (7.5yr 5/8) and light yellow (5y 7/4) near base of horizon; weakly developed, coarse blocky structure; very stiff; few fine roots; concretions: many; colours are light greenish-grey (7.5Gy 6/1, 7/1), black (7.5yr 1.7/1) surrounded by bright reddish-brown (5yr 5/8) material and also dark reddish-brown (2.5yr 3/6). Sharp smooth boundary.

2BCg >92

Light yellow (7.5y 7/3) sandy clay loam; abundant, coarse, prominent reddish-brown (5yr 4/8) and bright reddish-brown (5yr 5/8) mottles (2.5yr 4/8); massive structure; very stiff; no roots.

3R

Strongly weathered greywacke.


24

5.1.8.2 Profile Class F2.

Diagnostic Features.

Soils of this Profile Class have formed from slopewash loessial material overlying deep loess. The buried loess material in the subsoil may be regarded as a buried Profile Class C1.

1. Soils of the Profile Class have the following characteristic horizon sequence:-
   O
   Ah
   BA
   2Bwg
   2BCxg

2. The soil has an O horizon due to the presence of a root mat.

3. The Ah and BA horizons are considered to be slopewash material deposited on previously existing loessial material that now makes up the 2Bwg and 2BCxg horizons of the profile.

4. Textures range from silt loam in the Ah and BA horizons to silty clay loam in the 2Bwg and silty clay loam becoming silty clay in the 2BCxg horizon.

5. There is some mottling in the lower BA horizon and at the lower boundary of the 2BCx horizon. The columnar/prismatic structural units of the 2BCxg are separated by pale grey soil-filled veins.

6. There are a few concretions at the lower boundary of the BA horizon. Pinhead concretions were observed in the upper half of the 2Bwg horizon.

7. Structures are nutty or polyhedral in the Ah and BA

horizons. The upper 2Bwg has a blocky structure that becomes polyhedral breaking to fine crumb in the lower half of the horizon. The 2BCxg horizon has a columnar/ prismatic structure with massive intrusions.

8. There are some cutans on the peds in the upper 2Bwg horizon.

9. Worm mixing is a notable feature of the Ah and BA horizons and the BA horizon is being incorporated into the Ah horizon.

10. Matrix colours have medium values, low to medium chromas in the Ah horizon and upper BA horizon merging to medium to high values, high chromas in the 2Bwg horizon with brown mottles in the Bwg horizon of medium values, low to medium chromas. The 2BCxg horizon has brown mottles with medium to high values, high chromas and pale grey colours of high values, low to medium chromas.

11. The matrix of lower 2 Bwg is soft, wet and easy to dig, suggesting seepage in the subsoil.

Profile 40 is typical of this Profile Class and is shown in Fig. 45. The full pedological description of the profile is given in Appendix 32.

Figure 45. Profile Class F2 (Profile 56/40)

Site slope: 0^{o}. Elevation: approx. 240 m.
Topography: summit of gently sloping mound on broad interfluve.
Drainage: moderately well drained to well drained.

cm

O +8 - 0

Dull yellowish-brown (10yr 4/3, 5/3) silt loam; weakly developed, fine and medium crumb structure; firm; abundant fine roots; distinct, smooth boundary.

Ah 0 - 22

Dull and bright yellowish-brown (10yr 5/3, 6/6) silt loam; strongly developed, coarse nutty structure; stiff; many fine roots; distinct, smooth boundary.

BA 22 - 37

Dull and bright yellowish-brown (10yr 5/3, 6/6) silt loam; many fine faint orange (7.5yr 6/8) mottles at lower boundary; moderately developed, fine and medium blocky-polyhedral structure; very stiff; many, fine roots; indistinct, irregular boundary.

2Bwg 37 - 84

Dull yellowish-orange (10yr 6/4) silty clay loam; bright brown (7.5yr 5/8), orange (7.5yr 6/8), and light grey (5y 7/2) mottles at lower boundary; weakly developed blocky structure breaking to fine crumb in lower horizon; very stiff becoming stiff with depth; many fine roots;

2BCx >84

Light grey (5y 7/1) silty clay; many fine and medium, prominent bright brown (7.5yr 5/8) and orange (7.5yr 6/8) mottles; massive structure; very stiff.

5.2 Pedological Legend.

(To be used in conjunction with the Base Map 1).

5.2.1 Profile Group A.

Soils from deep loess with possible admixtures of volcanic ash and characterized by an allophanic clay mineralogy.

Profile Classes in Profile Group A have the following differentiating features:

Profile Class A1:

Soils with discrete Aokautere Ash layer in the lower part of the profile at >80 cm.

Representative Profiles: 65/14, 65/18, 62/25.

Profile Class A2:

Soils with Aokautere Ash present as a textural modifier only, in the lower silty clay loam horizon.

Representative Profiles: 64/3, 61/4 63/20.

Profile Class A3:

Soils with discrete Aokautere Ash layer present in the lower part of the profile at <80 cm.

Representative Profiles: 64/9, 62/19.

Profile Class A4:

Soils with discrete Aokautere Ash layer present and greywacke bedrock at the base of the profile pit at <120 cm.

Representative Profile: 60/11.

Profile Class A5:

Soils with Aokautere Ash absent from profile and greywacke bed-rock at the base of the profile pit at <120 cm.

Representative Profile: 63/16.

Profile Class A6:

Soils with discrete Aokautere Ash layer present in the profile and fragipan-like morphology present below the Aokautere Ash layer.

Representative Profile: 69/7.

Profile Class A7:

Soils with Aokautere Ash absent as a textural modifier or discrete layer and no basement greywacke within normal profile depth.

Representative Profiles: 63/17, 54/67.

5.2.2 Profile Group B.

Profile Class B1:

Soils formed from deep loess with an eluvial E horizon.

Reference Profiles: 49/29, 48/32, 72/42, 70/46, 74/50,
33/51, 73/54, 47/58, 47/60, 42/62.

Profile Class B2;

Soils formed from deep loess with an eluvial E horizon and fine sand fraction significant in the matrix at >70 cm.

Reference Profiles: 69/8, 37/31, 33/35, 70/49, 50/69.

Profile Class B3:

Soil formed from deep loess with an eluvial E horizon and fine sand fraction significant at <70 cm.

Reference Profile: 71/41.

Profile Class B4:

Soils formed from loess with an eluvial E horizon and a 2C horizon comprising marine sands at base of profile.

Reference Profiles: 67/1 , 69/44, 57/65

Profile Class B5:

Soil similar to Profile Class B1 but with redeposited marine gravels in the upper part of the profile.

Reference Profile: 37/38.

Profile Class B6:

Soil similar to Profile Class B3, having fine sand present in the profile at <70 cm but with redeposited marine gravels in the upper part of the profile.

Reference Profile: 70/55.

Profile Class B7:

Hill associate of Profile Class B1, with foreshortened profile.

Reference Profiles: 62/6, 58/22.

5.2.3 Profile Group C.

Profile Class C1:

Soils formed from deep loess, possessing a Bwg but lacking an E horizon.

Reference Profiles: 54/21, 66/23, 69/43, 69/52, 51/~~64~~68, 57/64, 50/70, 50/71, 36/72.

Profile Class C2:

Soils formed from deep loess having Bwg horizon but no E horizon and with fine sand significant at >70 cm.

Reference Profiles: 69/43, 69/52, 57/64.

Profile Class C3:

Soil formed from deep loess, having a Bwg but no E horizon and with fine sand present at <70 cm.

Reference Profile: 36/73.

Profile Class C4:

Soils formed from loess with a Bwg, no E horizon, and a horizon consisting of marine sand present at the base of the profile.

Reference Profiles: 52/28, 71/45.

Profile Class C5:

Soil formed from shallow loess mixed with sand and overlying a 2C sandy horizon.

Reference Profile: 47/56.

Profile Class C6:

Overdeepened associate of Profile Class C1 due to earthflow processes under gravity.

Reference Profile: 60/5.

5.2.4 Profile Group D.

Profile Class D1:

Soils formed from loess mantle over marine siltstone.

Reference Profiles: 38/33, 39/36, 37/39, 40/61.

Profile Class D2:

Soil formed from loess mantle over undisturbed marine gravels.

Reference Profile: 47/57.

Profile Class D3:

Soils formed from shallow loess mantle over undisturbed marine gravels.

Reference Profiles: 52/30, 70/47, 70/48, 47/59, 52/63.

5.2.5 Profile Group E.

Profile Class E1:

Soil formed from colluvium overlying greywacke and possessing an E horizon.

Reference Profile: 56/13.

Profile Class E2:

Soil formed from shallow loess overlying greywacke colluvium and possessing an E horizon.

Reference Profile: 69/37.

Profile Class E3:

Soils similar to Profile Class E1 but lacking an E horizon.

Reference Profiles: 65/10, 58/12, 65/15.

Profile Class E4:

Soil formed from loess cap directly overlying bedrock greywacke and lacking an E horizon.

Reference Profile: 59/66.

Profile Class E5:

Soil formed in very thin loess overlying bedrock greywacke (erosive phase of Profile Class E4).

Reference Profile: 65/26.

Profile Class E6:

Soil formed from loess overlying marine gravels redeposited in a silty matrix.

Reference Profile: 52/27.

Profile Class E7:

Soil formed from loess overlying an unsorted mixture of angular greywacke stones, boulders and marine gravels in a silt loam to sandy loam matrix.

Reference Profile: 67/2.

5.2.6 Profile Group F.

Profile Class F1:

Soil formed from loessial slopewash material overlying greywacke.

Reference Profile: 57/24.

Profile Class F2:

Soil formed from deep loessial slopewash material.

Reference Profile: 56/40.

5.3 Physiographic Legend. (To be read in conjunction with Figure 6, page 28).

Physiographic Unit 1 (U1)

Profile Group A: Profile Classes A1, A2, A3, A4, A5, A7.
Profile Group C: Profile Class C1.
Profile Group E: Profile Classes E3, E4, E5.

Physiographic Unit 2 (U2)

Profile Group B: Profile Class B7.
Profile Group C: Profile Class C6.
Profile Group E: Profile Classes E1, E2, E3.
Profile Group F: Profile Class F1.

Physiographic Unit 3 (U3)

Profile Group A: Profile Class A6.
Profile Group B: Profile Classes B1, B2, B3, B4.
Profile Group C: Profile Classes C1, C2, C3, C4, C5.
Profile Group D: Profile Classes D2, D3.
Profile Group E: Profile Classes E6, E7, E4, E5.
Profile Group F: Profile Class F2.

Physiographic Unit 4 (U4)

Profile Group B: Profile Classes B1, B2, B3, B5, B6.
Profile Group C: Profile Classes C1, C3.
Profile Group D: Profile Classes D1, D2, D3.

5.4 An Investigation of Soil Parameters Related to Soil Genesis.

5.4.1 General Introduction.

Particle size analyses and clay mineralogical analyses were undertaken on five soils, nominated to represent their respective Profile Classes, as follows:-

Profile 18, representing Profile Class A1;

Profile 7, representing Profile Class A6;

Profile 50, representing Profile Class B1;

Profile 1, representing Profile Class B4;

Profile 70, representing Profile Class C1.

5.4.2 Particle Size Analysis.

5.4.2.1 Introduction.

Particle size analyses were undertaken on the five selected profiles (see 5.4.1) in order to obtain information on the origin and variability of parent materials as well as evidence relating to pedogenic processes operating in the area.

5.4.2.2 Materials and Methods.

It was required that the particle size distributions obtained from analyses accurately represented the particle size distribution in the soil horizons. Pre-treatments were necessary therefore to counter the cementing effects of Fe and Mn oxyhydroxide compounds and to eliminate organic matter. Sodium dithionite was used to reduce Fe and Mn compounds, and hydrogen peroxide to digest organic matter in the Ah horizon.

Accurately weighed samples of approximately 75 gm were taken for each horizon of the soils and dispersed in an appropriate container in distilled water. The container was initially manually shaken and then ultrasonically dispersed for 2 minutes at 20 kHz. Dispersed samples from Ah horizons were then treated with 6% H_2O_2 and left for 1 week before further treatments.

All samples were further treated by adding 1-2 gm of sodium dithionite following buffering to pH 7 with 1M sodium bicarbonate. Heating to 80°C in a water bath was required to complete the reduction of Fe and Mn compounds. The samples were then centrifuged and washed twice with distilled water.

For each sample the sand fraction, >63 μm, was separated from the silt and clay fractions by wet sieving at 63 μm, dried and split into the following fractions: >500 μm, 250-500 μm, 125-250 μm and 63-125 μm. The suspension containing the <63 μm was placed in a 1ℓ cylinder and thoroughly dispersed following the addition of sodium hexametaphosphate and sufficient distilled water to bring the volume up to 1ℓ. It was found that buffering to pH 10 using NH_4OH

aided dispersion.

Subsamples of 20 ml were withdrawn by pipette at a depth of 100 mm during sedimentation of samples for the following times:

0, 2 mins., 8 mins., 30 mins., 2 hrs., 8 hrs. and 24 hrs.

for all profiles and additional subsamples were taken at 5 days and 10 days for profiles 50 and 70.

Temperature was critical during sedimentation as it affected the water viscosity and was therefore noted throughout the setting time so that the necessary adjustment could be made for the viscosity coefficient during later calculations. Variations in temperature did not exceed 3°-4°C day or night.

The subsamples were dried in an oven in polypropolene beakers at 105°C and weighed. Equivalent spherical diameters were calculated from Stoke's Law.

The cumulative percentage at each particle size class was plotted to obtain cumulative percentage curves and histograms were derived from these for each horizon.

5.4.2.3 Results of Particle Size Analyses.

5.4.2.3.1 - Profile 18 (nominated as typical for Profile Class A1).

Particle size distribution curves for horizons of the profile are shown in Fig. 46. The distribution of clay as a percentage of the mineral fraction in horizons down the profile is shown in Fig. 47. Results of the mechanical analysis of the profile are given in Table 1.

A. The particle size distribution curves for Ah1, BA, Bw1 and Bw3 horizons of the soil are very symmetrical and peak up strikingly in the coarse silt fraction with modes between 32 μm and 37 μm. The Ah2 horizon shows a distinctly different particle size distribution with a mode at 17 μm in the medium silt fraction. Its particle size curve is also less peaked and encompasses a wide spread of material. The 2Bw2 horizon (Aokautere Ash) has a particle size distribution curve with two peaks in the >2μm fraction, a primary mode at 19 μm in the coarse silt bordering on medium silt fraction and a secondary mode at 85 μm in the fine sand fraction.

B. The clay component shows increasing clay percentages down the profile from the Ah1 and Ah2 to BA horizons (ca 29% and 32% respectively). The percentage of clay falls in the Bw1 horizon to 24%, rises again in the 2Bw2 horizon to 29.75%, only to fall to 24.5% in the Bw3 horizon.

5.4.2.3.2 - Profile 7 (nominated as typical for Profile Class A6).

Particle size distribution curves for horizons of the profile are shown in Fig. 48. The distribution of clay as a percentage of the mineral fraction in horizons down the profile is shown in Fig. 49. Results of the mechanical analysis of the profile are given in Table 2.

Figure 46. Profile 18 - particle size distribution curves.

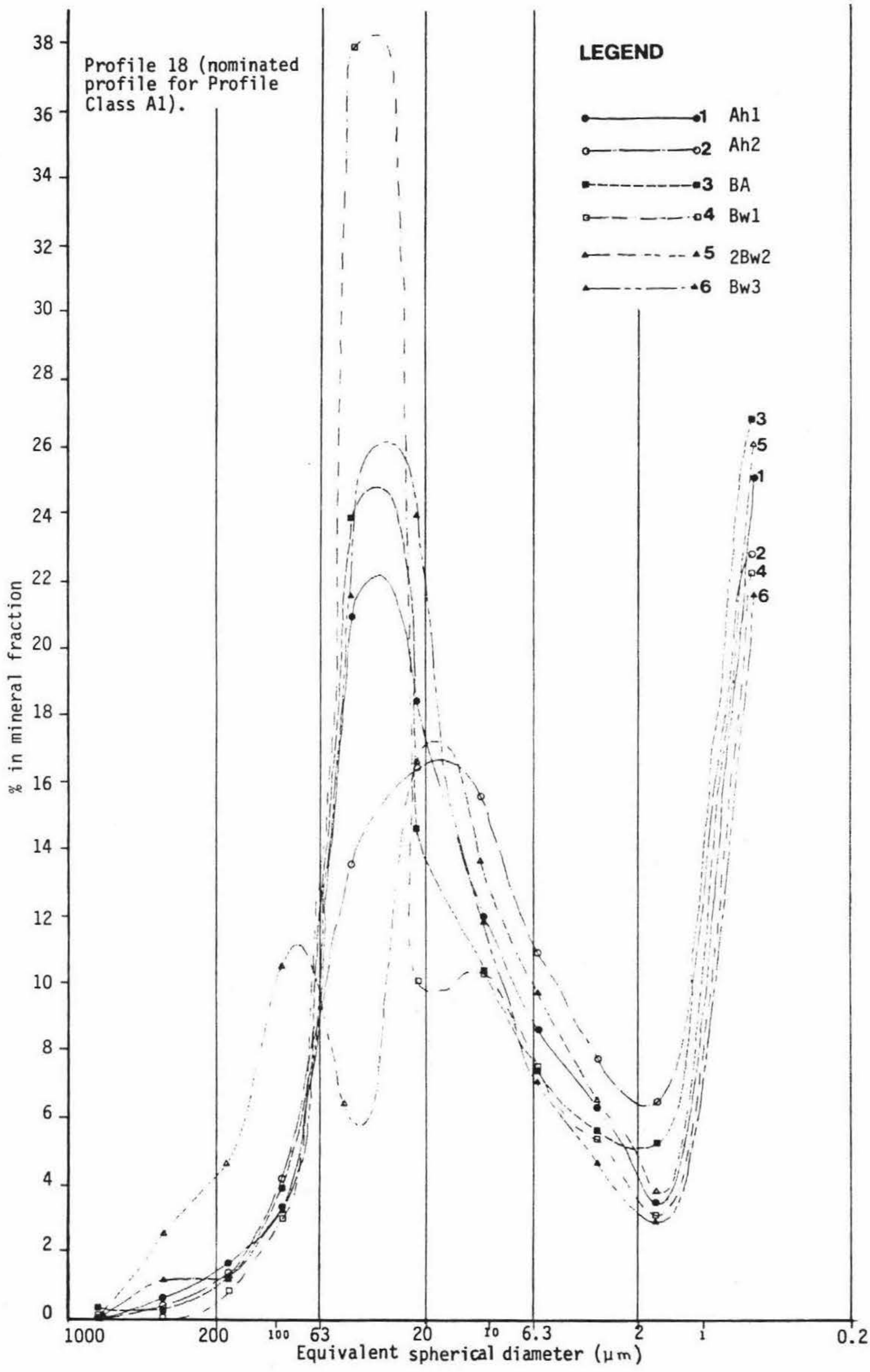


Figure 47. Profile 18 (nominated profile for Profile Class A1) - Distribution of clay as percentage of mineral fraction.

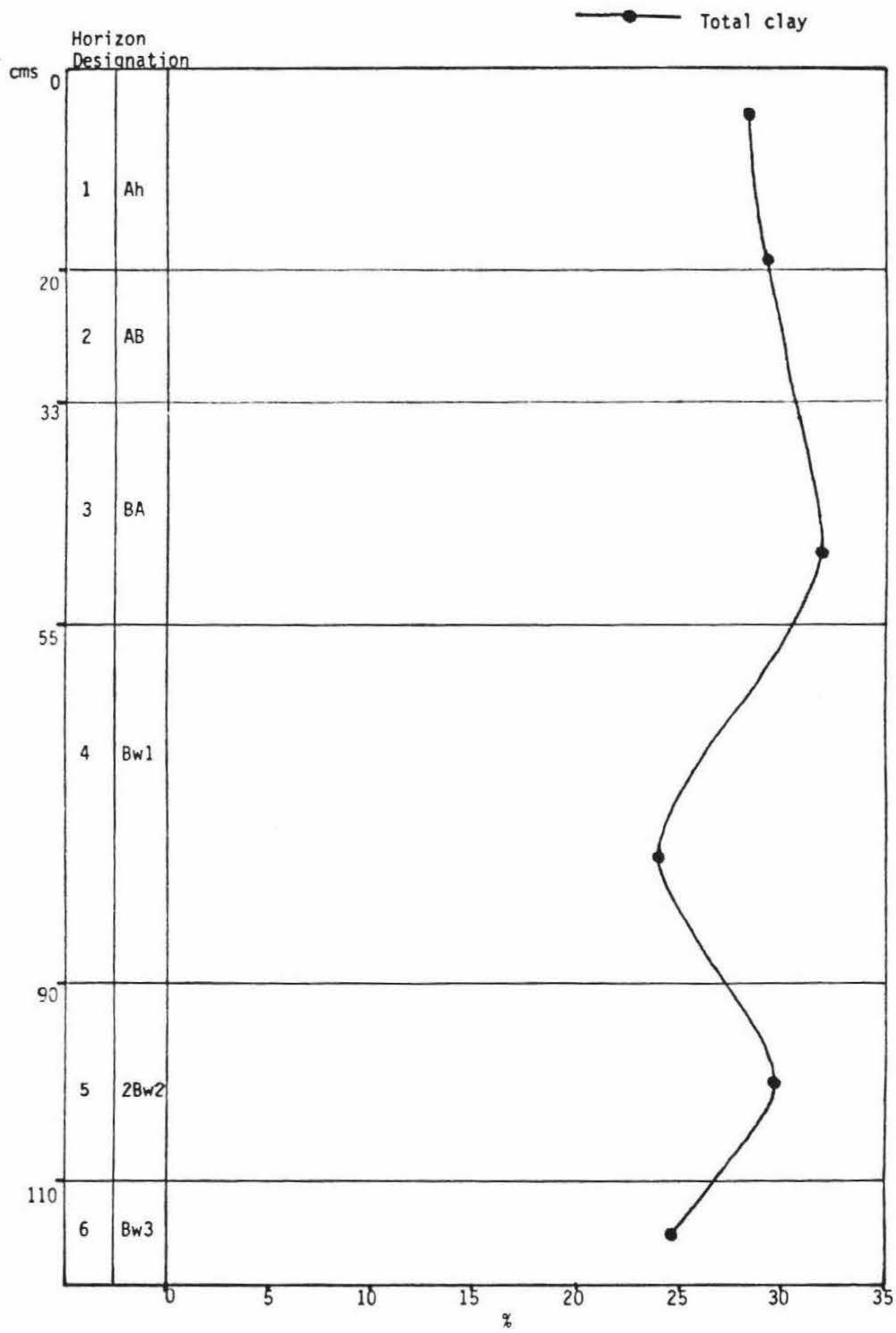


Table 1. Profile 18 - particle size analysis.

Equivalent spherical diameter (μm)

Horizon		>200 cse.sa. %	>63 f.sa. %	>20 cse.si. %	>6.3 m.si. %	>2 f.si. %	<2 cy. %
1	Ah1	1.1	4.5	31.3	23	12	28.5
2	Ah2	1.1	5.4	23.5	27	14	29.5
3	BA	1.25	4.35	33.4	19	10	32
4	Bw1	.25	3.5	43.25	18	10.5	24
5	2Bw2	4	14	16	23.5	12.5	29.75
6	Bw3	1.8	4.1	34.6	26	9.5	24.5

Figure 48. Profile 7 - particle size distribution curves.

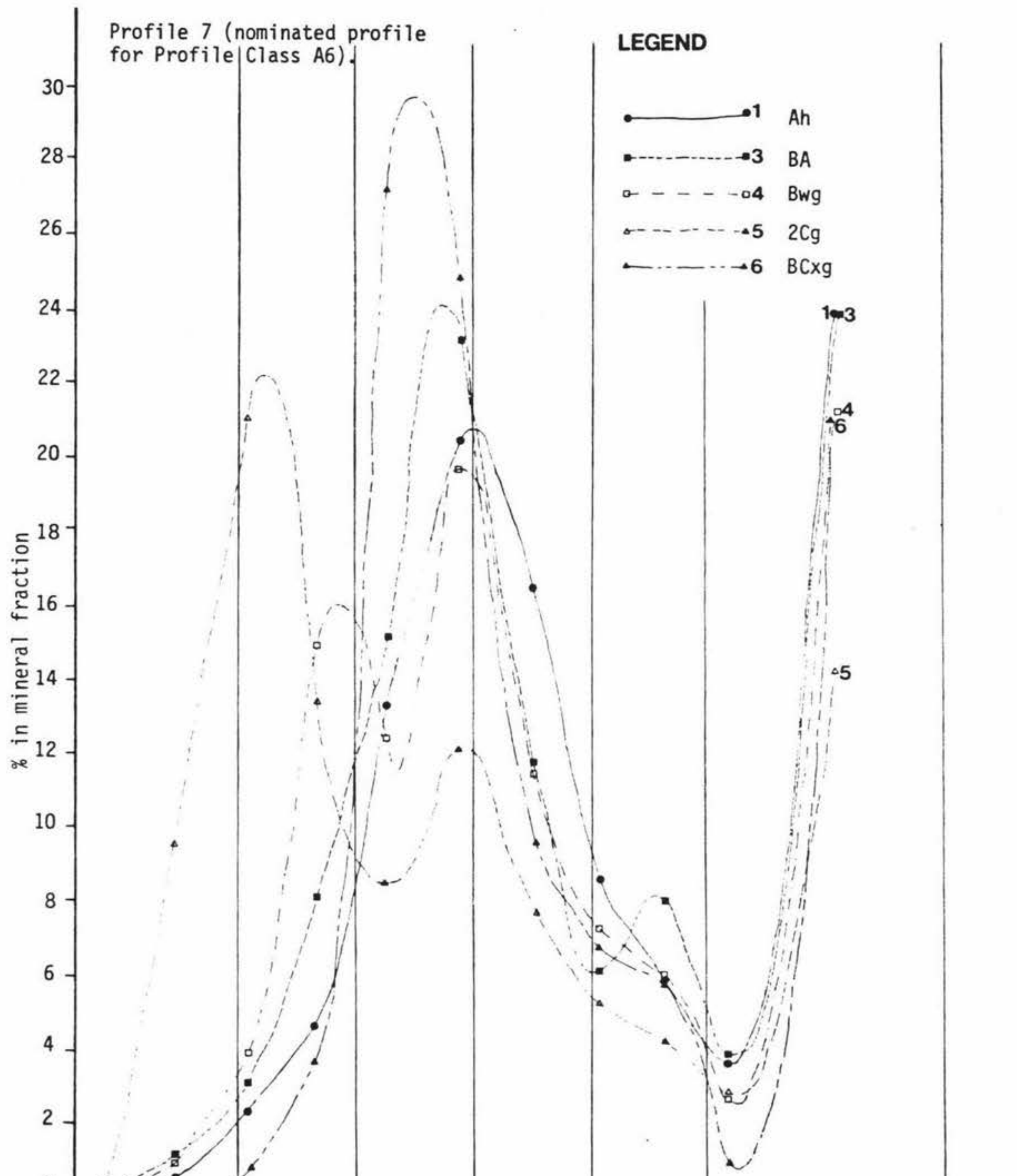


Figure 49. Profile 7 (nominated profile for Profile Class A6) - Distribution of clay as percentage of mineral fraction.

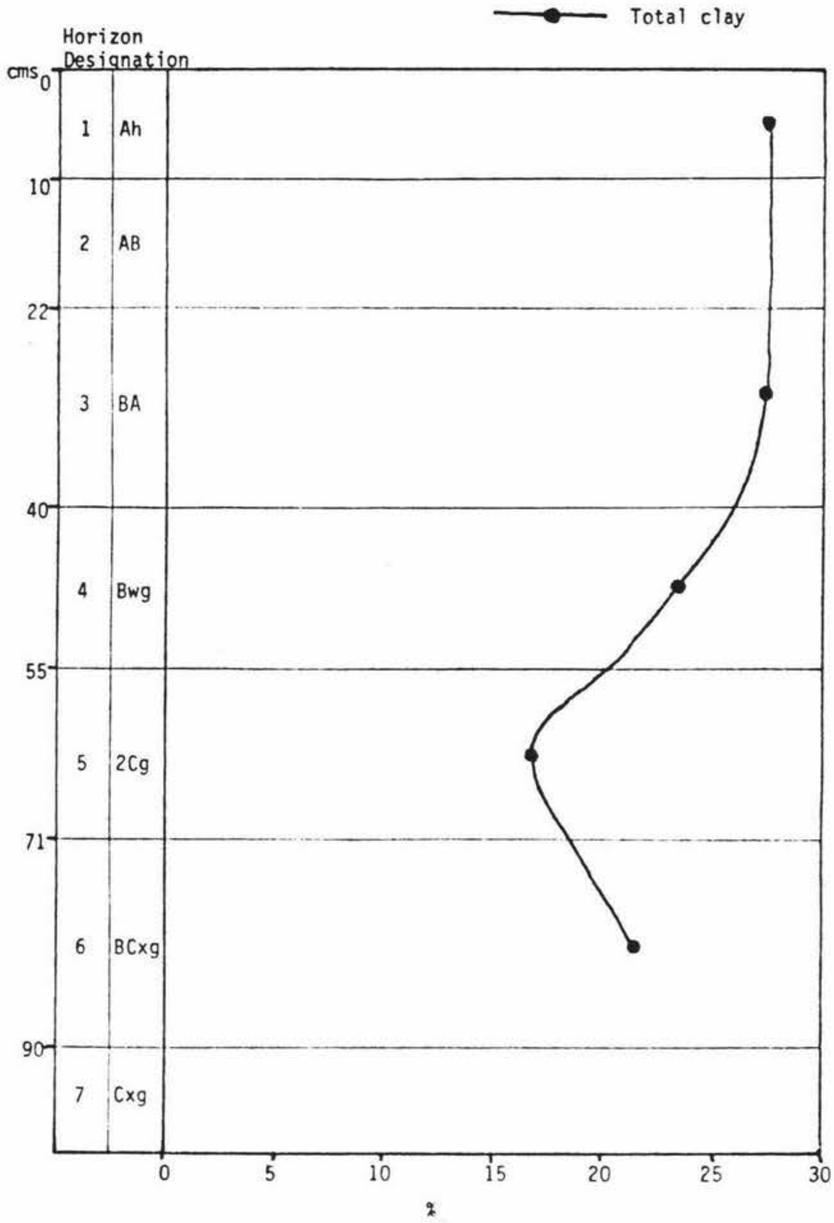


Table 2. Profile 7 - particle size analysis.

		Equivalent spherical diameter (μm)					
Horizon		>200 cse.sa. %	>63 f.sa. %	>20 cse.si. %	>6.3 m.si. %	>2 f.si. %	<2 cy. %
1	Ah	1.2	6.4	26	28	11	27.5
2	BA	1.6	6.3	29	23.5	12	27.5
3	Bwg lower	2	17.95	23	23	10.5	23.5
4	2Cg	15.5	29	15.5	15.5	7.5	16.9
5	BCxg	.35	4	44	20.5	9.5	21.5

A. The particle size distribution curves for the Ah and BA horizons of this soil and the BCxg horizon at the base of the profile exhibit symmetry and peak up strikingly around the coarse and medium silt fractions with modes at 20 μm, 27 μm and 35 μm respectively.

The curves for the Bwg and 2Cg horizons exhibit symmetry around two peaks in the >2 μm fraction. The Bwg horizon has a primary mode at 23 μm in the coarse silt fraction and a secondary mode at 75 μm in the fine sand fraction, while the 2Cg horizon exhibits a primary mode at 155 μm in the fine sand fraction and a secondary mode at 23 μm in the coarse silt fraction.

B. The clay component is constant in the Ah and BA horizons at 27.5% and falls to 23.5% in the Bwg horizon and 16.9% in the 2Cg horizon before rising again to 21.5% in the BCxg horizon.

5.4.2.3.3 - Profile 50 (nominated as typical for Profile Class B1).

Particle size distribution curves for horizons of the profile are shown in Fig. 50. The distribution of clay as a percentage of the mineral fraction in horizons down the profile is shown in Fig. 51. Results of mechanical analysis of the profile are given in Table 3.

A. The particle size distribution curves for all horizons of the profile exhibit symmetry and peak up around the coarse silt fraction. However there was a spread of material into the medium silt fraction. Curves have modes between 20 μm and 30 μm.

B. There is striking variation in the clay component down the profile of this soil. Percentages of clay fall from 20.5% to 16% from the Ah to Eg horizons but rise progressively from 27% to 31% in the Btg1 and Btg2 horizons before falling back again to 26% in the upper Cxg horizon. This trend is due to changes in the percentage of fine clay (<0.1 μm) down

Figure 50. Profile 50 - particle size distribution curves.

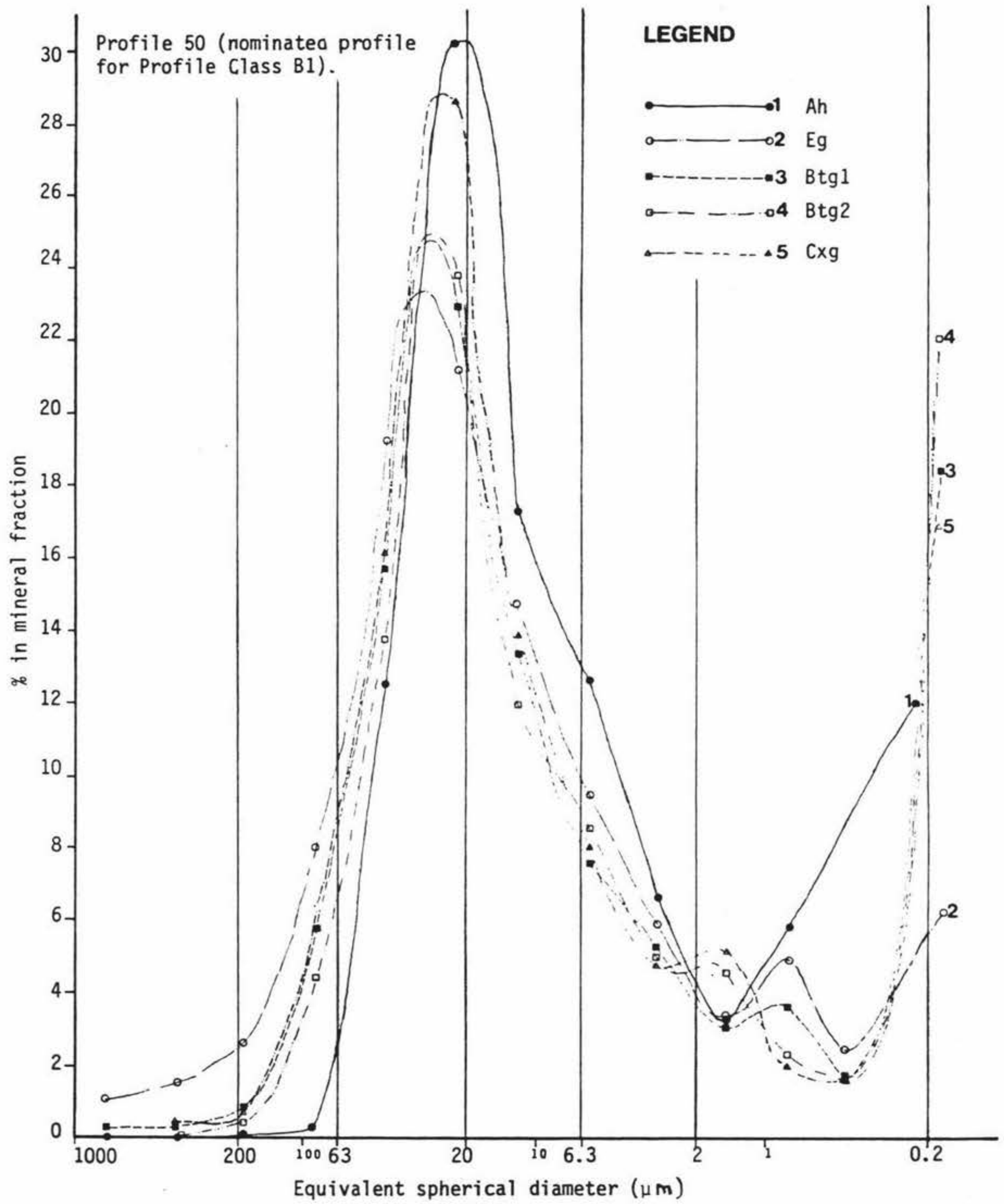


Figure 51. Profile 50 (nominated profile for Profile Class B1) - Distribution of clay as percentage of mineral fraction.

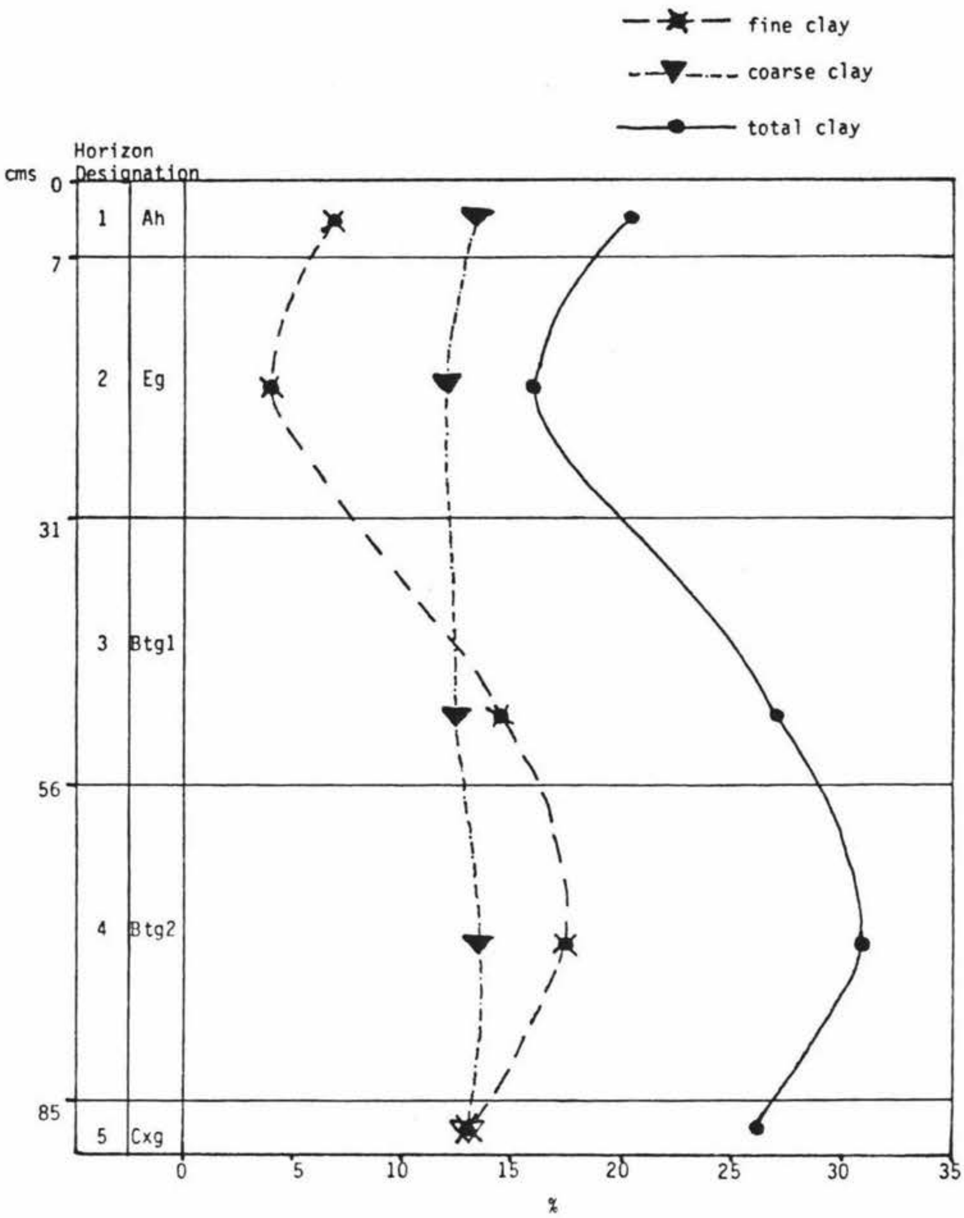


Table 3. Profile 50 - particle size analysis.

Equivalent spherical diameter (μm)

Horizon		>200 cse.sa. %	>63 f.sa. %	>20 cse.si. %	>6.3 m.si. %	>2 f.si. %	>0.2 cse.cy. %	<0.2 f.cy. %	T.cy. %
1	Ah	.02	.35	30.5	33.5	15	13.5	7	20.5
2	Eg	4.2	9.8	32	26	12	12	4	16
3	Btg1	1.3	5.7	30	25	11	12.5	14.5	27
4	Btg2	.5	6.5	28	24	10	13.5	17.5	31
5	Cx	5	6	29	24	10	13	13	26

the profile as coarse clay (0.1 μm) is fairly constant with depth. The fine clay constituent fell from 7% in the Ah horizon to 4% in the Eg horizon and rose sharply to 14.5% and 17.5% in the Btg1 and Btg2 horizons before falling to 13% in the upper Cxg horizon.

5.4.2.3.4 - Profile 1 (nominated as typical for Profile Class B4).

Particle size distribution curves for horizons of the profile are shown in Fig. 52. The distribution of clay as a percentage of the mineral fraction in horizons down the profile is shown in Fig. 53. Results of mechanical analysis of the profile are given in Table 4.

A. The particle size distribution curves for the >2 μm fraction of all horizons of the profile, excluding the 2C, exhibit symmetry and peak up in the fine sand and coarse silt fractions. The curves for the Ah and BEg horizons exhibit primary modes in the coarse silt fraction at 35 μm and 31 μm respectively. There is a trend towards increasing percentages of fine sand and decreasing percentages of coarse silt down the profile from the Ah to BEg horizons. Curves for the Btg and Bwg horizons show a continuence of this trend towards fine sand with primary modes in the fine sand fraction at 150 μm and secondary modes in the coarse silt fraction at 20 μm and 33 μm respectively. The 2C horizon contains fine sand almost exclusively and is not represented in Fig. 52.

B. The percentage of clay present rises from 20.5% in the Ah to 23% in the BEg horizons and jumps sharply to 29% in the Btg horizon before falling back again to 21.5% in the Bwg horizon. A nominal amount of clay is present in the 2C horizon.

Figure 52. Profile 1 - particle size distribution curves.

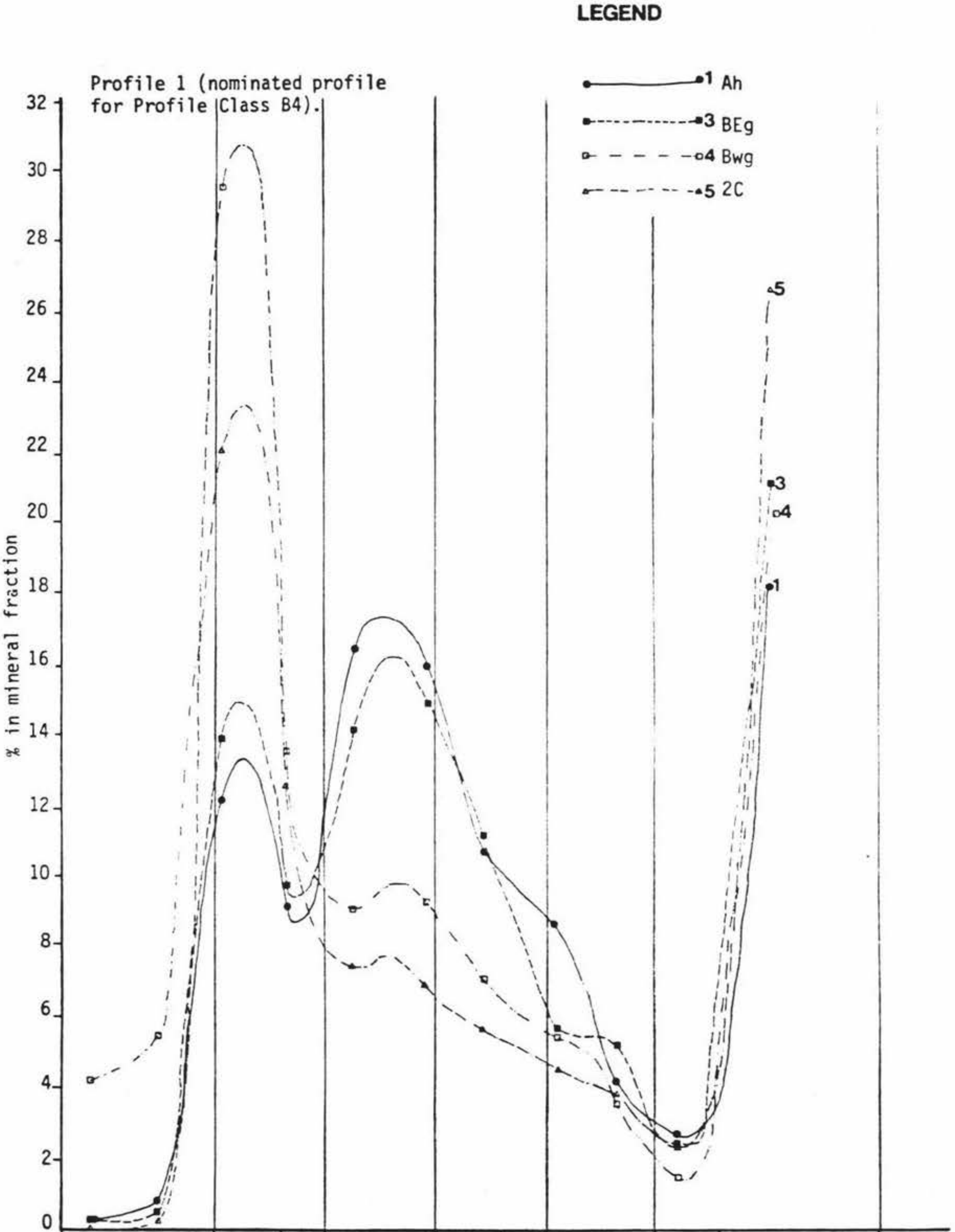


Figure 53. Profile 1 (nominated profile for Profile Class B4) - Distribution of clay as percentage of mineral fraction.

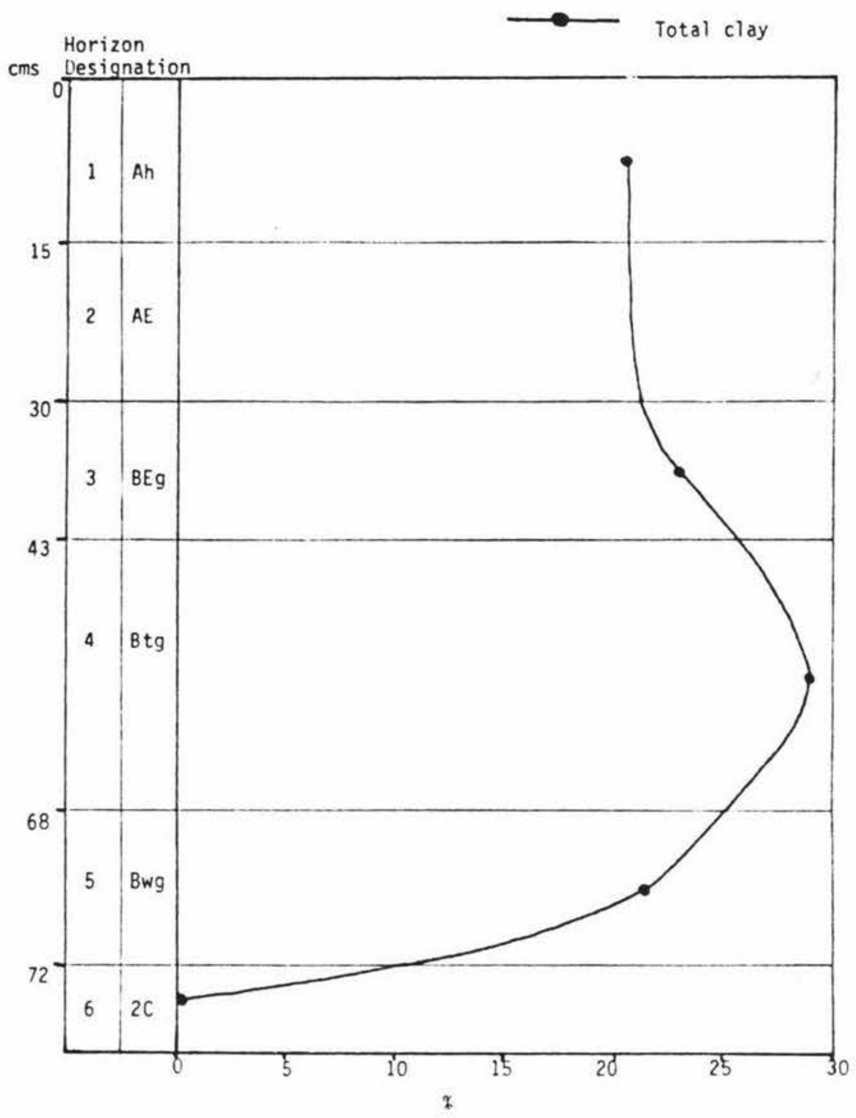


Table 4. Profile 1 - particle size analysis.

Equivalent spherical diameter (μm)

Horizon		>200 cse.sa. %	>63 f.sa. %	>20 cse.si. %	>6.3 m.si. %	>2 f.si. %	<2 cy. %
1	Ah	2.5	20	26	21	10	20.5
3	BEg	2.8	22.2	23	19.5	9.5	23
4	Btg	1	41	12	10	7	29
5	Bwg	15	30	13	12	8.5	21.5
6	2C	4	94.25	.36	.3	.15	.95

5.4.2.3.5 - Profile 70 (nominated as typical for Profile Class C1).

Particle size distribution curves for horizons of the profile are shown in Fig. 54. The distribution of clay as a percentage of the mineral fraction in horizons down the profile is shown in Fig. 55. Results of the mechanical analysis of the profile are given in Table 5.

A. The particle size distribution curves for all horizons of the profile exhibit symmetry and peak up around the coarse silt fraction with modes between 35 μm and 40 μm.

B. The clay component is at a maximum in the Ah and Bwg horizons with 24.25% and 24% respectively and falls to 20% and 17% in the BCxg and Cxg horizons. This trend represents a change in the distribution of fine clay down the profile as the coarse clay remains fairly constant with depth. The percentages of fine clay are 13.5% and 14% in the Ah and Bwg horizons, but fall to 9% and 8% in the BCxg and Cxg horizons.

Figure 54. Profile 70 - particle size distribution curves.

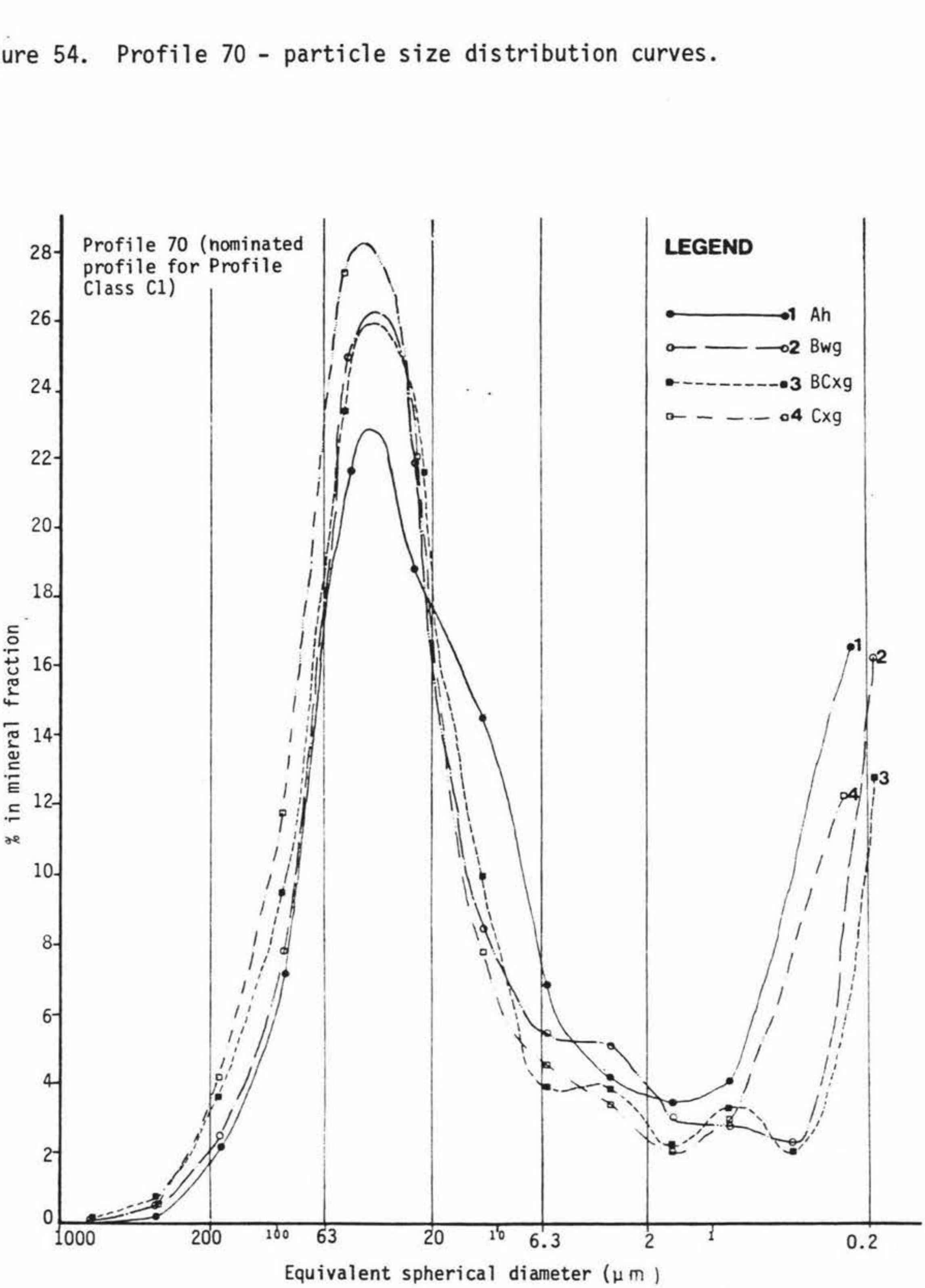


Figure 55. Profile 70 (nominated profile for Profile Class C1) - Distribution of clay as percentage of mineral fraction.

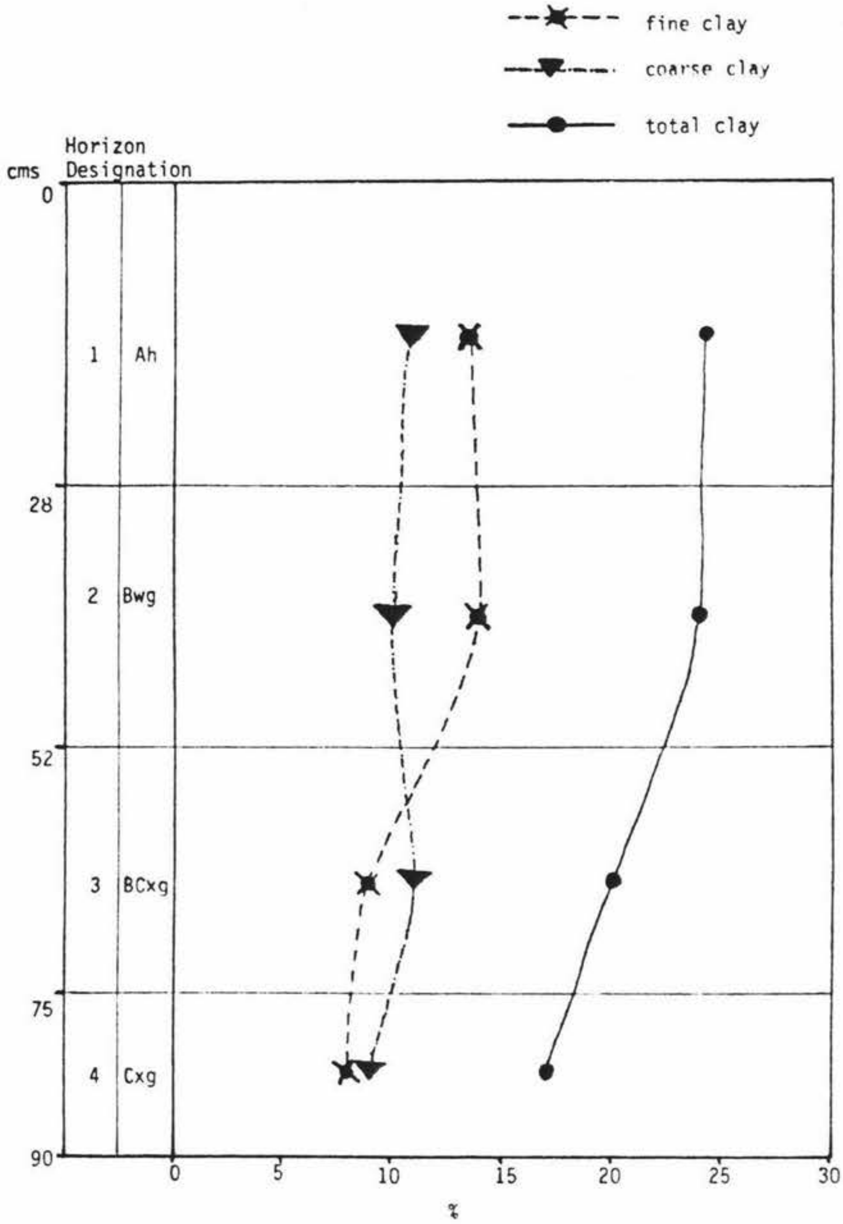


Table 5. Profile 70 - particle size analysis.

Equivalent spherical diameter (μm)

Horizon		>200 cse.sa. %	>63 f.sa. %	>20 cse.si %	>6.3 m.si. %	>2 f.si. %	>0.2 cse.cy. %	<0.2 f.cy. %	T.cy. %
1	Ah	.2	9.6	22.2	35	9	10.75	13.5	24.25
2	Bwg	.25	9.75	39	16.5	9.5	10	14	24
3	BCxg	1.4	14	38.5	19.5	6	11	9	20
4	Cxg	1.4	15	41	19	6	9	8	17

5.4.2.4 Discussion.

The particle size distribution results for Profile 18 (representing Profile Class A1) establish that the Ah1, BA, Bw1 and Bw3 horizons have a well-sorted loess parent material. The parent material of the Ah2 horizon has a considerable loessial component but is distinct in particle size distribution from overlying and underlying materials and may have been derived from soliflucted material. The 2Bw2 (Aokautere Ash) horizon contains volcanic ash in the fine sand fraction in a finely-sorted loess matrix.

It is concluded from the particle size distribution results for Profile 7 (representing Profile Class A6) that the Ah and BA horizons together with the BCxg horizon underlying the 2Cg (Aokautere Ash) horizon, have also formed from a well-sorted loess parent material. In this case the Bwg and 2Cg horizons have a heterogeneous parent material. The Bwg horizon is formed predominantly in loess with volcanic ash contamination, while the 2Cg horizon is formed predominantly from volcanic ash with loess contamination. The results for the Bwg and 2Cg horizons demonstrate that the Aokautere Ash layer has an indefinite, graditional upper boundary with post-Aokautere loess.

The distribution of clay down the profile of Profiles 18 and 7 indicates that its formation through weathering is at a maximum in the upper profile and reduces with depth above the horizons containing Aokautere Ash. Thus Profiles 18 and 7 have maximum clay percentages in the upper profile in the Ah, AB, BA and Ah and BA horizons respectively that reduce with depth through the Bw1 and Bwg horizons respectively of these profiles. There is a marked contrast in the percentages of clay present in the horizon containing the Aokautere Ash between these profiles. Thus the percentage clay component rises sharply in the 2Bw2 horizon of Profile 18 but continues to fall from the overlying Bwg into the 2Cg horizon in Profile 7. Profile 18 displays a 2Bw2 horizon as the Aokautere Ash is being incorporated into a cambic horizon by soil-forming processes while the 2Cg horizon displayed in Profile 7 has the Aokautere Ash clearly visible in a relatively unaltered state. This interpretation is in accordance with the high fine sand and low silt component present in the 2Cg horizon of Profile 7, as compared with Profile 18.

The particle size distribution results for Profile 50 (representing Profile Class B1) and Profile 70 (representing Profile Class C1) establish that those soils have formed in a well-sorted loess parent material. However, results for Profile 50 show that excepting the Ah horizon, this soil has a significantly higher medium silt component down the profile than is the case for Profile 70. Furthermore the fine sand component is significantly higher in the BCxg and Cxg horizons of Profile 70 than in the equivalent Btg2 and Cxg horizons of Profile 50. It is concluded that Profile 50 has a finer-textured loess parent material than Profile 70 and that there is contamination of the lower profile of Profile 70 with marine sands of the Tuapaka formation.

There is a striking contrast in the distribution of clay down the profiles of Profiles 50 and 70. The results indicate a process of lessivage operating in Profile 50, with translocation of fine clay from the Ah and Eg horizons to the Btg1, Btg2 and possibly upper Cxg horizons. Clay formation through weathering is considered to be active in the Ah and Bwg horizons of Profile 70 but there is little evidence of lessivage into underlying horizons.

The particle size distribution curves for Profile 1 (representing Profile Class B4) signify a heterogeneous parent material with loess the predominant component in the upper profile from Ah to BEg horizons but with fine sand of the Tuapaka formation becoming progressively more important with depth, to become predominant in the Btg and Bwg horizons. As noted, fine sand makes up the parent material of the 2C horizon.

The trend in clay distribution down Profile 1 is similar to that noted in Profile 50 and also may be related to a process of lessivage of clay from the eluvial horizons to the Btg horizon in this soil.

5.4.3 Clay Mineralogical Analysis.

5.4.3.1 Introduction.

Detailed clay mineralogical analyses were undertaken on the five nominated profiles (see 5.4.1). This was done to determine the composition of their clay assemblages from which inferences may be made on changes in weathering processes operating in soils in the study area.

The investigation was undertaken using three investigative techniques:

X-ray diffraction (XRD);
Infrared spectroscopy (IRS);
Transmission Electron Microscopy (TEM).

The mutually complementary XRD and IRS techniques permitted identification of the layer silicate and short-range order clays and crystalline accessory materials of the clay fractions in horizons of the five profiles under study. The XRD investigation provided information on crystalline clay material, especially 2:1 and 1:1 minerals, together with quartz, feldspar and goethite. This was supplemented and extended by IRS investigations identifying short-range order clay constituents not detected by the XRD technique. The TEM study supplied visual evidence of the principal crystalline and short-range order constituents present, together with additional information on minor constituents not previously detected by other methods. Further, the TEM study enabled a subjective visual assessment of proportions of principal clay constituents in each soil horizon.

A semi-quantitative summary of the clay mineralogy of each nominated profile is given as follows:

Profile 18	Table 6 (p. 247).
Profile 7	Table 7 (p. 252).
Profile 50	Table 8 (p. 257).
Profile 1	Table 9 (p. 262).
Profile 70	Table 10. (p. 267).

5.4.3.2 Methods.

The <1.0 μm clay fractions were separated after NH_4^+ saturation of samples in the case of Profile 18, 7 and 50. Samples from Profile 1 and 70 were dispersed in deionized water as NH_4^+ saturation was observed to cause a shift in 14Å peaks to 12Å on patterns obtained from clay samples of these soils. Separation was effected in all cases by ultrasonic dispersion and centrifugation, and prepared for XRD, IRS and TEM analyses as described by Kirkman and Pullar (1978).

However, problems were encountered in the preparation of slides using clay samples from horizons of profiles 7 and 18. The clay film shrank on drying, resulting in slides covered in small, non-adhering curled-up flakes that had a tendency to move and blow off the slide on handling and to powder on heat treatment. Several expedients were attempted to overcome these problems. Moist samples were scanned but poor results were obtained due to imperfect orientation and background 'noise'. Samples were scanned dry in their cracked and curled-up state and this gave better results but loss of orientation, and deterioration with handling and heat treatment occurred. An attempt was made to prepare samples with a paste of finely ground clay mixed with silica but this proved unsuccessful. The most satisfactory results were obtained by allowing clay suspensions to dry overnight at room temperatures, as this produced good orientation on the slides. These were then stored away from wind movement. Prior to scanning, the slides were carefully damped from the edges, using deionized water from a Pasteur pipette. This caused the clay flakes to uncurl and adhere to the glass. The slides were then placed in the goniometer and scanned over the range 3°-40° 2θ using Fe filtered CoK α radiation.

During subsequent heat treatments, these slides were taken out of the furnace and allowed to cool in a dessicator before being carefully dampened at the edges prior to scanning, as previously described. This procedure permitted a succession of heat treatments to be carried our on samples and gave good results overall.

Clay samples were K^+ saturated and sequentially heated at 300°C, 450°C and 550°C for 2 hours and X-ray diffraction patterns from 3° to 15° 2θ obtained in each case. In the case of Profile 70 a further heat treatment was carried out at 100 °C for 2 hours.

5.4.3.3 XRD

5.4.3.3.1 Interpretation of XRD Patterns.

X-ray diffraction patterns were examined for possible 14Å vermiculite, chlorite and smectite, 10Å mica minerals, interstratified material of C- spacing 11Å-13Å, together with quartz, feldspar and crystalline iron oxides, all of which diffract at higher values of 2θ. Quartz characteristically gives peaks at 3.34Å and 4.26Å, feldspar from 3.14Å to 3.22Å and goethite at 4.18Å.

The 14Å clay vermiculites are considered to form by weathering of 10Å mica minerals. Weathering procedes by a process of removal of interlayer potassium and by the invasion of the interlayer space by a variety of cations including hydroxy forms of Al^{3+} and Mg^{2+}. The net result is an expansion of the lattice and considerable modification to physical and chemical properties of the clay. The clay species undergoing this process display a continuum of hydroxy interlayered forms depending on the degree of in-filling of interlayer spaces with hydroxy polymers.

When clay vermiculite forms under weakly acid conditions, the interlayer space is commonly occupied by hydrated Mg^{2+} ions. Thus K^+ saturation in the laboratory causes the C- spacing to collapse from approximately 14Å towards 10Å. When vermiculite forms under more acid conditions, the proportion of hydroxy-Al ions in the interlayer space increases, at the expense of Mg^{2+}, and the lattice collapses only with difficulty on K^+ saturation. Indeed, heat treatment over the temperature range 300°C to 550°C may be needed to bring about collapse to near 10Å. When in-filling of the interlayer space with hydroxy-Al material is complete, the mineral, now regarded as pedogenic chlorite, will not collapse on K^+ saturation and heat treatment, and the C-spacing remains at approximately 14Å. Thus K^+ saturation and sequential heating at 300°C, 450°C and 550°C may cause varying lattice collapse in the region of 10Å to 14Å, depending on the completeness of the hydroxy-Al intercalating layer.

For some of the clays investigated it was noted that when sequential heating was carried out a strengthening of reflections in the 7Å region occurred even though the 14Å peak shifted towards 10Å. Since the 7Å reflections disappeared on heating the clays to 550°C it was concluded they were due to a kandite mineral, probably halloysite, and were not 002 reflections of 14Å materials.

On several of the XRD patterns a shoulder was present on the 14Å peaks. This could be interpreted as indicating either 2:1 materials having variable in-filling of the interlayer space with Mg and Al-hydroxy materials, or interstratified minerals of the mica-vermiculite or mica-chlorite type.

Investigation of the 14Å material was completed by treatment of the clays with 5% glycerol in ethanol, after appropriate cation saturation, and inspection of subsequent diffraction patterns for presence of a reflection in the 18Å region which would indicate a smectite mineral. Smectite minerals were found to be absent from all the clays investigated.

The clays were also investigated for the presence of halloysite. If clays are not permitted to dry out between sampling in the field and placement in the XRD goniometer halloysite maintains a C-spacing of approximately 10.4Å. Thus aliquots of the clays were examined as a paste, and then re-examined after drying on the slide at 105°C for 15 minutes. A peak shift from 10.4Å to 7.4Å indicated halloysite.

5.4.3.3.2 Results of XRD Analyses

5.4.3.3.2.1 Introduction.

The following terms are used in the XRD results section:

magnesium vermiculite - 14Å vermiculite that collapses on potassium saturation to 10Å.

very weakly interlayered vermiculite - 14Å vermiculite that collapses to 10Å on heating at 100°C for 2 hours.

weakly interlayered vermiculite - 14Å vermiculite that collapses to 10Å on heating at 300°C for 2 hours.

moderately interlayered vermiculite - 14Å vermiculite that collapses to 10Å on heating to 400°C for 2 hours.

strongly interlayered vermiculite - 14Å vermiculite that collapses to 10Å on heating to 550°C for 2 hours.

pedogenic chlorite - 14Å material that remains at 14Å after heating at 550°C for 2 hours.

The following horizon designations were used in the study for convenience:

Profile 18

H1	represents	Ah1
H2	represents	Ah2
H3	represents	BA
H4	represents	Bw1
H5	represents	2Bw2
H6	represents	Bw3

Profile 7

H1	represents	Ah
H2	represents	AB
H3	represents	BA
H4	represents	Bwg
H5	represents	2Cg
H6	represents	BCxg
H7	represents	Cxg

Profile 50

H1	represents	Ah
H2	represents	Eg
H3	represents	Btg1
H4	represents	Btg2
H5	represents	Cxg

Profile 1

H1	represents	Ah
H2	represents	AE
H3	represents	BEg
H4	represents	Btg1
H5	represents	Bwg
H6	represents	2C

Profile 70

H1	represents	Ah
H2	represents	Bwg
H3	represents	BCxg
H4	represents	Cxg

5.4.3.3.2.2 - Profile 18 (nominated as typical of Profile Class A1).

The XRD patterns for H4, H5 and H6 are shown in Figs. 56, 57, and 58 respectively.

The XRD patterns of NH_4^+-saturated clays of Profile 18 established that vermiculitic minerals dominate the clay mineral assemblage. The 14Å reflections were larger than the 7Å reflections for clay samples from all horizons and vermiculite is therefore the principal clay species. It was noted that the 7Å reflections for samples H1, H2, H3, H4 and H5 were large and sharp, strikingly different from those for H6 and those previously observed for other profiles. The significance of these will be examined in a following section.

Traces for NH_4^+-saturated clay samples of H1 and H2 displayed a sharp, major peak at 14Å and a smaller peak at 12Å, together with a significant 11Å-13Å component and only minor amounts of mica.

Equivalent traces of NH_4^+-saturated clay samples of H3 and H4 retained sharp 14Å peaks and showed an increase in the proportion of 11Å-13Å material. The proportion of 10Å material indicated by the patterns from H3 clay to H4 clay. showed significant increase.

The traces obtained from the NH_4^+-saturated H5 and H6 clay continued these trends. The pattern for the H5 clay shows two major peaks at 10Å and 14Å of approximately equal strength, together with a reduction in significance of the 11Å-13Å component (compared to upper horizons). The pattern of the H6 clay displayed the major peak at 10Å with a sharp but smaller peak at 14Å. The 11Å-13Å component is further reduced in significance in the H6 clay.

These results underline the increasing importance of mica and the persistence of a significant 14Å clay component in the crystalline clay assemblage with depth.

The degree of aluminous-hydroxy interlayering of the vermiculite component was ascertained down the profile by K^+ saturation and sequential heating of the clays.

The response of H1, H2, H3 and H4 clays to these treatments was similar and suggested a range of aluminous interlayered material in all clays. Potassium saturation did not produce a shift of 14Å peaks and thus magnesium vermiculite is absent from the clay assemblage of these horizons. The shift of 14Å peaks in all cases upon heating of the clay at 300°C gave broad 12Å-13Å peaks for H1 and H2 and 11Å-13Å peaks for H3 and H4 indicating the presence of some aluminous interlayered material in all clays. Moderate to strong interlayering with aluminous material was considered to be dominant in all four clays with considerable ongoing shifting on traces of peaks to 12Å for H1 and H2 and 11Å for H3 and H4 on heating of clay samples at 400°C. Further shifting of peaks on these traces and strengthening of peaks at 11Å occurred on heating at 550°C. These C-spacings suggest marginally greater aluminous interlayering of the minerals in the H1 and H2 clays than for H3 and H4 clays. The presence of small amounts of chlorite is indicated by residual 14Å peaks in all cases after heating of the clays.

The equivalent results for the H5 clay indicate the presence of a weakly to moderately aluminous interlayered vermiculite together with a larger chlorite component. In this case only a small amount of moderately to strongly aluminous interlayered material is present and magnesium vermiculite is absent from the clay mineral assemblage. Thus K^+ saturation brought no shift of the 14Å peak while heating to 300°C brought a strengthening of the 10Å peak through shifting of 11Å-13Å peaks. Further heating at 400°C and 550°C confirmed the collapse of residual 11Å-13Å material towards 10Å. Throughout these treatments a strong, sharp peak persisted at 14Å.

The pattern obtained from the K^+ saturated H6 clay indicates that the clay mineral assemblage is composed of magnesium vermiculite and weakly aluminous-hydroxy interlayered vermiculite. The traces for this sample showed the 10Å peak strengthening at the expense of the 14Å peak, as compared with the equivalent NH_4^+ saturated sample and an almost complete collapse of the residual

14Å material occurred on heating at 300°C, leaving only a small amount of 11Å-13Å material. The traces for this clay sample indicate that chlorite is absent from the clay assemblage.

Patterns of clay samples from all horizons displayed a peak at 10Å that shifted towards 7Å on drying the clay at 56°C. This material in H6 gave a broad peak at 7.2Å that persisted through K^+ saturation and sequential heating to 400°C but disappeared from the trace on heating at 550°C. The collapse of this material on heating of H1 to H5 clays gave shoulders on the sharp second order 7Å peaks already evident on the patterns. These shoulders disappeared after heating of the clays at 550°C, thus indicating the presence of halloysite.

Quartz and feldspar were observed to be present in minor amounts in all clays.

Figure 56.

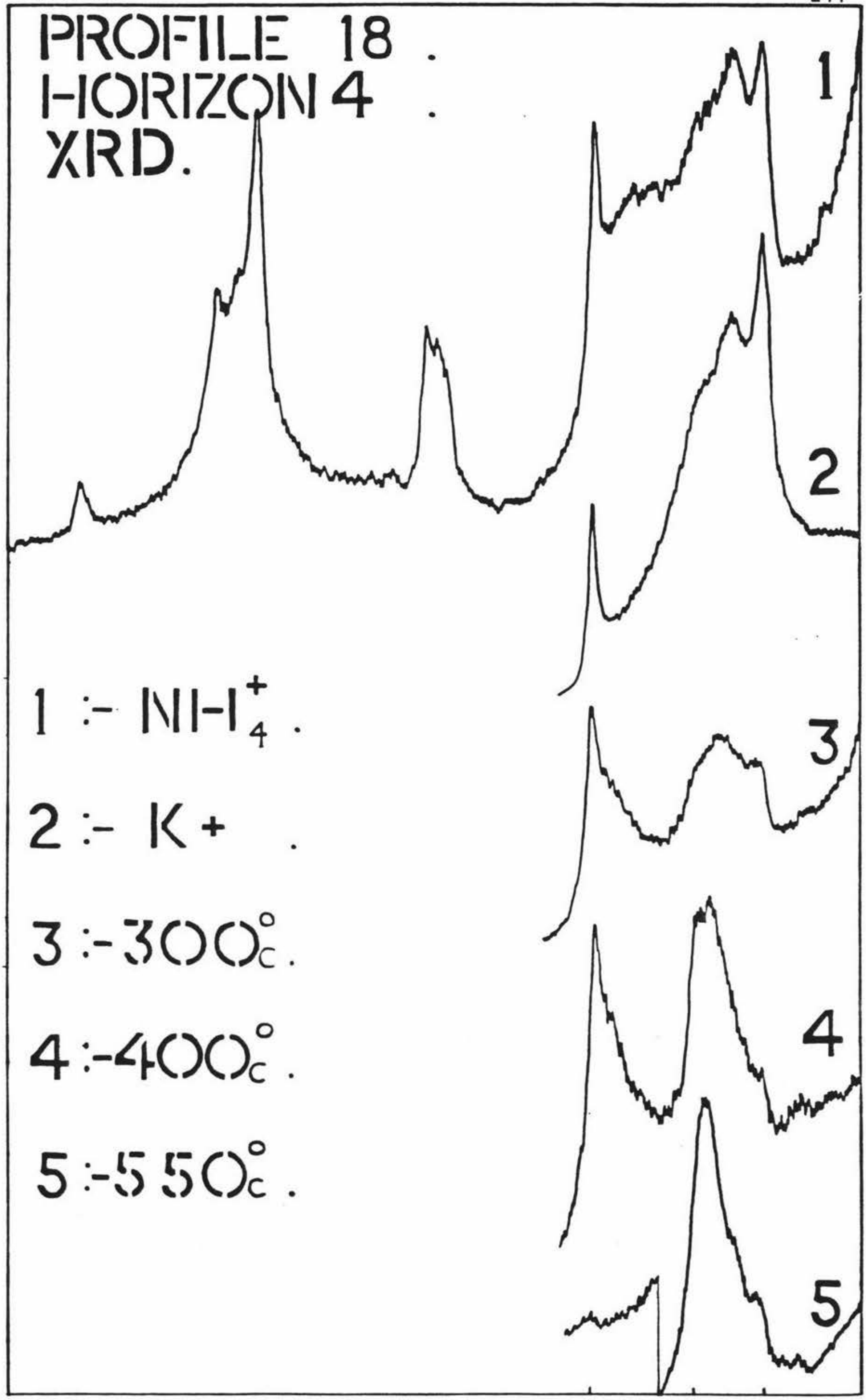

PROFILE 18.
HORIZON 4.
XRD.
1
2
3
4
5
1 :- NH_4^+.
2 :- K+.
3 :- 300°c.
4 :- 400°c.
5 :- 550°c.
Å
7
10
14

Figure 57.

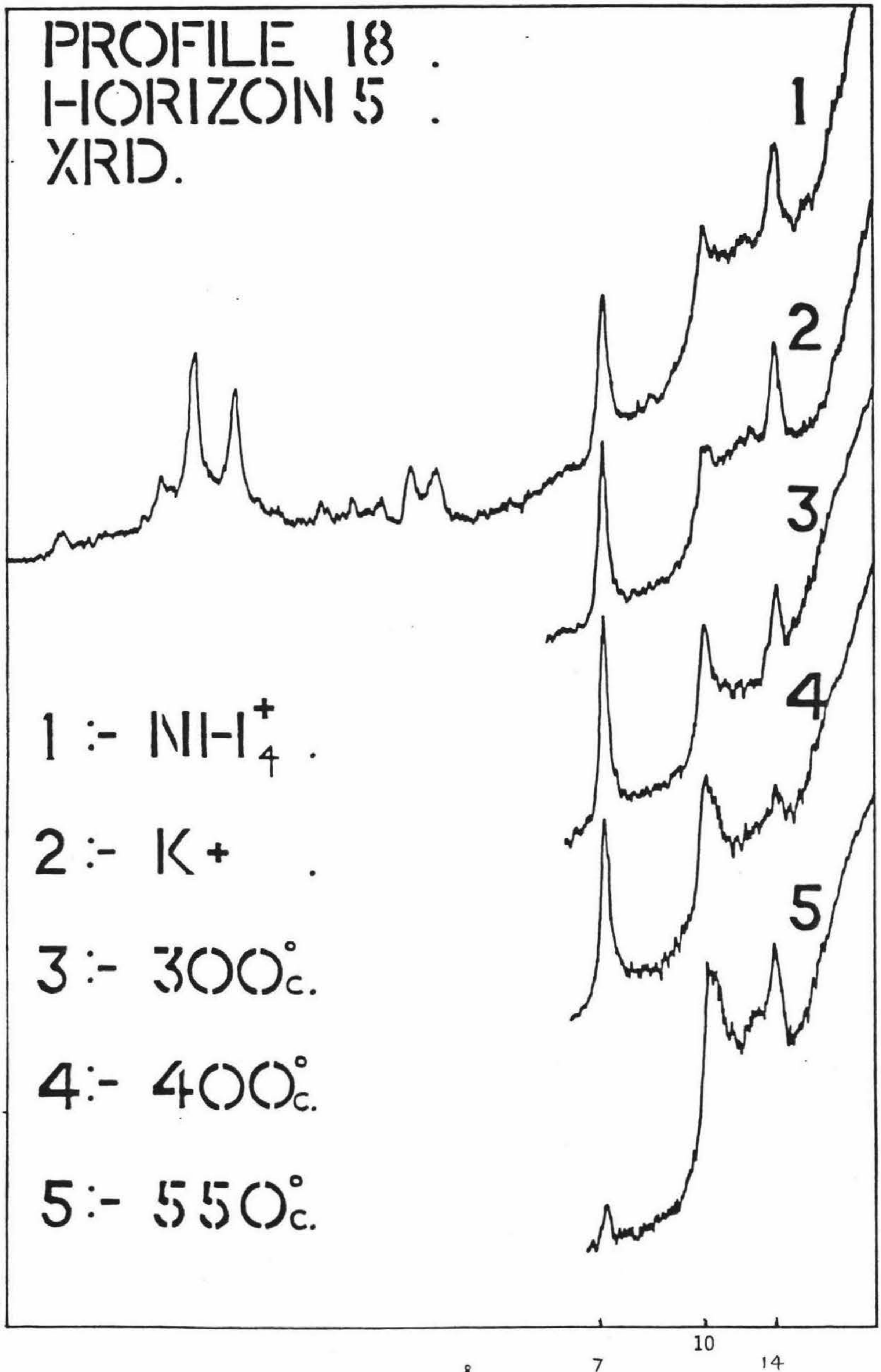

PROFILE 18.
HORIZON 5.
XRD.
1
2
3
4
5
1 :- NH_4^+.
2 :- K+.
3 :- 300°c.
4 :- 400°c.
5 :- 550°c.
Å
7
10
14

Figure 58.

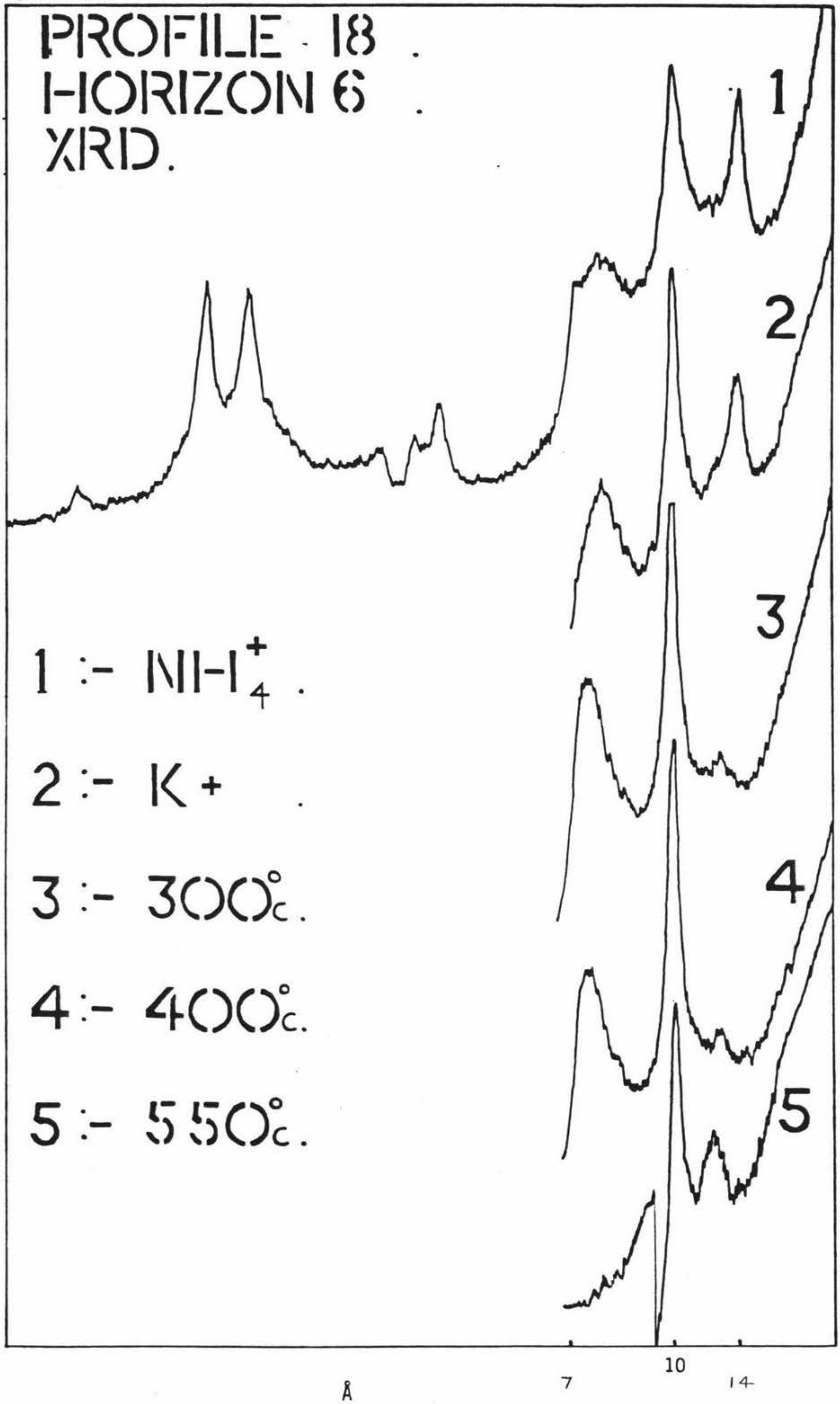

PROFILE 18 .
HORIZON 6 .
XRD.
1
2
3
4
5
1 :- NH_4^+ .
2 :- K+ .
3 :- 300°c.
4 :- 400°c.
5 :- 550°c.
7
10
14
Å

Table 6. Profile 18 - Clay Mineralogy.

horizon		mica	vermiculite: magnesium vermiculite	vermiculite: weakly interlayered	vermiculite: moderately interlayered	vermiculite: strongly interlayered	vermiculite: 11 - 13 Å material	pedogenic chlorite	quartz	feldspar	goethite	halloysite	allophane	imogolite
1	Ah1	tr	-	+	+++	-	+	tr	tr	tr	tr	±	+++	-
2	Ah2	tr	-	+	+++	-	+	tr	tr	tr	-	±	++±	-
3	BA	+	-	+	±++	-	++	tr	tr	tr	-	±	++	-
4	Bw1	++	-	+	±++	-	++	tr	tr	tr	-	±	+±	-
5	2Bw2	-	-	-	-	-	+	++	tr	tr	-	+	++++	tr
6	Bw3	++++	+++	+++	-	-	±	-	tr	tr	-	+++	±	-

++++ large amount.

+++ considerable amount.

++ moderate amount.

+ small amount.

± half a unit of amount.

tr trace.

5.4.3.3.3.3 - Profile 7 (nominated as typical of Profile Class A6).

XRD patterns for H2 are shown in Fig. 59.

The XRD patterns of NH_4^+-saturated clay samples of H1, H2, H3 and H4 show that vermiculitic minerals dominate the crystalline clay assemblage of these horizons. It was noted that 11Å-13Å material is also present, as indicated by shoulders on 14Å peaks, together with small amounts of mica.

Potassium saturation of H1, H2, H3 and H4 clays did not produce any measure of collapse of the clay minerals and therefore magnesium vermiculite is not present in the clays of these horizons.

Heating of the H1 clay at 300°C did not result in a shift of the 14Å peak towards 10Å and in fact the 14Å peak was strengthened. Further heating at 450°C caused the 14Å peak to shift to a broad-based 11.9Å peak while leaving a residual 14Å peak. Heating of the clay at 550°C caused a further shift of the broad-based peak at 11.2Å, and the small persistent peak at 14Å was still evident.

These results indicate the presence in the H1 clay of a predominant moderately aluminous-hydroxy interlayered vermiculite component with strongly interlayered vermiculite present in small amount, and chlorite in minor amount.

The heating of clay samples of H2, H3 and H4 at 300°C caused a shift of the 14Å peak to a broad, rounded peak in the 11Å-13Å region, centred from C-spacing 12Å to 13Å. Heating of these samples at 400°C resulted in further lattice collapse and broad peaks were displayed on these traces at 11.5Å with some residual 14Å material in all cases. Heating of the clays at 550°C confirmed peaks at 11.4Å for H2 and H3 and at 11.2Å for H4. Traces of 14Å material remained after sequential heating of these samples in all cases.

It was concluded that weakly aluminous-hydroxy interlayered vermiculite is present in considerable amounts in H2, H3 and H4 clays together with small amounts of moderately and strongly aluminous-hydroxy interlayered vermiculite. Chlorite is present in minor amounts in all clays.

The XRD patterns of NH_4^+-saturated clay samples of H5, H6 and H7 had larger 14Å peaks than 7Å peaks and therefore the clay assemblage of these horizons had a vermiculite rather than chloritic clay species. In contrast to H1, H2, H3 and H4, however, the traces for H5, H6 and H7 clays show that vermiculitic material is not dominant in the clay assemblage. The trace of H5 clay has a double-peaked configuration with 10Å and 14Å material present in apparently equal amounts. The traces of H6 and H7 clays had dominant 10Å peaks with smaller 14Å peaks and the ratio of 10Å to 14Å material increased with depth, as evidenced by changes in respective peak strengths. A considerable 11Å-13Å component was present in these clays.

Potassium saturation of H5 clay caused no shift of the 14Å peak and magnesium vermiculite is therefore considered to be absent. As noted, difficulties in obtaining a satisfactory trace on sequential heating of H5 clay made interpretation difficult but there is evidence that heating at 300°C, 400°C and 550°C brought an ongoing shift of material from 14Å to 10Å, leaving some residual material at C-spacing 14Å.

Potassium saturation of the H6 clay caused no change to the 14Å material, and it was concluded that magnesium vermiculite is absent from the clay assemblage of this horizon. Heating of the H6 clay at 300°C caused a shift of the 14Å peak and strengthening of the major 10Å peak. A small amount of material with C-spacing 13Å was also recorded. Further heating of this clay at 400°C and 500°C confirmed the major, sharp 10Å peak with smaller peaks lying at C-spacings 12Å to 13Å and 11.6Å to 12.6Å. A small amount of pedogenic chlorite is present in each case.

Potassium saturation of the H7 clay caused strengthening of the 10Å peak, but a small 14Å peak still remained. Heating of the clay at 300°C caused a strengthening of the 10Å peak, leaving material which gave a rounded peak at 13Å, as for H6. Heating of the clay at 400°C and 550°C confirmed the 10Å peak with a shoulder from 11Å-13Å and a minor amount of material at 14Å.

It was concluded from these results for H5, H6 and H7 clays that mica had now become a significant component in the clay assemblage. Mica and aluminous-hydroxy interlayered vermiculite is present in approximately equal amounts in H5 clay while mica is the dominant 2:1 layer lattice clay in H6 and H7 with aluminous vermiculite present only in small amounts. The mica component thus appears to increase with depth. As previously noted magnesium vermiculite is absent from the clay assemblage of H5 and H6 but it present in significant amounts in H7. The H5 clay contains aluminous interlayered vermiculite but further conclusions are not possible due to inferior pattern definition. The H6 and H7 clays contain small amounts of weakly, moderately and strongly aluminous-hydroxy interlayered vermiculite together with minor amounts of chlorite. The clays of these horizons also contain 11Å-13Å material in their assemblage.

The NH_4^+-saturated clay samples of all horizons were scanned damp and then after drying at 56°C. A peak of approximately 10Å was observed to shift to 7.2Å after drying of the clays, and after heating at 550°C the 7.2Å peak disappeared. This indicates the presence of a small amount of halloysite in all clays.

Quartz and feldspar are present in minor amounts in all clays.

Figure 59.

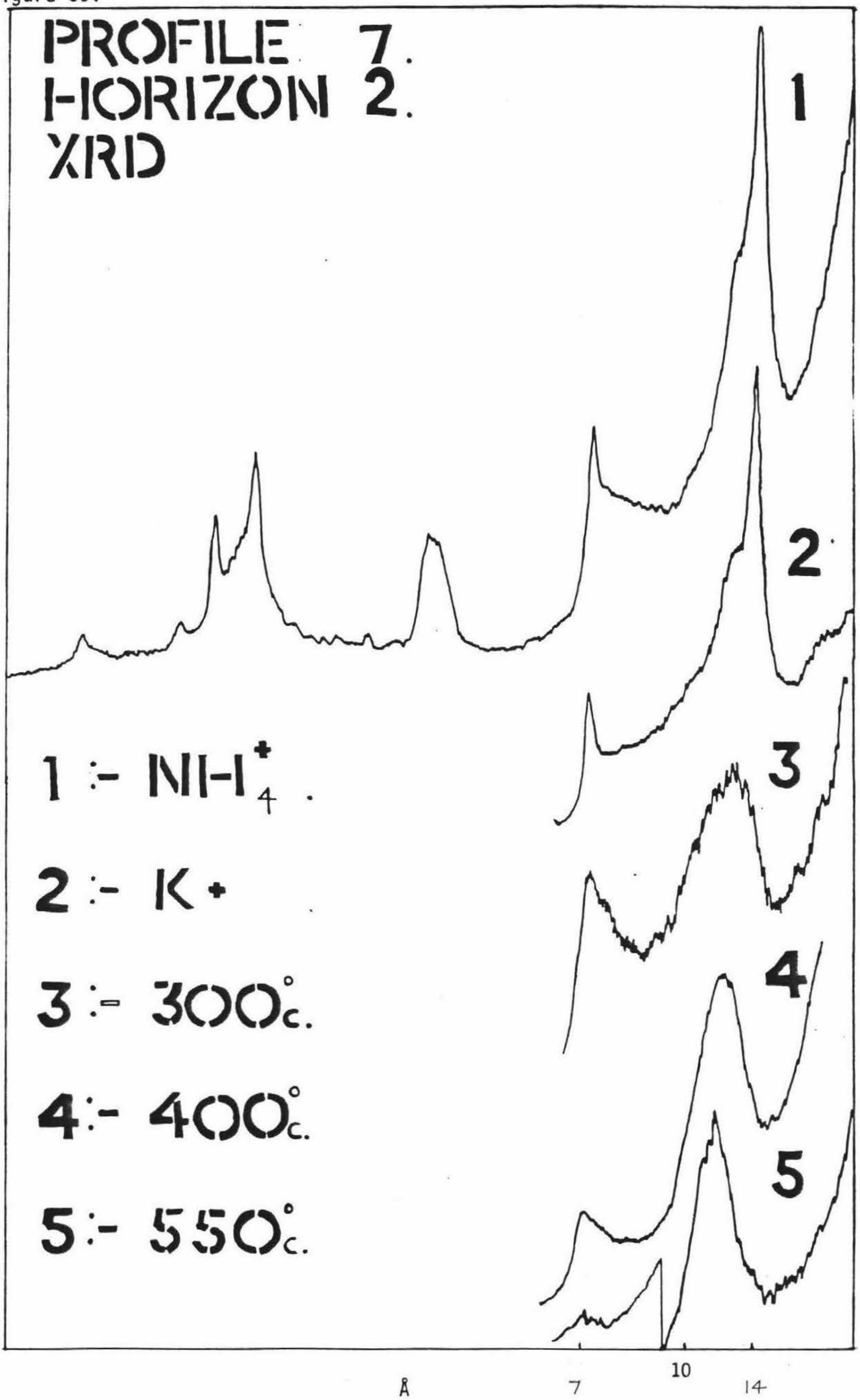

PROFILE 7.
HORIZON 2.
XRD
1
2
3
4
5
1 :- NH_4^+.
2 :- K+
3 :- 300°c.
4 :- 400°c.
5 :- 550°c.
Å
7
10
14

Table 7. Profile 7 - Clay Mineralogy.

	horizon	mica	vermiculite: magnesium vermiculite	vermiculite: weakly interlayered	vermiculite: moderately interlayered	vermiculite: strongly interlayered	vermiculite: 11 - 13 Å material	pedogenic chlorite	quartz	feldspar	goethite	halloysite	allophane	imogolite
1	Ah	±	-	-	+++	+	±	±	tr	tr	-	±	+++	-
2	AB	±	-	+++	+	+	±	±	tr	tr	-	±	++±	-
3	BA	±	-	+++	+	+	±	±	tr	tr	-	±	++	-
4	Bwg	±	-	+++	+	+	±	±	tr	tr	-	±	+±	-
5	2Cg	+++	-	?	?	?	-	tr	tr	tr	±	+	++++	tr
6	BCxg	++++	-	+	+	+	-	tr	tr	tr	-	+++	±	-
7	Cxg	++++	+++	+	+	+	-	tr	tr	tr	-	+++	±	-

5.4.3.3.2.4 - Profile 50 (nominated as typical of Profile Class B1).

XRD patterns for H3 are shown in Fig. 60.

The XRD patterns of NH_4^+-saturated clays from Profile 50 established that vermiculitic minerals dominate the clay assemblage for all clays show that the reflections at 14Å are markedly larger than those at 7Å, and vermiculite is therefore the principal clay species.

The absence of mica from all clays is evidence of an almost complete transmutation of mica through weathering to vermiculitic material.

Except for H2, all traces showed a shoulder at 11Å-13Å which merged into the 14Å peak. Its absence from the H2 clays implies total conversion of mica to vermiculite or pedogenic chlorite, and thus may reflect more vigorous weathering in this horizon.

Potassium saturation of H1 and H2 clays produced a shift in the position of the 14Å peak. Sequential heating resulted in a shift of the 14Å peak towards 10Å in each case but with some difference in degree of shift and resultant peak definitions. The pattern of H1 clay showed a partial shift of the 14Å peak and a loss of peak definition on heating through to 450°C, resulting in a broad, rounded peak from 10.3Å to 12.8Å. There was no further peak shift when the clay was heated at 550°C. These results indicate a moderate to strong degree of aluminium hydroxy interlayering. The trace from the H2 clay also showed partial shift of the 14Å peak towards 10Å on sequential heating to 450°C with a broad peak from 10.3Å to 12.1Å. This sharpened to a clearly-defined peak at 11Å on further heating of the clay at 550°C. These results were taken to suggest that a marginally greater degree of aluminious-hydroxy interlayering had taken place in the clay of H2 compared to that for the clay from H1.

Potassium saturation of the H3 clay caused collapse of some material from 14Å to 11.8Å but a sharp, predominant 14Å peak persisted, giving a double-peak configuration. Subsequent heating of the clay at 300°C caused the 14Å peak to shift, producing a sharp, dominant peak at 10Å, together with a broad peak at 13Å. Heating to 450°C caused the disappearance of the 13Å peak and a sharp 10Å peak remained.

The collapse of part of the clay mineral assemblage on K^+ saturation was considered to be consistent with the presence of a magnesium vermiculite dominated clay assemblage in H3. Interlayered aluminous vermiculite probably accounts for the minerals which collapse after heating. The performance of the clay on sequential heating suggests a considerable range in the degree of interlayering and a broad spectrum of aluminous-hydroxy interlayered vermiculite in this horizon, ranging from the magnesium vermiculite noted above through weakly interlayered towards moderately aluminous-hydroxy interlayered vermiculite.

The traces obtained for H4 and H5 clays showed a marked shift in the 14Å peaks on K^+ saturation. The trace for H4 clay showed a relatively sharply-defined peak due to material with a C-spacing of 11.4Å, together with a small peak at 13.7Å. Heating at 300°C caused the peak at 13.7Å to shift, giving a striking, sharp peak at 10Å. The pattern for the H5 clay showed an almost complete shift in the 14Å peak to a sharp peak at 10Å on K^+ saturation, and heating at 300°C was observed to accentuate this peak.

Results for H4 and H5 clays indicate the dominance of magnesium interlayered vermiculite. Aluminous-hydroxy interlayered vermiculite was almost entirely absent, very weakly interlayered vermiculite being present in small amount in H4 clay. The H5 clay was considered to contain only vestigial amounts of aluminous interlayered clay material.

It was noted on the traces of all K^+ saturated clays heated to 450°C that a small 'blip' persisted at 7.2Å. This disappeared from the patterns on heating of the clay at 550°C and it was taken as indicative of small amounts of 1:1 material, probably halloysite, in the clay.

Results for all clays confirmed the presence of minor amounts of quartz and feldspar. The somewhat larger quartz peak observed for H1 clay may be due to aeolian additions of very fine material from adjacent marine beds exposed through faulting and erosion while increases in the quartz constituent at the base of the profile in H5, as indicated by a peak of similar size, can perhaps be attributed to contamination from underlying marine material.

The presence of small amounts of goethite is indicated by a small peak at 4.18Å on XRD patterns obtained for H3 and H4 clays.

Figure 60.

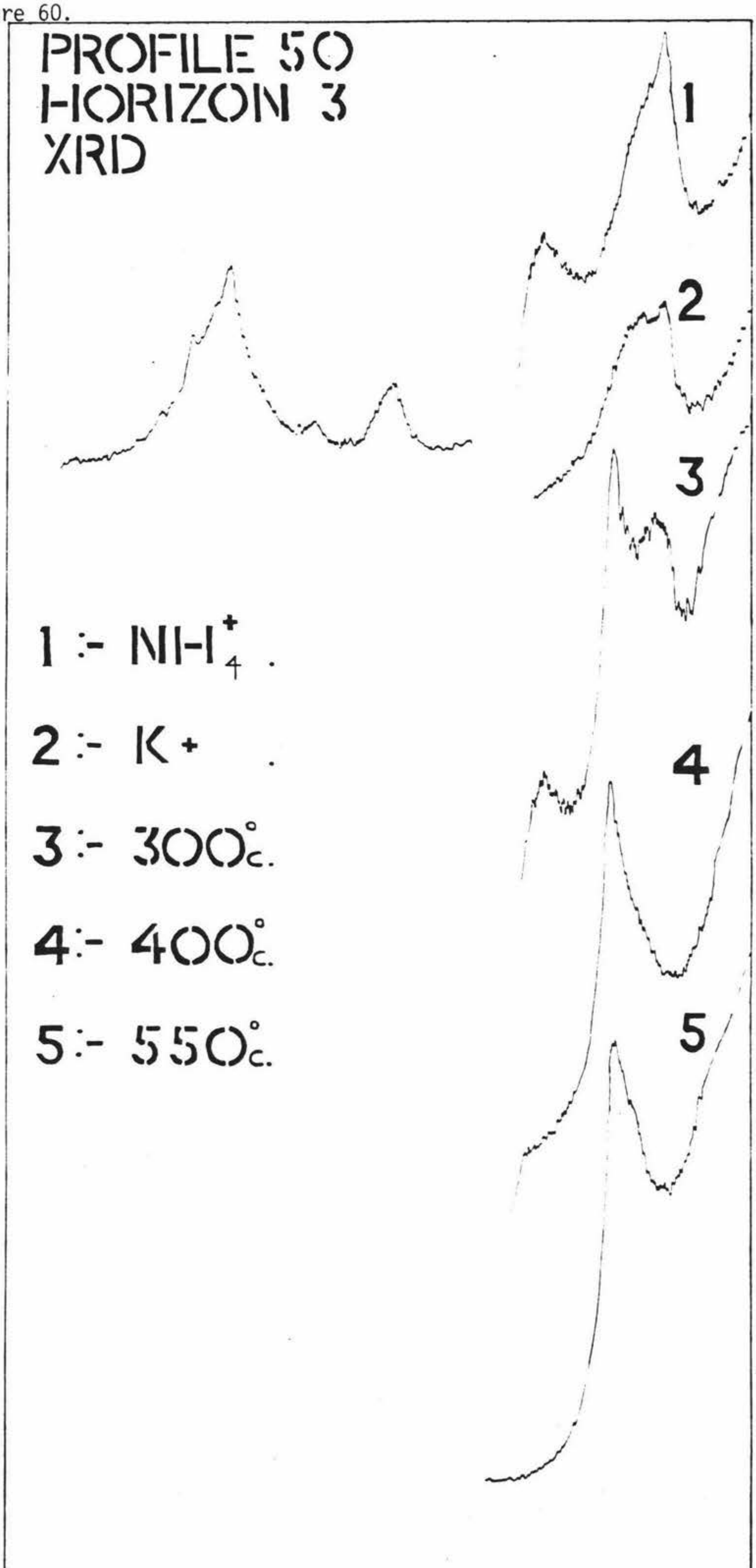

PROFILE 50
HORIZON 3
XRD
1
2
3
4
5
1 :- NH_4^+ .
2 :- K^+ .
3 :- 300°c.
4 :- 400°c.
5 :- 550°c.
Å
7
10
14

Table 8. Profile 50 - Clay Mineralogy.

horizon		mica	vermiculite: magnesium vermiculite	vermiculite: weakly interlayered	vermiculite: moderately interlayered	vermiculite: strongly interlayered	vermiculite: 11 - 13 Å material	pedogenic chlorite	quartz	feldspar	goethite	halloysite	allophane	imogolite
1	Ah	-	-	-	++±	±	±	-	±	tr	-	±	±	-
2	Eg	-	-	-	+++	+	-	-	tr	tr	-	±	±	-
3	Btg1	-	++	+	+	-	±	-	tr	tr	tr	tr	tr	-
4	Btg2	-	+++	±	-	-	±	-	tr	tr	tr	tr	tr	-
5	Cxg	-	+++	-	-	-	±	-	±	tr	-	tr	tr	-

5.4.3.3.2.5 - Profile 1 (nominated as typical of Profile Class B4).

XRD patterns for H3 are shown in Fig. 61.

The XRD patterns of deionized water-dispersed clays (no NH_4^+ added) of Profile 1 established that vermiculite minerals dominate the crystalline clay mineral assemblage throughout the profile. The patterns of H1, H2 and H3 clays show strong, sharp 14Å peaks in all cases together with a 11Å-13Å shoulder and a small peak at 10Å.

Potassium saturation of these clays did not initiate a 14Å peak shift and therefore magnesium vermiculite is absent.

Sequential heating of K^+-saturated clay samples brought ongoing collapse of 14Å and 11Å-13Å material towards 10Å and therefore vermiculitic clays with a range of aluminous-hydroxy interlayering are present in H1, H2 and H3. The heating of K^+-saturated clays of H1, H2 and H3 at 300°C gave a shift of 14Å peaks to broad bands in the 11Å-13Å region in all cases, indicating the presence of weakly aluminous-hydroxy interlayered vermiculite. Patterns for H1 and H2 clays had a clear bias in distribution of material towards 14Å with broad peaks at 12.8Å and 14Å respectively and in addition the trace of H2 clay displayed a minor peak at 10.4Å. The distribution of material shown on the trace of H3 clay was strongly biased towards 10Å with a peak displayed at 10.2Å. These results suggest that the component of weakly interlayered vermiculite present in these horizons is greatest in H3 and is reduced in amount in H1 and further reduced in amount in H2.

The K^+-saturated clay samples of H1, H2 and H3 were heated at 400°C, resulting in a further shifting of peaks on all traces towards 10Å. This signified the presence of a moderately aluminous-hydroxy interlayered vermiculite component in the clay assemblage. The trace for the H3 clay now displayed a broad-based peak at 10.3Å with a shoulder at 10Å-14Å and comparison with the 300°C trace showed that a very considerable collapse of material towards 10Å had occurred. The trace obtained for the H1 clay indicates material with a C-spacing from 10.4Å to 13Å, peaking at 11.4Å. This trace also showed a considerable shift of peaks towards 10Å. The peak shift shown on the trace for the H2 clay was not so complete as for H1 and showed a broad band of material with C-spacings of 10.1Å-13.8Å but without discernible bias towards 10Å.

Heating of the clay samples of H1, H2 and H3 at 550°C resulted in strong peaks at 10.8Å on traces for H1 and H3 clays. The equivalent trace for H2 clay displayed a broad-based peak at 10.7Å with material with C-spacings from 10.3Å-11.6Å, together with a shoulder of material from 11.6Å-13Å and some residual material with a C-spacing of 14Å.

It is concluded from these results that weakly, moderately and strongly aluminous-hydroxy interlayered vermiculite is present in the clay assemblage of H1, H2 and H3, together with small amounts of mica, probably muscovite. The clay assemblage of H3 has the greatest component of weakly aluminous-interlayered material and only small amounts of strongly aluminous-hydroxy interlayered vermiculite are present. The clay assemblage of H1 and H2 has a large weakly interlayered component with H1 having a larger moderately interlayered and smaller strongly interlayered component than H2. The clay assemblage of H2 may also contain a small amount of pedogenic chlorite together with material with C-spacing of 11.6Å-13Å, which does not collapse towards 10Å.

The patterns of untreated clay samples of H4, H5 and H6 had sharp major peaks at 14.9Å and minor peaks at 9.7Å. The significance of these 9.7Å peaks is examined later in this section.

Potassium saturation of these samples shifted the 14Å peaks on their respective traces to 10Å. The 14Å peak shown on the trace of the untreated H4 clay shifted after potassium saturation to give a broad peak from 11Å-11.5Å with some residual material represented by a minor peak at C-spacing 13.7Å. This minor peak was absent after heating the clay to 300°C; instead a sharp peak was obtained at 10.2Å. The traces for H5 and H6 clays showed that the collapse of material to 10Å was complete on potassium saturation.

It was concluded that magnesium vermiculite makes up the entire 2:1 clay assemblage of H5 and H6 and is present with a very small amount of weakly interlayered material in H4.

Patterns of untreated clays from all horizons, scanned damp, had a peak at 10Å. This peak on traces of air-dried clay samples of H1, H2 and H3 shifted to indicate a spread of material between 7Å and 10Å. Shift of this peak after air-drying the clays was only partial for H4, H5 and H6 and traces for these samples showed a peak remaining at 9.7Å, as noted above. Collapse of the 9.7Å peak was effected in these cases by heating at 56°C for 30 minutes and this indicates halloysite. Further heating of all clay samples at 300°C resulted in the appearance of a broad, strong peak at 7.2Å that disappeared on heating the clays at 550°C. This peak was smaller than the 14Å peak on traces of H1 and H2 clays, but became progressively dominant with depth on the traces of clay samples of H4, H5 and H6. Thus an important halloysite component is present in the clay assemblage of these soils.

The presence of goethite was indicated by a reflection at 4.18Å. Examination of traces from untreated samples suggests its presence in small amounts in H3 clay, rather larger amounts being present in H4, H5 and H6 clays.

Quartz and feldspar are present in minor amounts in all clays.

Figure 61.

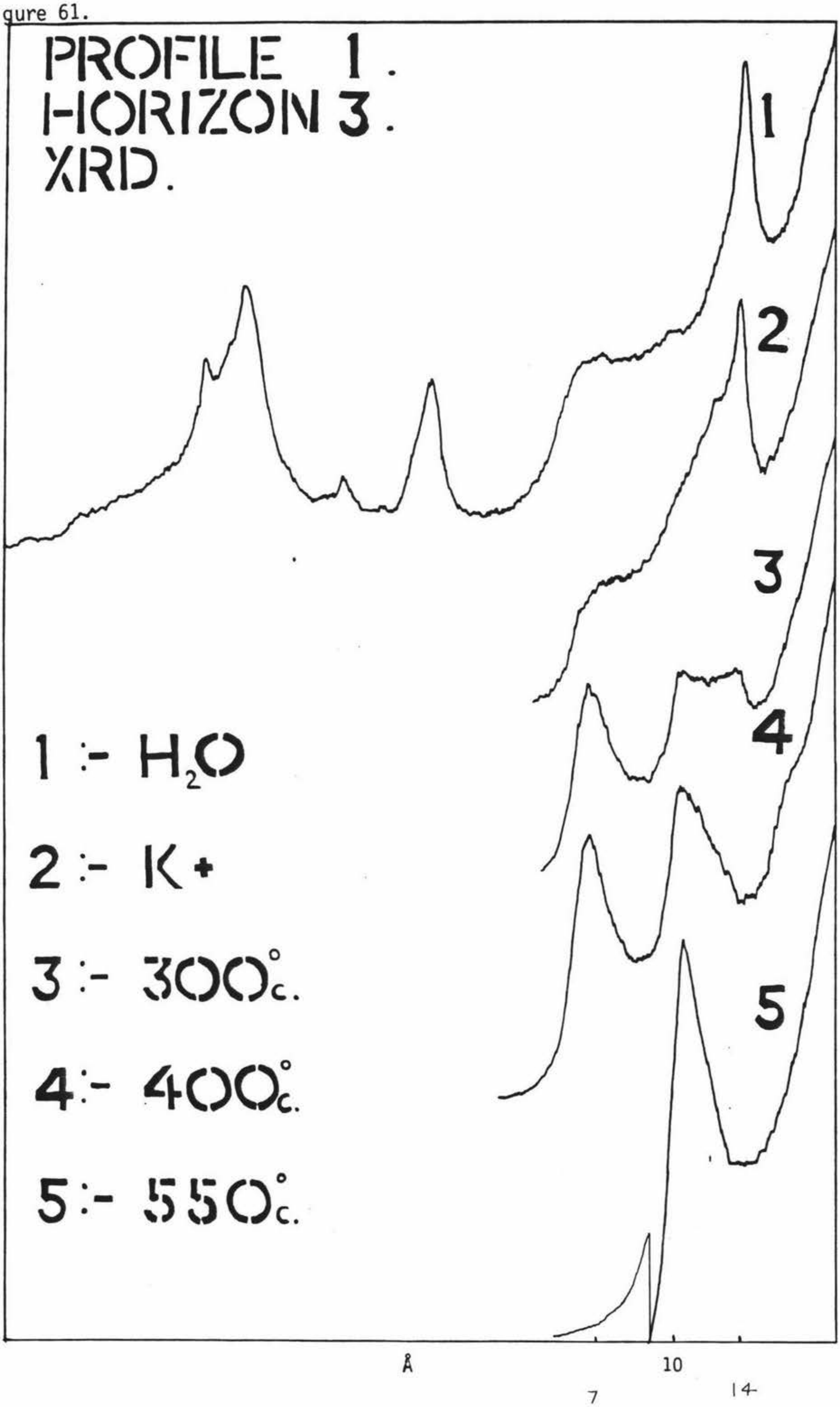

PROFILE 1.
HORIZON 3.
XRD.
1
2
3
4
5
1 :- H_2O
2 :- K+
3 :- 300°c.
4 :- 400°c.
5 :- 550°c.
Å
10
7
14

Table 9. Profile 1 - Clay Mineralogy.

horizon		mica	vermiculite					pedogenic chlorite	quartz	feldspar	goethite	halloysite	allophane	imogolite
			magnesium vermiculite	weakly interlayered	moderately interlayered	strongly interlayered	11 - 13 Å material							
1	Ah	tr	-	+++	+++	-	±	-	±	±	-	++	++	tr
2	AE	tr	-	++	++	++	±	tr	±	±	-	++	+	-
3	BEg	tr	-	++++	+++	+	±	-	±	±	tr	++	±	-
4	BTg	-	++++	±	-	-	-	-	±	±	++	+++	tr	-
5	Bwg	-	++++	-	-	-	-	-	±	±	++	++++	tr	-
6	2C	-	++++	-	-	-	-	-	±	±	++	++++	tr	-

5.4.3.3.2.6 - Profile 70 (nominated as typical of Profile Class C1).

XRD patterns for H1 are shown in Fig. 62.

The XRD patterns of water-dispersed clays, (no NH_4^+ added), of Profile 70 established that vermiculitic minerals dominate the clay mineral assemblage throughout the profile. The reflection at 14Å is substantially larger than the 7Å reflection for all clays, and vermiculate is therefore the principal clay species. The C-spacings of the clay minerals increased down the profile as follows: H1 - 14.5Å, H2 - 14.6Å, H3 - 14.9Å, H4 - 15Å.

Traces for all clays showed a minor peak at 10Å due to residual mica. The presence of a component of C-spacing 11Å-13Å was observed for all clays. This material is present in greatest amount in H1 and H2 and is progressively reduced to small amounts in H3 and H4 clays.

The traces obtained for H1 and H2 clays upon K^+-saturation displayed a shift of 14Å peaks and their replacement by broad, rounded peaks over the range 11Å-13Å. The trace for H1 clay indicated material of C-spacing 10.2Å to 14Å with a bias in distribution towards 14Å. In contrast the traces for the H2 clay displayed a marked bias towards 10.2Å.

The K^+-saturation and sequential heating treatments were supplemented for these clays by initial heating of K^+-saturated samples at 100°C. This resulted in no appreciable change for H1 clay compared with the non-heated sample but the trace for H2 clay displayed a sharp peak at 10.2Å, indicating a minor amount of 11Å-13Å material.

Heating of the K^+-saturated H1 clay at 300°C produced a sharp, broad peak at 10.2Å with a little residual material apparent as a shoulder at 10.2Å. The trace was notable for the disappearance of peaks in the 14Å region and the clear emergence of a considerable sharp, broad-based peak at 7Å. This peak could not now be regarded as an 002 reflection of 14Å and was thus indicative of 7Å material, probably halloysite. The trace obtained after heating the K^+-saturated clay at 300°C gave an accentuated 10Å peak similar to that for the equivalent H1 clay.

Heating of H1 and H2 clays at 450°C caused little change to previous patterns except perhaps for some strengthening of 10Å and 7Å peaks in each case. However, heating at 550°C resulted in the disappearance of the 7Å peak and a residual 10Å peak in both cases.

The results obtained from the K^+-saturation and sequential heating of H3 and H4 clays are similar to each other in all respects. Patterns for the K^+-saturated clays recorded collapse from 14Å to 10.5Å and 10.4Å respectively for H3 and H4. Further, there remained in each case a considerable 11Å-13Å component. Heating of these samples at 100°C caused a strengthening of the 10Å peak, due to a collapse of 11Å-13Å material to 10Å, and the patterns clearly record a broad, rounded, and small peak at 7Å. Further heating at 300°C and 450°C resulted in accentuated 10.2Å peaks and clearer definition of the 7Å peak. Traces after heating at 550°C displayed the sharp 10.2Å peaks and disappearance of 7Å material, as in H1 and H2.

It is concluded that the most important crystalline clay is megnesium vermiculite. This is associated in varying proportions with mica and aluminous-hydroxy interlayered vermiculite. Magnesium vermiculite is a major component in the clay assemblage of H1, proportionately the most important species in H2 with yet increased importance in H3 and H4. The degree of interlayering of the clay minerals is weak to moderate in H1 but minimal in H2, H3 and H4 clays.

It was observed that 11Å-13Å material is found in considerable amounts in H1 and H2 and reduces progressively down the profile through H3 and H4. Minor amounts of halloysite are present throughout the profile, and chlorite is entirely absent.

Sharp and imposing peaks due to quartz were displayed at 3.35Å and 4.26Å on all traces. Feldspar is also present in H1 and H2 clays but was not so definitively expressed on traces for H3 and H4 clays. The occurrence of goethite was inferred in H2 clay from a minor peak at 4.18Å. All clays, excepting H1, gave a strongly expressed 003 reflection for 14Å material.

Figure 62.

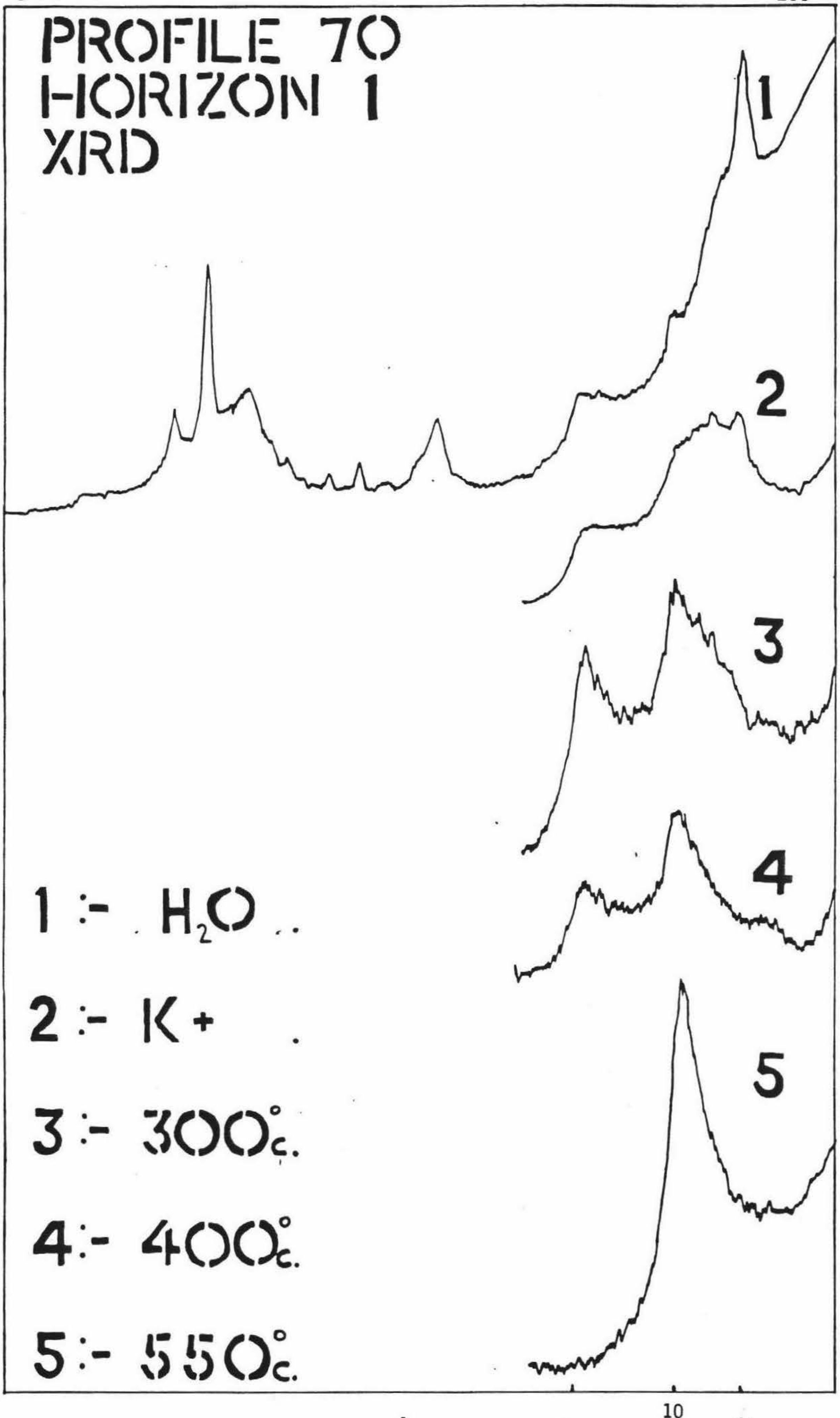

PROFILE 70
HORIZON 1
XRD
1
2
3
4
5
1 :- H_2O
2 :- K +
3 :- 300°c.
4 :- 400°c.
5 :- 550°c.
Å
7
10
14

Table 10. Profile 70 - Clay Mineralogy.

horizon		mica	vermiculite: magnesium vermiculite	vermiculite: very weakly interlayered	vermiculite: weakly interlayered	vermiculite: moderately interlayered	vermiculite: strongly interlayered	vermiculite: 11 - 13 Å material	pedogenic chlorite	quartz	feldspar	goethite	halloysite	allophane	imogolite
1	Ah	tr	+±	-	+±	tr	-	+	-	±	tr	-	tr	±	-
2	Bwg	tr	++	+	-	-	-	+	-	±	tr	tr	tr	tr	-
3	BCxg	tr	+++	+	-	-	-	±	-	±	?	-	tr	tr	-
4	Cxg	tr	+++	+	-	-	-	±	-	±	?	-	tr	tr	-

5.4.3.4 Infra-red Spectroscopy.

5.4.3.4.1 Interpretation of IRS Patterns.

The infra-red spectroscopy absorption bands at 3700 cm^{-1} and 3620 cm^{-1} represent surface and internal stretching bonds of OH^- groups in the octahedral planes of clay crystalline components and the absorption band at 915 cm^{-1} is due to Al-OH bonds in the crystalline structure.

The absorption bands at 3450 cm^{-1} represent OH^- stretching bonds associated with short-range order material (allophane) and are accompanied by absorption in the 1700 cm^{-1} to 1600 cm^{-1} region due to OH^- herding vibrations. A shoulder at 1100 cm^{-1} suggests the presence of highly condensed silica in the allophane.

Absorption at 1020 cm^{-1} to 1040 cm^{-1} is assignable to Si-O-Al bonds and its strength of expression is a measure of the Al/Si ratio. A strengthening of the peak accompanies a fall in the Al to Si ratio.

5.4.3.4.2 Results.

5.4.3.4.2.1 Introduction

In this section, while recognizing that non-crystalline clay material exhibits considerable variability in chemical composition and is frequently referred to as short-range order material, the term allophane is used for convenience. This term is used in its broadest sense and is not intended to be regarded as a mineral of fixed chemical composition and structure.

The IRS absorption patterns for clay samples of the nominated profiles are shown as follows:

Profile 18 - Fig. 63.
Profile 7 - Fig. 64.
Profile 50 - Fig. 65.
Profile 1 - Fig. 66.
Profile 70 - Fig. 67.

The relative distributions of allophane in the nominated profiles are shown in Fig. 68.

5.4.3.4.2.2 Results for all Profiles.

The presence of allophane and phyllo-silicate minerals in the clays of all horizons of all profiles was established by the appropriate fingerprint absorption bands on all traces.

The degree of expression of these absorption bands in the clay samples of Profiles 50 and 70 indicates that the ratio of allophane to crystalline clays is highest in H1 of these profiles and reduces with depth through H2 and H3 and is constant in H4, but increases slightly in H5 of Profile 50.

Absorption bands near 1100 cm^{-1} for all clays of Profile 70 indicate a high silica component in the allophane. For the H1 clay this band is supplemented by further absorption at 1160 cm^{-1} suggesting an even more condensed silica phase in this soil.

The degree of expression of fingerprint absorption bands indicates that allophane is a significant component in the clay assemblage of H1, H2, H3 and H4 horizons in Profiles 7 and 18. Further, it is clearly shown that the allophane to crystalline clay mineral ratio declines with depth through H2 to H3 and H4. Allophane dominates the clay assemblage of H5 in both profiles and its fingerprint absorption bands overwhelm the absorption bands for crystalline clay minerals in this horizon. In contrast, H6 and H7 of Profile 7 and H6 of Profile 18 have low allophane to phyllo-silicate ratios and crystalline clay minerals dominate the clay assemblage of these horizons.

The allophane to phyllo-silicate ratio was highest in the H1 clay of Profile 1 but the relative strengths of fingerprint absorption bands show that crystalline clay is clearly dominant over allophane in lower horizons. The ratio was constant in H2 and H3 but markedly decreased in H4 and H5 and was lowest in H6.

Figure 63. Profile 18.

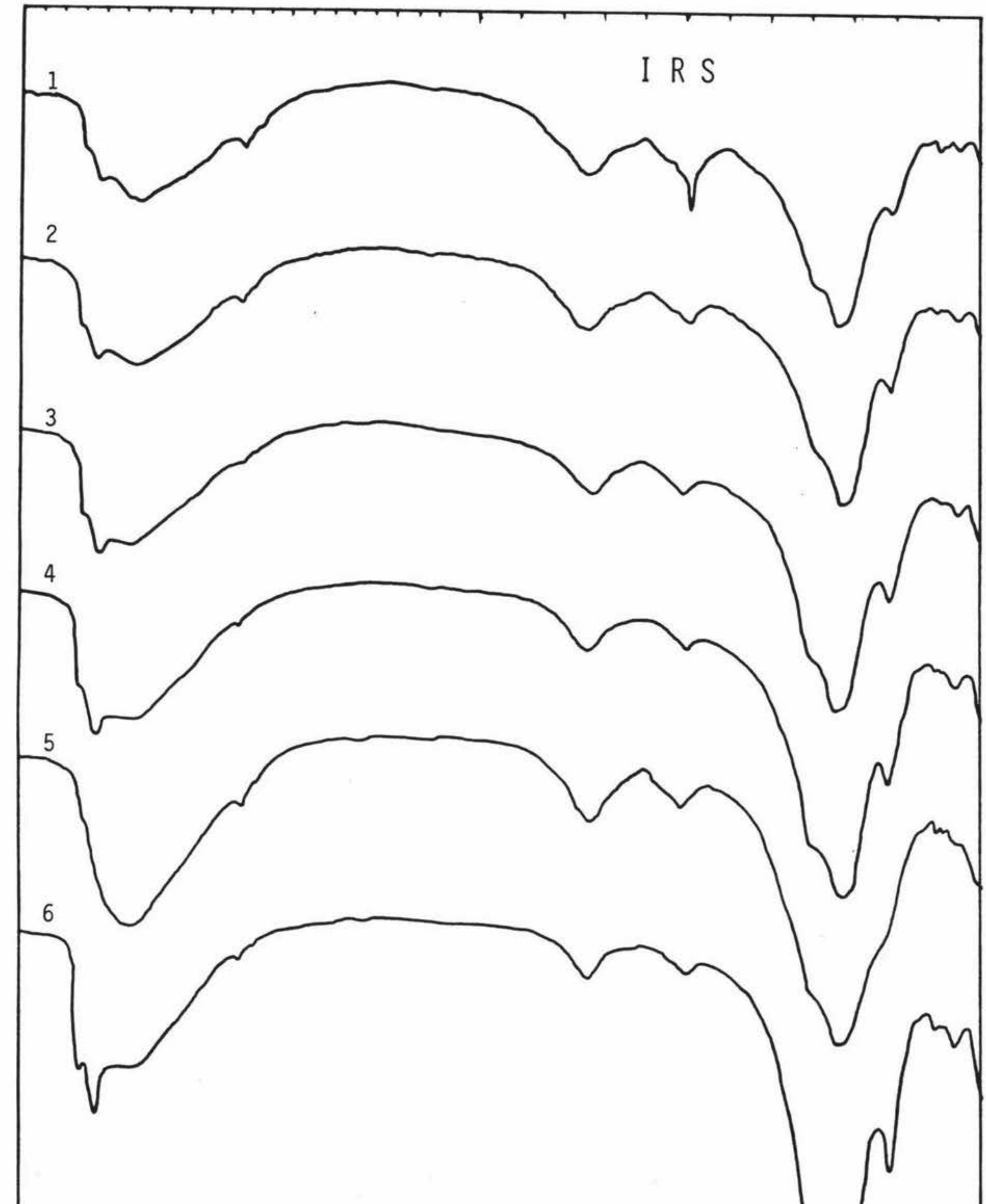


Figure 64. Profile 7.

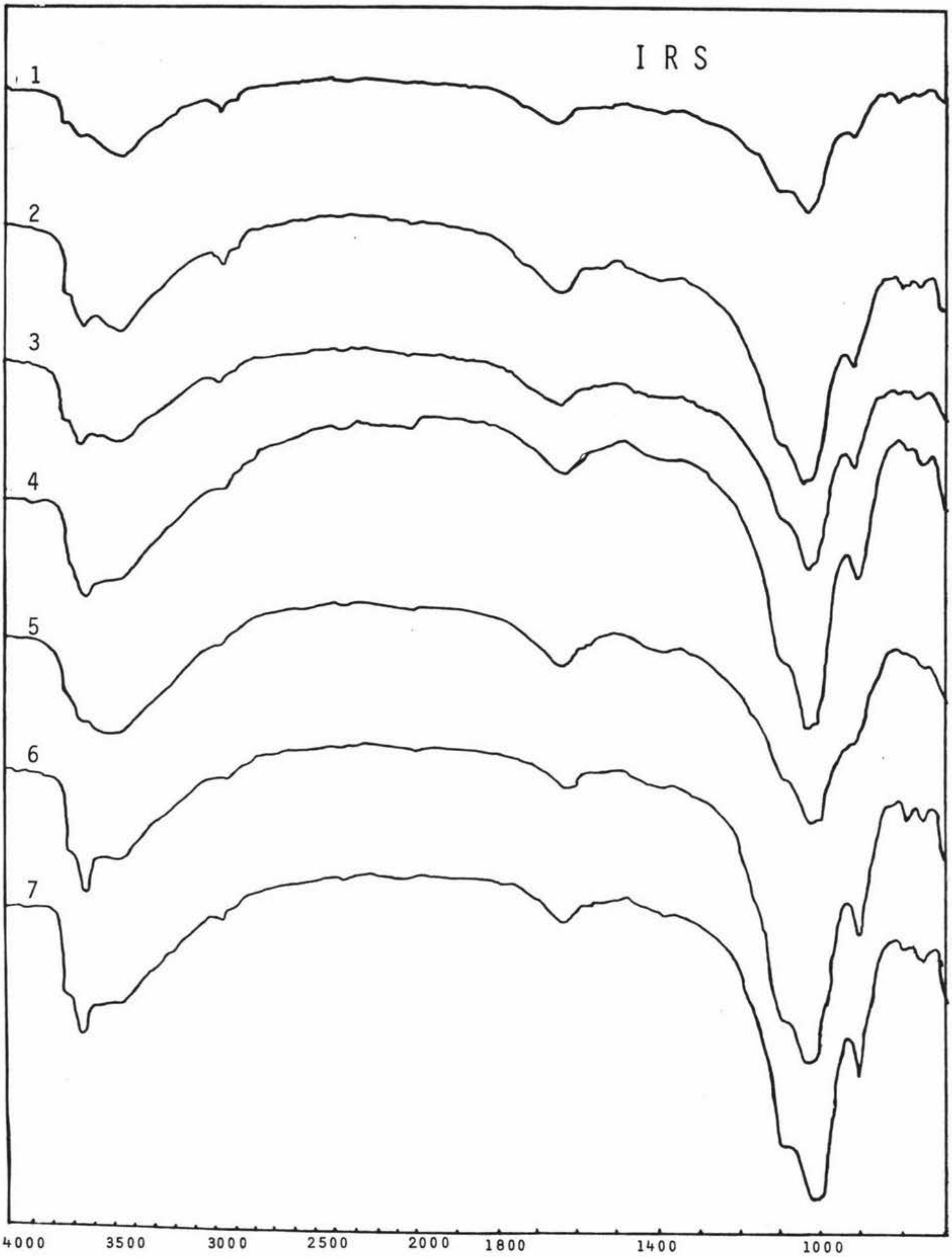


Figure 65. Profile 50.

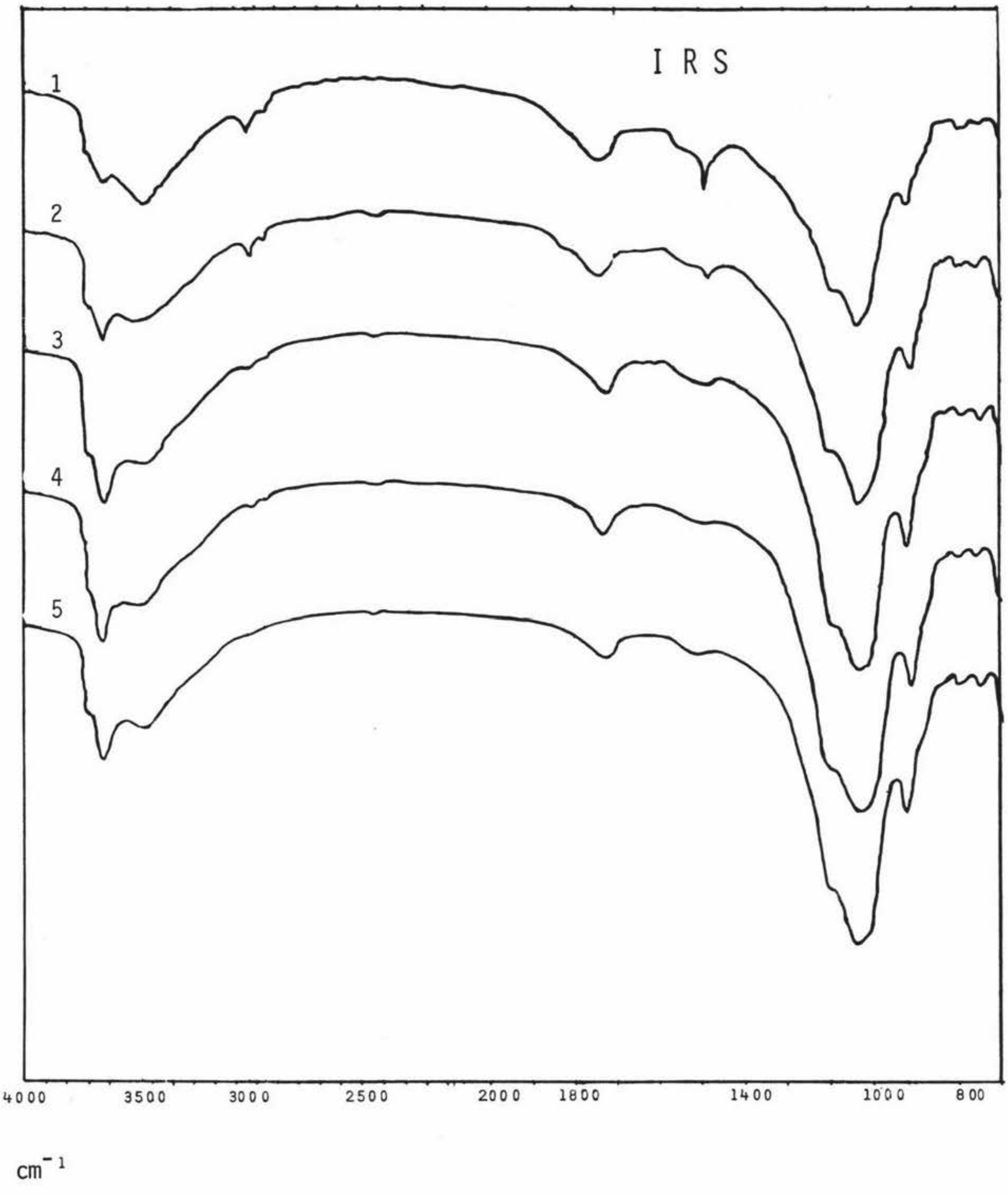


Figure 66. Profile 1.

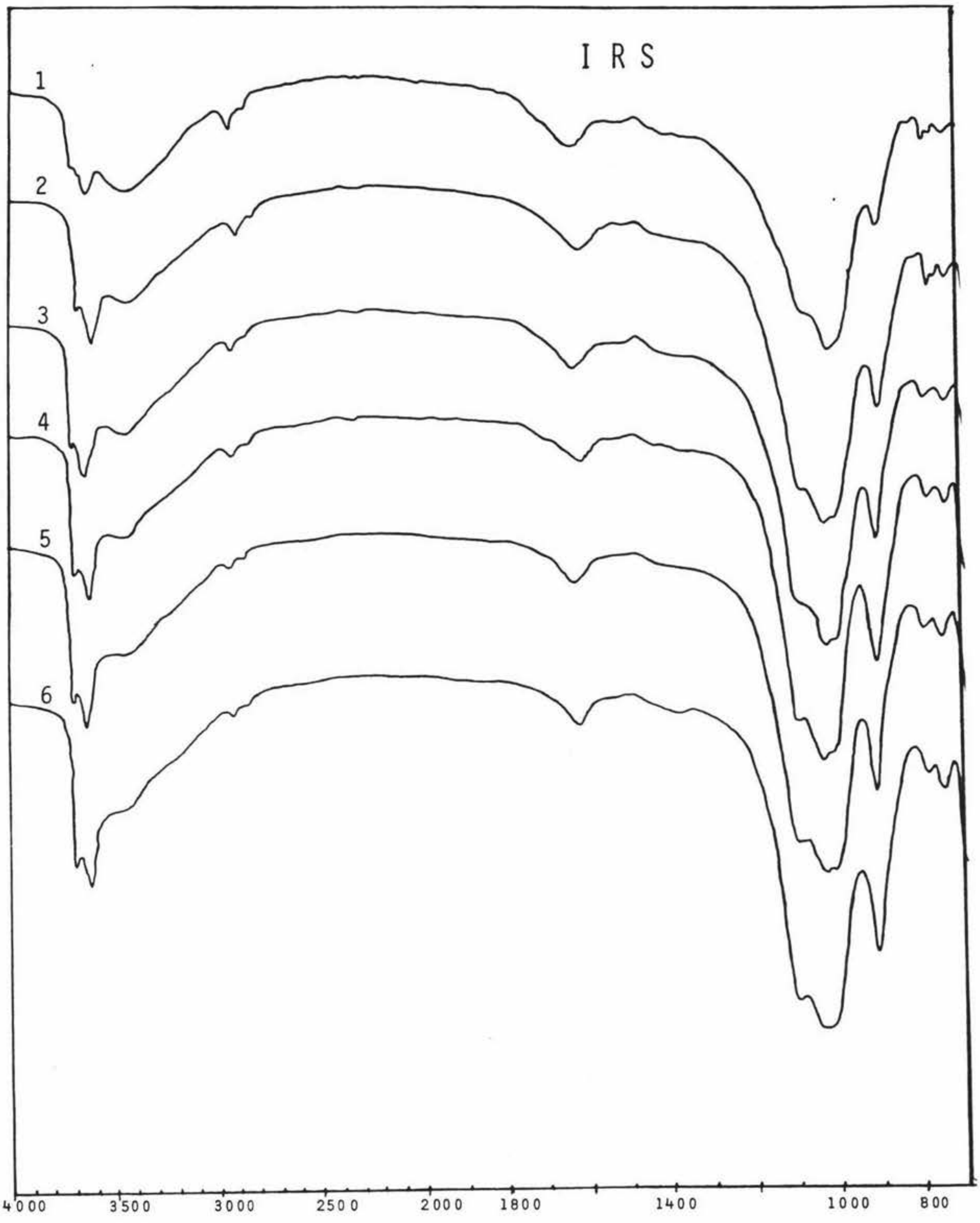


Figure 67. Profile 70.

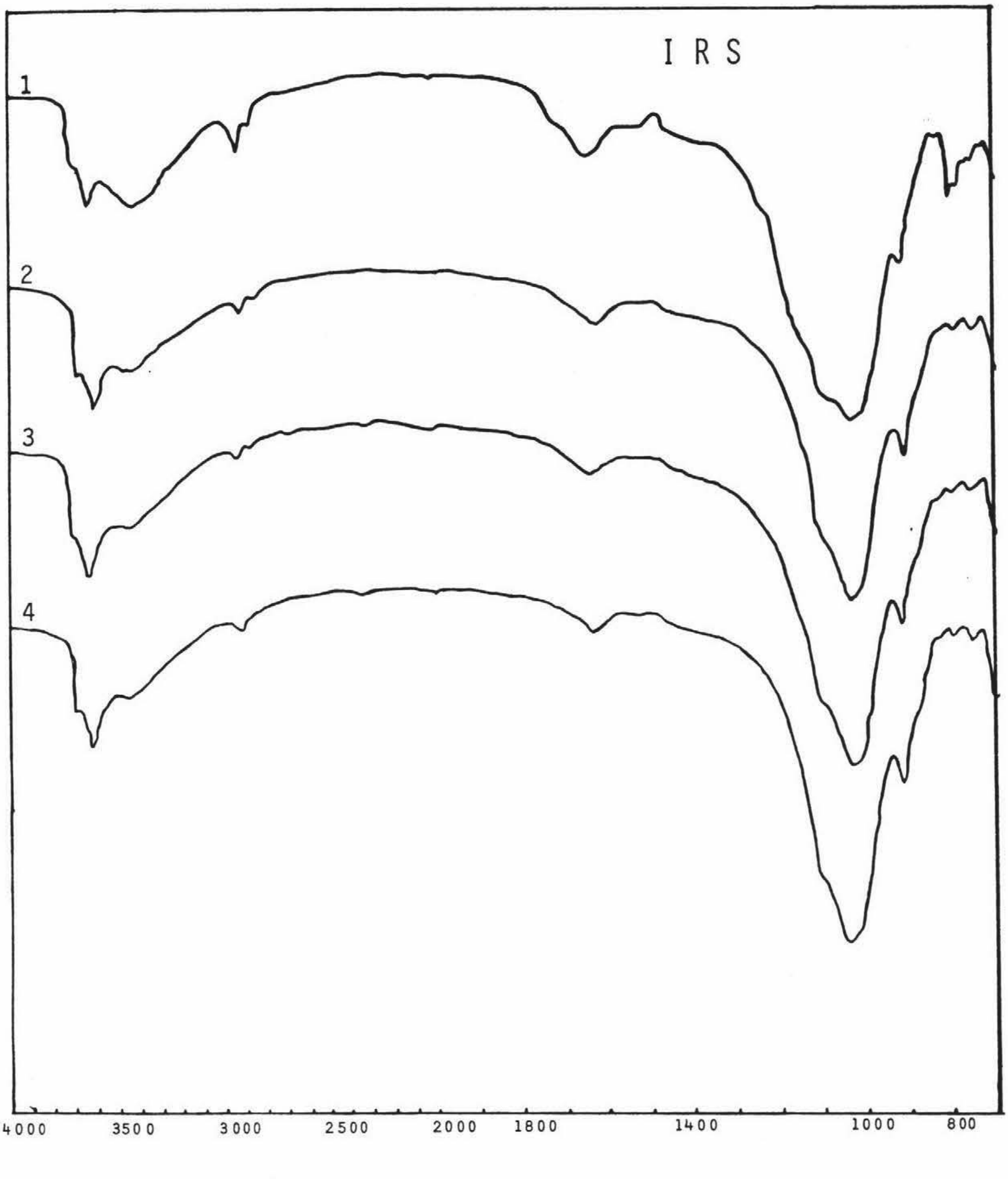
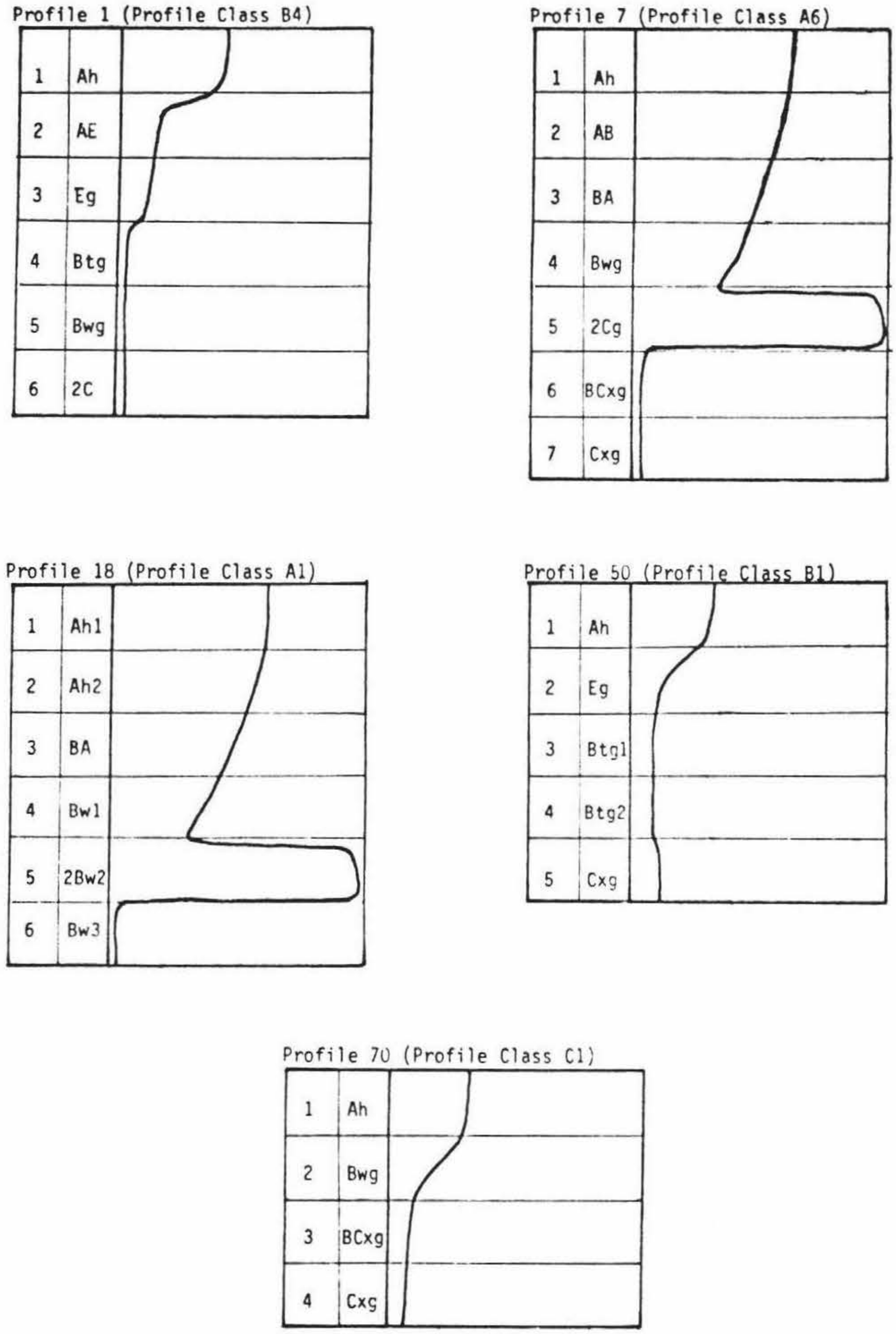


Figure 68. Distribution of allophane in nominated profiles.



Note - these diagrams illustrate the relative distribution of allophane within each profile, not absolute amounts between profiles.

5:4:3:5 Transmission Electron Microscopy.

Electron optical studies of clay separated from horizons of all profiles confirmed the presence of 2:1 material, allophane and halloysite in varying proportions.

The clays of Profiles 50 and 70 consist predominantly of 2:1 material with a high proportion of finely particulate, comminuted material present in all horizons. Allophane is present in greatest amounts in H1 and H2 of Profile 50 and H1 of Profile 70, and reduces with depth through the lower horizons. This confirmes the IRS evidence. Small, curled halloysite flakes and weathered glass are present in small amounts in the clay assemblage of all horizons in both profiles. Needle-like crystals, which were not identified, are present in small amounts in H1 and H2 of Profile 50 and in all clays of Profile 70.

The clays of H1, H2, H3 and H4 of Profiles 7 and 18 are dominated by 2:1 material which is finely particulate. Allophane and short, curled halloysite flakes are also present in moderate and small amounts respectively. Allophane is overwhelmingly dominant in H5 clay in Profiles 7 and 18; again this confirms IRS evidence. Small amounts of 2:1 material and traces of imogolite and short, curled halloysite flakes are also present. The H6 and H7 clays of Profile 7 and the H6 clay of Profile 18 consist largely of 2:1 material with a substantially greater component of short, curled halloysite flakes that were observed in clays of the overlying horizons. Minor amounts of iron oxides are present in the H1 and H7 clays of Profile 7.

The largest component in the clays of Profile 1 is 2:1 material, characterized by large flakes in all clays together with some small flakes in clays of the upper horizons. Halloysite is present in considerable amounts in the clay assemblage of all horizons, and is characterized by both long and short, large and small tubes and flakes together with a few spheroidal halloysite particles in H1, H2 and H3 clays. The incidence and coarseness of halloysite increased with depth and there is a marked amount of coarse particles in H5 and H6 clays. Allophane is present in small amounts in H1, H2 and H3 clays and in reduced amounts in H4, H5 and H6 clays. Needle-like crystals, similar to those observed in clays of Profiles 50 and 70, and traces of imogolite and weathered glass are present in H1, and traces of iron oxides are present in H3 clay.

CHAPTER 6. GENERAL DISCUSSION.

6.1 The Influence of Variation in Parent Materials on the Soil Pattern.

6.1.1 Introduction:

The soil pattern displayed on the soil map reflects the effects of erosion processes on surficial deposits in the study area.

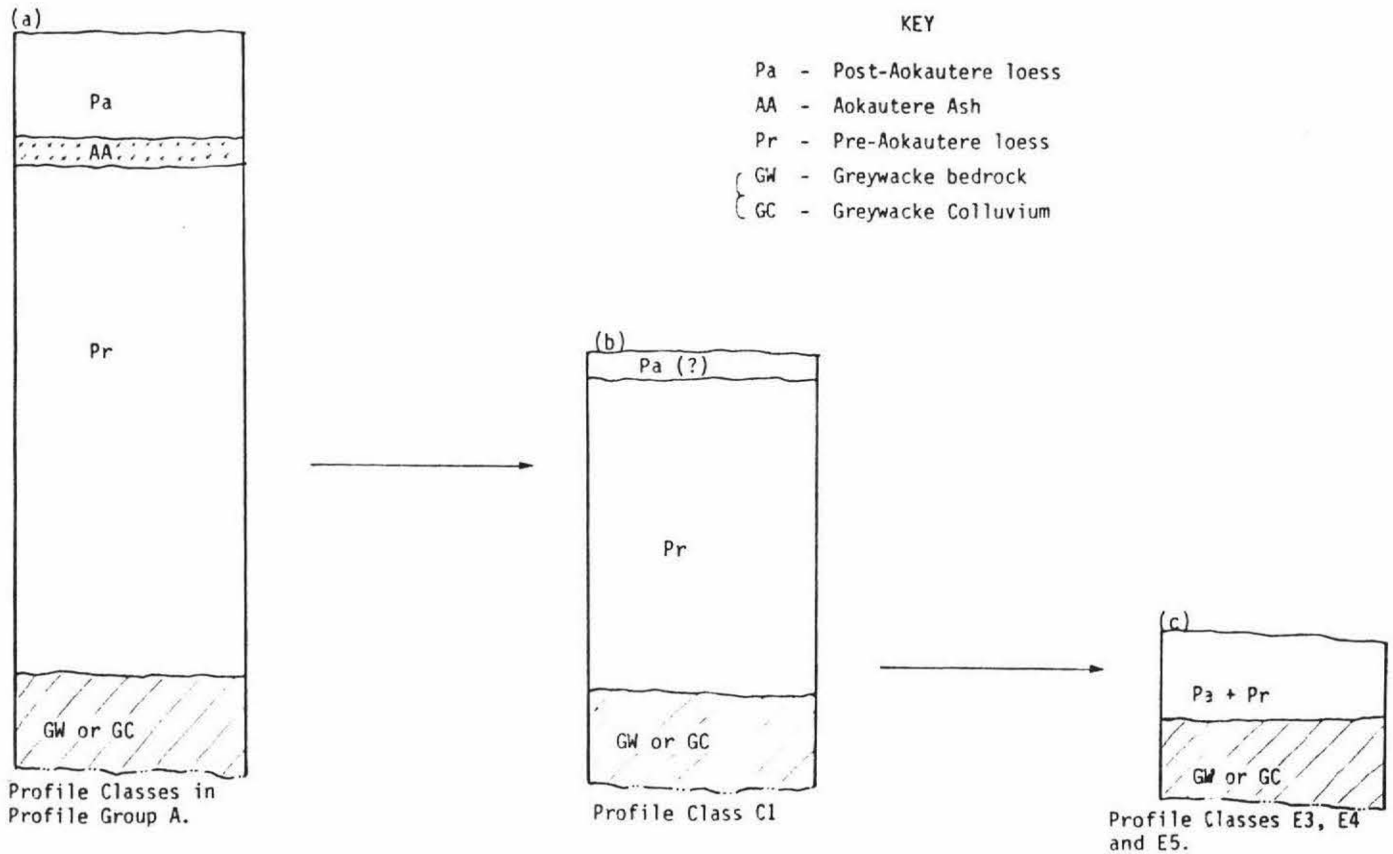
6.1.2 Soil Pattern on Physiographic Unit 1. (U1)

The stratigraphic succession of surficial deposits on this surface is loessial materials mantling basement greywacke or greywacke colluvium. The loess mantle is generally deep but varies in thickness to less than 1 m, with rock exposures in some locations. The variation in thickness of loess is considered to be due to irregularity of greywacke bedrock and to the effects of sheet erosion in stripping part of the loess mantle.

The considerable thickness of the loess mantle over much of the surface together with interbedding of Aokautere Ash in many locations at a depth of <1 m suggests that materials from several depositional episodes are present on this surface. The characteristic bedding features diagnostic of Aokautere Ash were observed undisturbed in many locations, suggesting that the surface had been stable for more than 21,000 years.

The stratigraphic succession at its fullest expression on this surface is shown in Fig 69(a) and has post-Aokautere loess over Aokautere Ash and pre-Aokautere loess resting on greywacke. Soils of Profile Group A (Profile Classes A1 - A6) are extensive on the surface and have formed in post-Aokautere loess. In addition to these soils there are limited areas of soils from Profile Classes C1, E3, E4 and E5 found on interfluves and surfaces at the lower margin of the Physiographic Unit where it adjoins Physiographic Unit 2. Soils of Profile Class C1 have formed from pre-Aokautere loess exposed by sheet erosion and removal of post-Aokautere loess, as shown in Fig. 69 (b). Soils of

Figure 69. Erosion sequence of parent materials, Physiographic Unit 1 and associated Profile Classes.



Profile Classes E3, E4 and E5 are present where the loess cap has been almost entirely removed by erosion leaving soils forming in a thin loess cap over greywacke bedrock or colluvium, as shown in Fig. 69 (c).

6.1.3 Soil Pattern on Physiographic Unit 2.(U2)

This surface, the break in slope between Physiographic Units 1 and 3, has exposures of greywacke rock, soils forming from deep loess, or shallower loess over greywacke bedrock or colluvial materials. The variety of Profile Classes present on the surface establishes an extended history of erosion and mass movement affecting soil parent materials.

Soils from Profile Class B7 are hill associates of Profile Class B1. They have formed from deep loess but have foreshortened profiles due to the influence of slope movement on the loess parent material.

Soils of Profile Classes E1, E2 and E3 have shallow loess topsoils over greywacke colluvial materials, the loess mantle having been removed by erosion associated with sheet erosion and slope processes.

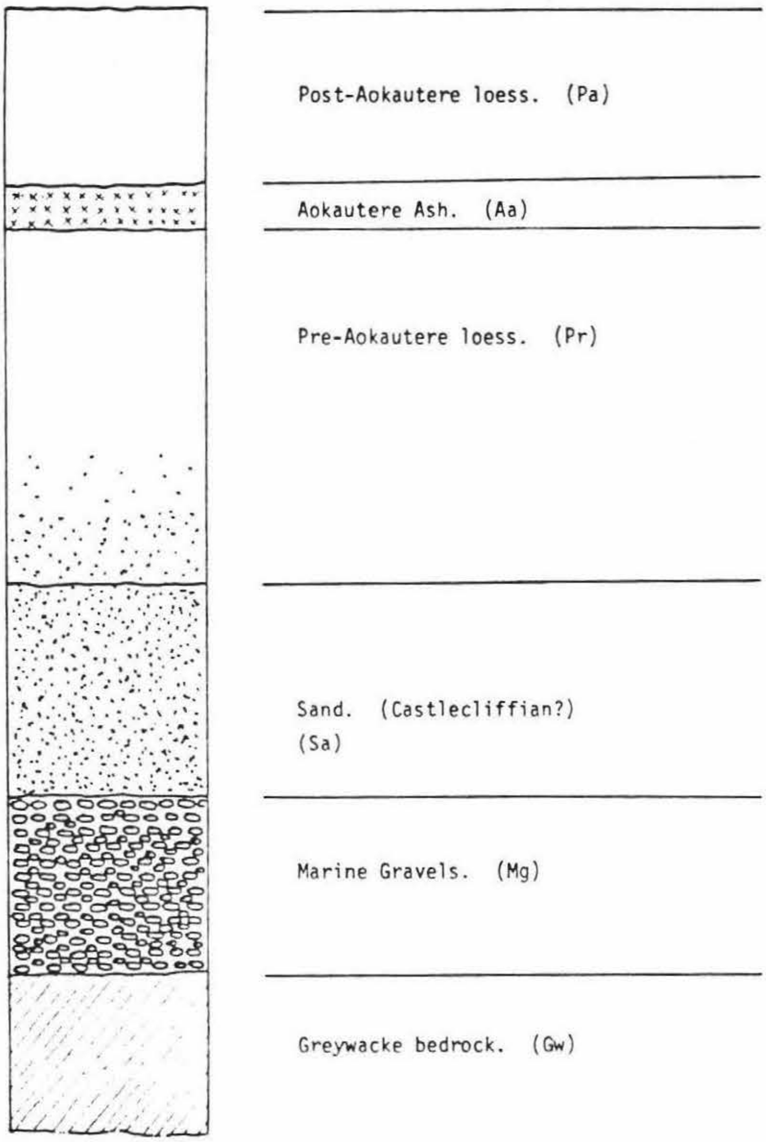
Soils of Profile Class C6 have profiles similar to Profile Class C1 but overdeepened through downslope accumulation of loessial material from Physiographic Unit 1.

Profile Class F1 represents soils found on a narrow bench cut into the relict sea cliffs at the height of marine transgresion in the area. The profile has a deep layer of loessial material considered to have flowed in a water-saturated state from Physiographic Unit 1 to bury existing loessial material on greywacke at this location.

6.1.4 Soil Pattern on Physiographic Unit 3. (U3)

The stratigraphic succession of surficial deposits on this surface consists of a capping loess mantle overlying unconsolidated Castlecliffian sands and marine gravels of the Tua Paka formation, resting on greywacke bedrock. The fullest expression of this stratigraphic formation at the end of the Ohakean cycle of loess deposition is shown in Fig. 70.

Figure 70. Stratigraphic column on Physiographic Unit 3.



The stratigraphic succession in its fullest expression on the marine bench (Physiographic Unit 3). Parent materials of soils on U3 represent a continuum in progressive degradation of this stratigraphic formation.

Formations of unconsolidated Castlecliffian sediments resting on impermeable surfaces are notoriously susceptible to dissection when the loess cap is penetrated and unconsolidated Castlecliffian materials exposed by gullying. Exposure results in slipping, dumping, tunnel gullying and stream bank erosion, especially during periods of high intensity storms (D.G. Bowler, Lectures, M.U., 1980; A.N. Glass, 1957).

The first order gully channels crossing the surface of Physiographic Unit 3 have cut through the surficial deposits and incised themselves to varying degrees into the bedrock greywacke of the marine bench, reducing the surface to a number of elongated interfluves running parallel to the slope. Tunnel gullying and slumping was observed along these major gully channels (see Fig.71) and also at the Tuapaka Fault intersect. These erosion features are considered of secondary importance in the dissection of the stratigraphic formation on the interfluves and the emergent soil pattern.

The degree of dissection of the stratigraphic formation is related in large measure to the lateral extent of the interfluves on which the formation rests and the incidence of lower order drainage tributaries on broad interfluves. Broad interfluves accommodate a network of lower-order channels that were observed to have cut through the loess mantle to flow through sediments of the Tuapaka formation on basement greywacke (see Fig. 72). Equivalent networks of lower-order drainage channels are not present and can not be supported by narrow interfluves with insufficient catchment areas. The lower-order drainage channels on broad interfluves are in the process of destroying the Tuapaka formation by washing away unconsolidated sediments, especially during high intensity storm events as observed by Bargh (1976). The erosive phases in the area postulated by Grant (1981 a, b) since the end of the last stadial account for the extent of degradation of the stratigraphic formation observed on broad interfluves.

Thus the broad interfluves on the surface display a full erosive sequence of parent materials associated with the dissection of the stratigraphic formation reflected in the complex variety of Profile Classes encountered in these areas. In contrast the stratigraphic formation remains intact and capped with loess on narrow interfluves, resulting in a more simple soil pattern in these areas (see Fig.73).

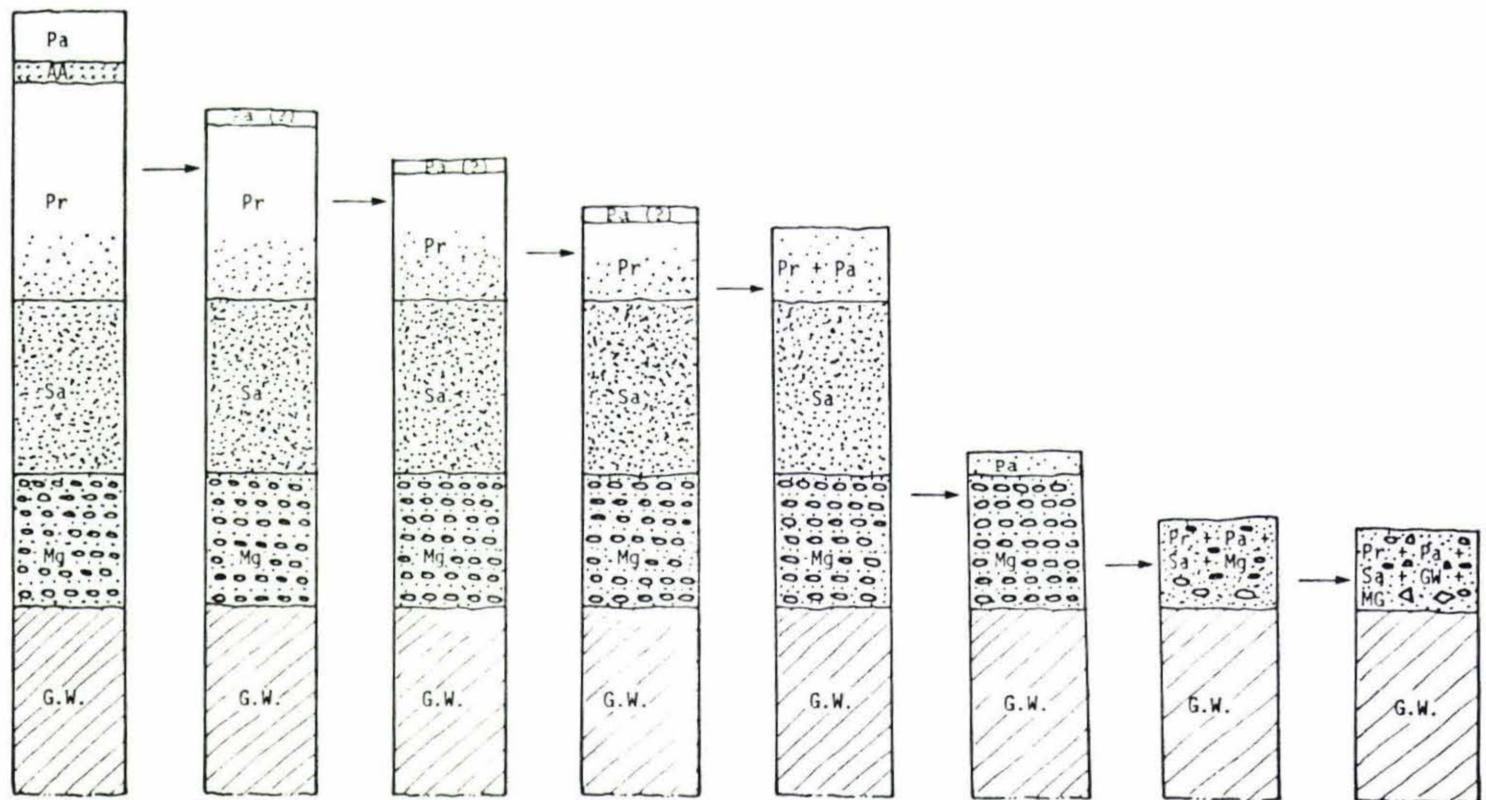
Figure 71 (a). Slumping of unconsolidated sediments of the Tuapaka formation overlain with loess into a deeply-incised gully channel on Physiographic Unit 3.

Figure 71 (b). Entrance to tunnel gully on side of incised gully channel on Physiographic Unit 3.

Figure 72. View of a gully channel on Physiographic Unit 3. The gully has incised through the overlying loess cap and sediments of the Tuapaka formation to flow on bedrock greywacke.

Figure 73. View of part of the Physiographic Unit 3 surface. Note the undulating surface displayed by a broad interfluve in the foreground caused by dissection of the Tuapaka formation and contrast this with the narrow interfluve surface in the background where the Tuapaka formation has not undergone a similar degree of dissection.

Figure 74. Erosion sequence of parent materials on Physiographic Unit 3 and associated Profile Classes.



(a) Profile Class A6

(b) Profile Classes B1,C1

(c) Profile Classes B2, C2, B3

(d) Profile Classes B4, C4

(e) Profile Class C5

(f) Profile Classes D2, D3

(g) Profile Class E6

(h) Profile Class E7

Figure 75. Cutting showing undisturbed marine gravels of the Tuapaka formation overlain with loess on Physiographic Unit 3.

The erosion sequence in soil parent materials is summarized in Fig.74 and its relationship to Profile Classes on Physiographic Unit 3 outlined below.

The soils represented by Profile Class A6 are located in undisturbed locations at the intersection of Physiographic Units 2 and 3. They have formed from parent materials of post-Aokautere loess overlying pre-Aokautere loess with Aokautere Ash interbedded in the profile, as shown in Fig. (a).

Soils of Profile Classes B1 and C1 have formed from deep pre-Aokautere loess overlain by recently deposited post-Aokautere loess, as shown in Fig. 74 (b). Post-Aokautere loess and Aokautere Ash have been removed during post-erosive events.

Profile Classes B2, B3, C2 and C3 represent soils whose parent materials show an increasing incidence of fine sand in the lower profile due to progressive stripping of pre-Aokautere loess in the area, as shown in Fig. 74 (c).

Soils of Profile Classes B4 and C4 have sand present at the base of the profile as a discrete 2C horizon, as shown in Fig. 74 (d).

Soils of Profile Class C5 represent a further step in the erosion sequence and have a shallow topsoil of mixed sand and loess over sand in a discrete 2C horizon, (see Fig. 74 (e)).

Soils of Profile Classes D2 and D3 take the erosion sequence a step further. The sand has been removed and a topsoil formed in shallow loess, possibly mixed with fine sand, rested on undisturbed marine gravels, (see Fig. 74 (f) and Fig.75).

Profile Classes E6 and E7 represent the end of the erosion sequence on this surface. In soils of Profile Class E6, erosion agents have disturbed and redeposited marine gravels in a silty matrix, see Fig.74 (g). Profile Class E7 represents the almost complete removal of the Tuapaka formation. The soil is forming from an unsorted matrix of silt, sand and angular greywacke rocks with some residual marine gravels, resting on basement greywacke, as shown in Fig. 74 (h).

Figure 76. View of undulating surface on a broad interfluve of Physiographic Unit 3 with remnants of sediments of the Tuapaka formation overlain with loess and resting on bedrock greywacke. Note the greywacke bedrock exposed by a lower order drainage channel in the foreground and the relict sea cliffs of Physiographic Unit 2 in the background.

It was noted that soils of Profile Class B4 were located along the intersect of Physiographic Units 2 and 3, the foot of the relict sea cliffs, in addition to their distribution in association with the erosion sequence outlined above.

In accordance with this analysis of variations in the soil parent materials on this surface, soils on narrow interfluves are confined to Profile Classes A6, B1, B2, B3 and C1, with Profile Class B4 in some locations, as noted above, while broad interfluves have a complex pattern of all Profile Classes shown in Fig. 74. This complex soil pattern is associated with an irregular, undulating terrain (Fig. 76.)

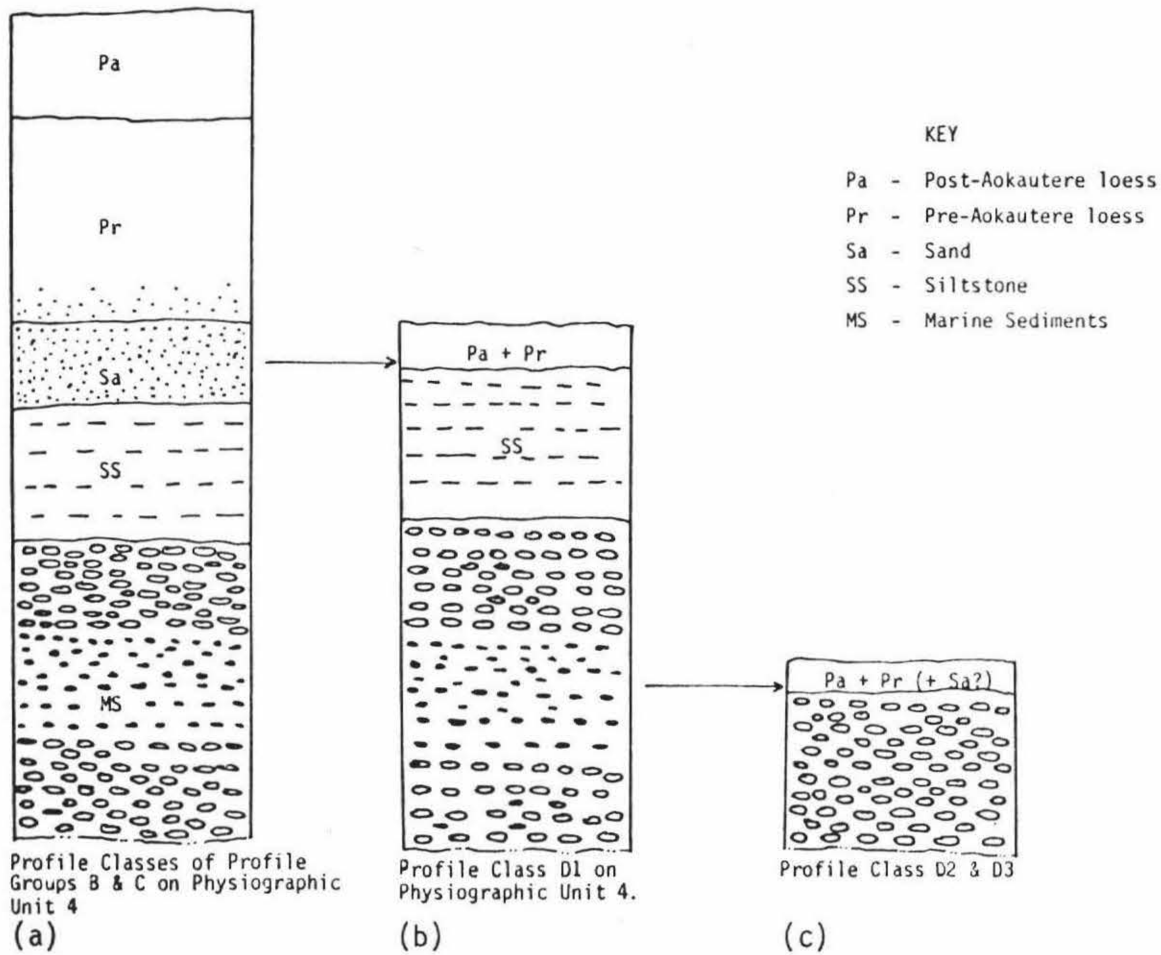
Soils of Profile Class F2 are located near the intersect of this Physiographic Unit with U2. Profiles display a deep mantle of loessial material that has flowed under gravity in a water-saturated state from U2 to inundate existing deep loessial material in some locations.

6.1.5 Soil Pattern on Physiographic Unit 4. (U4)

The stratigraphic formation of surficial deposits on this surface is deep lower Castlecliffian sediments of the Tuapaka formation mantled with loess. These sediments of the Tuapaka formation are different in character from those encountered on Physiographic Unit 3. They are composed of interbedded marine gravels and siltstones mantled with fine sand and loess. An idealized section through the upper region of the formation is shown in Fig. 77 (a).

The stratigraphic formation of loess over marine sediments, as shown in Fig. 77 (a), is preserved to varying degrees on this surface to the Aokautere side of the farm and in an area in the vicinity of the farm boundary on the Manawatu Gorge side of the farm. In the intervening area, gully channels arising at the location of the Tuapaka Fault through seepage from the upthrown greywacke marine bench have deeply incised into the marine gravels and sedimentary rocks of the Tuapaka formation, resulting in steep-sided gully channels separated by narrow finger-like interfluves. These interfluves have been stripped of their loess cover and marine sands, resulting generally in soils forming from siltstone material with a thin loess cover (see Fig. 77 (b)). Soils forming from undisturbed marine gravels covered with varying

Figure 77. Erosion sequence of parent materials on Physiographic Unit 4 and associated Profile Classes.



depths of loess are located along the intersect of the Tuapaka Fault and at other locations where exposed by erosion (see Fig. 77 c).

Soils from Profile Groups B and C (Profile Classes B1, B2, B3, C1 and C3) are forming from loess over marine sediments in the locations noted above. These soils display the characteristic erosion sequence noted on Physiographic Unit 3 with an increasing importance of fine sand in the profile due to stripping of the loess mantle.

The soils of Profile Class D1 are present on interfluves as noted above, where the loess topsoil and marine sands have been stripped and the soils are forming out of siltstone of the Tuapaka formation with a superficial covering of loess topsoil. There are includions of C1 and B2 on the interfluves in some locations.

Soils of Profile Classes D2 and D3 are located adjoining the Tuapaka Fault, as noted above; where stripping of overlying deposits results in undisturbed marine gravels near the surface, mantled in shallow loess deposits.

Soils from Profile Classes B6 and B7 are found in some locations below the Tuapaka Fault where marine gravels dislodged from exposures on its upthrown side have been transported under gravity onto existing loess surfaces. These soils therefore have redeposited gravels in the upper profile overlying subsoils similar to Profile Classes B1 and B3 respectively.

6.2 Pedogenic Processes.

6.2.1 General.

It has been observed by Pohlen (1972) that major changes in soil morphology occur in New Zealand at mean annual rainfalls of approximately 1000 mm and this phenomenon has been noted at similar rainfall levels in other parts of the world. Processes begin to change markedly at mean annual rainfalls between 750-1000 mm and the dominance of new processes is finally complete at rainfalls between 1000 mm and 1250 mm. The main difference in the rainfall pattern is related to an increase in total rainfall and an increase in the distribution of rain days with 2.5 mm of rain or more during the moist period of the year from late autumn to early spring. These morphological changes within New Zealand occur over a wide range of mean temperatures (3°C to 16°C).

The main differences in soil processes may be attributed to the additional amount of water infiltrating into the soil increasing soil moisture and percolation. Increasing soil moisture favours the weathering and persistence of allophane and 'free' sesquioxides, and is accompanied by markedly stronger resistance to dispersal of clays. These conditions also increase leaching with the development of lowered pH and the mobility of chelating agents. Broad morphological differences reflect the extent to which positive colloids are sufficient to aggregate the negative clay minerals.

The N.Z. Zonal classification of soils has given the YGE soil group an upper rainfall limit of 1000 mm, the YBE soil group a lower rainfall limit of approximately 1250 mm and the soils between are classed as Integrades(N.Z. Soil Bureau, 1954).

The conspicuous morphological feature of YGE soils derived from siliceous parent materials is the fragipan, which is considered to be pedogenic in origin (Soil Survey staff, 1975). This has been defined by Taylor & Pohlen (1962) as follows:-

> "a compact, massive or near massive horizon rich in silt, sand or both, and generally low in clay. When dry, the fragipan is brittle and has the appearance of being strongly cemented but the cementation if present disappears on moistening. They are

"characteristic of C horizons that are weathering undisturbed by root penetration, rapid moisture fluctuations, or other strong biological or physical activity."

The fragipan creates conditions of internal drainage impedence and as precipitation approaches the 1000 mm mark this results in seasonal waterlogging and reducing conditions alternating with moisture deficiency and oxidation over the yearly cycle. These conditions promote pseudogleying and ferrolysis above the fragipan and lessivage of fine clay down the profile (Pollok, 1975).

The process of pseudogleying resulting from oxidation and reduction results in clay formation. Iron is mobilized and segregated into mottles and ironstone concretions. In addition hydroxy polymers are formed, and there is increasing Al_3^+ interlayering of 2:1 clays to form ultimately pedogenic chlorite. Exchangable bases are displaced and lost through leaching. Further in time and intensity alternate oxidation and reduction results in the process of ferrolysis in which clay minerals are decomposed (Brinkman, 1979). The decomposition of weatherable minerals and the relative accumulation of silica in the upper horizon under acid conditions can result in the formation of pale-coloured (albic) horizons on removal of the grain coatings of ferric oxides.

The process of wetting and drying of the soil promotes lessivage (Soil Survey staff, 1975). Wetting of a dry soil leads to the disruption of the soil fabric and the dispersal of clay. Organic matter also seems to play an important but possibly indirect role in dispersal. The fragipan of the YGE soil shrinks when dry and a system of permanent joints are opened up. In the early stages of wetting, before the whole mass has absorbed enough water to close the joints, drainage water percolates down the joint network. On saturation the fragipan swells and the joints close, presenting an effective barrier to further downward percolation (Raeside, 1964). Ground water carrying fine clay in suspension percolating into the system of open joints in the fragipan is stopped by capillary withdrawal into the soil fabric and the clay is redeposited on the walls of non-capillary voids as cutans (U.S. Taxonomy, 1975). Thus the space between the joints becomes filled with fine textured soil material characteristically gleyed pale grey. Seasonal waterlogging of YGE soils is observed to be fragmenting and apparently destroying the upper surface of the fragipan (Pollok, 1975). The destruction process occurs through chemical weathering when ground water percolates into the joints and fissures between and within the peds to disrupt the upper fragipan.

Soils of the yellow-brown earth soil group are formed from quartzo-feldspathic parent materials. The fragipan formation of the yellow-grey earth soil group is absent and they are are free-draining and at or near field capacity for most of the year. The morphological difference of these soils from yellow-grey earth are related to processes associated with higher effective rainfalls, as noted above. These processes have resulted in higher contents of short-order materials and free sesqui-oxides that structure up the profile, giving resistance to dispersal of their clays, secondary products of weathering.

The yellow-grey earth - yellow-brown earth integrade soils show morphological features that are intermediate in nature between those exhibited by yellow-grey earth and yellow-brown earth soils. The fragipan formation in the subsoil softens and the depth and extent of its fragmentation increases with increasing effective rainfall in areas of integrade soils (Pohlen, 1972; Raeside, 1964). Soils at the drier end have prominent mottling above a compact fragipan and mottling intensifies above the fragipan and in the joints and fissures of the upper fragipan with increasing rainfall. Soils at the wetter end of the zone have solums more characteristic of yellow-brown earth with faint mottling in the upper solum while the lower part of the subsoil has features more characteristic of yellow-grey earth's in the form of a weakly compacted fragipan (Watt, 1972).

Soils of the integrade yellow-brown earth - yellow-brown loam group have properties intermediate between those of yellow-brown loams formed mainly from volcanic ash and yellow-brown earths formed from ordinary siliceous rocks. They have formed in a quartzo-feldspathic parent material contaminated by additions of volcanic ash in the weakly weathering environment associated with integrade soils. They acquire their yellow-brown loam characteristics through weathering of volcanic ash to form allophane and the iron-oxide ferrihydrite. Rhyolitic and andesitic tephras weather to allophane, the former less rapidly than the latter and ultimately to halloysite (Kirkman, 1977). Differences in the rate of formation and subsequent alteration of allophane in the two types of tephra are determined largely by the chemical composition and porosity of the respective glasses. The andesitic tephra being highly porous weathers rapidly and its high Al_2O_3:SiO_2 ratio introduces strains between particles tending to increase its weatherability (Kirkman, 1977). The short-range order of these two minerals results in a large and varying capacity for water retention. In addition allophane imparts a low bulk density to the soil matrix, promotes free drainage and contributes to high sorption of phosphate anions in the soil. The CEC of allophane decreases and AEC increases with decreasing pH of the saturating solution and this imparts a variable charge property to the soil.

6.2.2 Profile Group A.

The soils of Profile Group A had been classified and mapped as Ramiha silt loam (Cowie, 1978) and were considered to have formed in a parent material of loess solifluction material and slope deposits. Pollok, (1975), had earlier referred to possible contamination with volcanic ash and drawn attention to the presence of Aokautere Ash at a depth of 150 cm within the soil profile. Observations during the execution of this survey and particle size distribution results from nominated profiles of Profile Classes A1 and A7 confirm the existence of a loessial parent material with the possible interbedding of Aokautere Ash and solifluccted material in this Profile Group.

The soils of Profile Class A1 are forming in a weakly weathering environment with cool temperatures and high rainfall conducive to the persistence of amorphous products of weathering. The yellow-brown loam character of these yellow-brown loam - yellow-brown earth integrade soils, well developed nutty structures in the upper profile, friability, water-retentivity and free-draining properties, are considered due to the aggredation of the mineral soil components by allophane that has weathered from a volcanic ash component in the loessial parent material.

The study has established that the characteristic allophane component in these soils is restricted to loess of post-Aokautere age and is present irrespective of the specific incidence of the Aokautere Ash layer. The trend of reducing amounts of allophane with depth above the Aokautere Ash and the high allophane content in the ash itself tend to confirm the non-association of the allophane component in the upper profile and the Aokautere Ash layer. Furthermore soils forming in pre-Aokautere loess at erosion sites on Physiographic Unit 1 adjacent to soils of Profile Group A had the YGE-YBE characteristics of soils from Profile Class C1 and were classified as such. It was concluded that the allophane component in the upper profile of soils of this Profile Group had formed through weathering of a possible andesitic ash contaminant in post-Aokautere loess. This conclusion is confirmed by the presence of soils of Profile Class A6 at stable, uneroded sites on Physiographic Unit 3 where post-Aokautere loess and the Aokautere Ash layer remain undisturbed. Elsewhere on this surface the post-Aokautere loess and Aokautere Ash has been stripped and soils of Profile Groups B and C have formed largely in pre-Aokautere loess. The conclusions are in accordance with the results of Wallace and Neall, (1982).

The soils of Profile Group A exhibit contrasting morphologies in the upper and lower profile zones. As has already been noted upper horizons exhibit characteristics of yellow-brown loams, while subsoils have morphologies more akin to those found in yellow-brown earth - yellow-brown loam integrade soils in the area. Thus there is a marked change in structure down the profile from well-developed nutty-granular structures in the upper profile to very coarse blocky, going to massive structures in the subsoil. The blocky structures are associated with a modest degree of mottling and the incidence of Fe/Mn concretions that vary between Profile Classes in the Group. Soils of Profile Class A7 on Physiographic Unit 2 have developed BCx and Cx horizons below the Aokautere Ash layer similar to those observed in Profile Groups B and C.

It is considered that these integrading properties are derived from an interaction between a weak weathering regime and a possible andesitic ash component in post-Aokautere loess. The weathering regime had been most effective in the upper profile of these soils and its effects have been reduced with depth towards the Aokautere Ash layers.

The allophane released through weathering has structured up the upper profile and imparted the characteristic yellow-brown loam properties. The horizons in the lower profile are poorly structured and their allophane content is reduced. As a consequence these horizons do not possess the free-draining properties imparted to the upper profile, with the result that mottles and concretions form and the lower part of the profile becomes more akin to that of a yellow-brown earth.

In the integrading situation, rainfall mobilizes 'free' sesquioxides and some clay, (including allophane) is moved down through the profile. Iron mobilized in the lower part of the profile is precipitated at the impedence to drainage caused by the blocky compacted subsoil. It forms incipient placic horizons in some cases or, in association with translocated clay, is deposited on blocky peds and in relict root channels in the lower profile in the form of ferri-argillans and argillans (Brewer, 1964). This process will operate principally at the end of the dry summer and during the early period of autumn rains when structural cracks are still present and before the subsoil peds have swollen through absorption of ground water. Where Aokautere Ash is present, it creates a textural break towards the base of the profile. The coarser pore size within the Aokautere Ash presents an impedence to capillary water movement so that this water is seasonally perched in the subsoil. Again the consequence is the precipitation of iron in the form of reddish-brown mottles and concretions.

6.2.3 Profile Groups B and C.

Profile Groups B and C comprise Profile Classes in an erosional sequence. There is a gradational change in the composition of parent materials through the sequence associated with increasing fine sand and reducing coarse silt fractions in the soil matrix. This has resulted from the progressive contamination of the loessial parent material by underlying marine sands.

Profile Classes of Profile Group B are differentiated from those of Profile Group C by the presence of a bleached eluvial horizon. The distribution of these soils, classified and mapped in Bulletin 33 as Tuapaka hill soils, coincides to some extent with the occurrence of an original black beech forest cover and their impoverished nutrient status and bleached appearance has been attributed to the effects of this vegetation (Cowie, 1978). However soils of this Profile Group are also located along the intersect of Physiographic Units 2 and 3 where this pedological feature has resulted from seepage of ground water from higher elevation.

Soils of Profile Classes B1 and C1 have developed largely in deep pre-Aokautere loess in a similar soil-forming environment and subject to similar soil-forming processes, excepting the influence of the beech forest cover and seepage, as noted above. The soils have deep, strongly mottled subsoils above a fragipan, a characteristic of yellow-grey earth - yellow-brown earth integrades. The deep, strongly mottled subsoils represent soil formation in situ above the Cxg horizon. It is believed that they have formed through fragmentation of the upper fragipan by chemical weathering in an integrade situation where the soil is on or above field capacity for a considerable part of the year. In the soils of Profile Class C1 darker material from the Ah horizon has been carried down root channels and structural points to link up with the grey veins in the fragmented fragipan zone.

Soils of Profile Classes B1 and C1 display marked contrasts in many pedological features that signify that the degree of weathering is farther advanced in soils of Profile Class B1 than is the case for Profile Class C1. For example the degree of aluminous interlayering of the vermiculite clays is different. The clay assemblage of Profile

Class C1 is made up largely of K^+ collapsible vermiculite, with some weakly aluminous interlayered vermiculite present in the Ah horizon and minor amounts present in the Bwg horizon. In contrast, moderate-strongly aluminous interlayered vermiculite is predominant in the clay assemblage of the Ah and E horizons of Profile Class B1, with K^+ collapsible vermiculite predominant in the lower Btg2 and Cxg horizons.

Soils of Profile Class C1 have a fine-clay bulge in the Ah and Bwg horizons while in Profile Class B1 the fine clay component is low in the Ah and E horizons and rises sharply in the Btg1 and Btg2 horizons. Cutans were observed on peds in the subsoils of profiles of both Profile Classes examined in wet weather.

The solum of Profile Class C1 does not display an eluvial horizon, although the Bwg, BCx and Cxg horizons are strongly mottled and concretions are present throughout these horizons. Soils of Profile Class B1 have striking bleached E horizons resulting from the removal of ferric coatings on mineral grains while ironstone concretions were noted as a prominent feature in the Bt2 horizon above the fragipan.

The IRS investigation established that some allophane is present throughout the soils of both Profile Classes. The amorphous to crystalline ratio is highest in the Ah horizons and falls progressively down the profile.

The features enumerated above suggest that pedogenic processes associated with seasonal oxidation and reduction, progressive fragipan fragmentation and lessivage have operated to different degrees in the various soils. The evidence indicates that the effects of the pseudogleying and lessivage processes are not far advanced in Profile Class C1 but that active fragmentation of the fragipan is taking place due to these soils being at or above field capacity for a considerable period throughout the year. Such features accord with yellow-grey earth - yellow-brown earth integrade soils forming in a mild, weathering environment. Soils of Profile Class B1 are considered to have experienced ferrolysis, marked lessivage and some fragmentation of the fragipan. The strong aluminous interlayering of the vermiculite in the Ah and E horizons and its absence in the subsoil eliminated the possibility of cheluviation in this case. The low fine clay component in the Ah and E horizons and the removal of iron oxide coatings on the grains of the E horizon together with the degree of aluminous interlayering of vermiculite in these horizons indicates a process of ferrolysis accompanied by mobilization of 'free' sesquioxides down the profile and lessivage of the fine clay into the Btg1 and Btg2 horizons. The large concretions present in the Btg2 horizon are further evidence of considerable mobilization of iron down the profile.

The acid conditions under beech have contributed to aluminium interlayering in the Ah and E horizons and the removal of bases to produce a chemically impoverished soil (Soil Bureau Bulletin 33, [Cowie, 1978] Fig. 7). The degree of fragipan fragmentation is not as far advanced in this soil as in the case of Profile Group C. It was concluded that soils of Profile Class B1 have formed in a more extreme weathering environment than is the case in Profile Class C1 due to greater seasonal variations in soil moisture conditions.

It should be noted however that the soils of Profile Class B4 have an eluvial horizon, a degree of alumium interlayering of the vermiculite clay in the upper profile and an apparent clay shift to the subsoil equivalent to those observed in Profile Class B1, despite the absence of the impedence to drainage necessary to initiate the ferrolysis process. Consequently pedogenic processes operating in soils of Profile Class B4 merit further investigation.

The presence of significant amounts of fine sand in the parent material and lower solum has considerably modified pedogenic processes. Thus soils of Profile Classes B3, B4, C4 and C5 with high fine sand components in their profiles do not develop fragipans. Soils of Profile Classes in intermediate situations in respect of fine sand contamination of the loess parent material were inconsistent in this regard. Soils of Profile Class C3 with a significant fine sand component in the matrix above 70 cm develop a fragipan while this feature is absent in some soils of Profile Class B2 that have the significant fine sand component below 70 cm. These soils develop instead deep blocky Bwg horizons that become massive with depth. The critical factor in fragipan formation in these circumstances appears to be the degree of contamination of the loess parent material by fine sand on the one hand the the local drainage conditions on the other. Fragipan formation occurs in soils of

Profile Class B2 on free-draining sites but is absent in poorly-drained sites.

The absence of a fragipan together with coarsening texture promotes freer draining conditions thus eliminating the effects of pseudogleying. The persistence of a degree of oxidation and reduction is evidenced however by the strong mottling in the subsoils.

It was observed that concretions were absent from the subsoils of Profile Classes B2 and B3, suggesting that 'free' sesquioxides were being flushed out of the system. In Profile Classes B4 and C4 incipient placic horizons had formed in the subsoil through precipitation of this material, often at the textural break with the 2C horizon.

6.3 Conceptual Framework.

The complex and variable nature of the soilscape on the Tuapaka Hill Block is typical of hill country soil conditions. In this instance the complex soil pattern is the result of the interaction of pedogenesis, geogenesis and geomorphic processes. The conceptual framework used in this study has elicited the underlying order in this confused situation and allowed its representation in a coherent and explicit form.

The soilscape did not meet the criteria of 'orderliness' and was characterized by a large volume of 'pedogenic noise', as specified in 3.8.3.

There is short-range, horizontal and vertical variation in parent materials over much of the study area that has little or no external topographic expression. The use of the Base Map with contours and paddock boundaries drawn and the associated controlled selection of sampling sites across the landscape, together with limited free sampling provided a framework of interrelated pedogenic information on local soil variations that facilitated its ordering and structuring into a coherent local classification.

The basis of the local classification is the Profile Class. This concept has the flexibility to accommodate the reality encountered in the soilscape on the Hill Block. The concept grouped profiles on the incidence of a particular characteristic combination of simple, objective morphological and other features, capable of evaluation or inference from field examination. Variation in the degree of expression of these features within each Profile Class was permitted, accommodated and expressed by the erection of Taxonomic Units whose specifications were in accordance with the degree of variation observed in the field through sampling.

The further grouping of Profile Classes into Profile Groups was interpretative and based on inferred interrelationships between Profile Classes, for example the erosion sequence demonstrated in Profile Groups B and C. These further groupings provide an overview, a rational ordering and interpretation of the apparent disorder observed in nature and permit general observations to be made on pedogenic, geogenetic and geomorphic processes operative in the study area.

The local classification provides a sound basis for mapping the study area. The complex nature of the soilscape necessitated the use of compound mapping units in most cases. The mapping units were erected and represented initially using the Profile Group as the classification unit. The Profile Group is a suitable classification unit for the purpose in these circumstances as it is a collection of related Profile Classes representing soils that are by their nature contiguous in the landscape. The mapping unit was defined by its predominant Profile Group. Profile Classes of the predominant Profile Group present were specified where possible, together with unrelated Profile Classes from other Profile Groups, specified as inclusions. This system greatly facilitated the representation of the complex soilscape on a map sheet. The specifying of Profile Classes within the mapping unit allows greater precision of information and enhances the predictive power of the map. This can be further supplemented by the use of the soil map in conjunction with the pedological information contained in the soil inventory (4.6) and the Base Map showing sampling sites across the landscape.

6.4 Correlation of Local Soil Classification with Existing Soil Classifications.

6.4.1 Introduction.

Northcote (1981) notes the importance of soil classification as a transfer technique for improved soil use and management from one place to another. He observes, however, that there are considerable dangers in this transfer process unless the basic tenets of the classification are known and understood. These dangers are multiplied several times over when one or more classifications are involved since their basic tenets are likely to be different.

Butler (1980) considers that a "Taxonomic Hiatus" may occur on integrating local Profile Classes into regional or national classifications. This term is used to describe the loss of definition of information on local soils through the generalizations necessary to fit them into these broader groups.

Having due regard to the above, the Local Soil Classification has been correlated with the New Zealand Zonal Soil Classification and the U.S.D.A. Soil Taxonomy Classification.

6.4.2 Soil Profile Classes Related to the New Zealand Zonal Soil Classification.

The Zonal and Series groupings previously used to characterize soils in and immediately adjacent to the study area, contained principally in Soil Bureau Bulletin 33, may be correlated with Profile Classes within Profile Groups of the Local Soil Classification produced in this study.

The Ramiha silt loam falls into Profile Class A1 of Profile Group A in the Local Soil Classification as presented in this study. This was classified as a yellow-brown earth in Soil Bureau Bulletin 33. However, Pollok (1975) had earlier referred to it as a yellow-brown loam - yellow-brown earth integrade and this is the classification currently assigned to the soil by the New Zealand Soil Bureau (Wilde, pers. com.). The yellow-grey earth - yellow-brown earth integrades of the Tuapaka hill soil and the Shannon silt loam are similar to Profile Classes B4 and C1 of Profile Groups B and C respectively. The profile description of the Korokoro hill soil corresponds most closely with Profile Class E4 of Profile Group E.

The yellow-brown loam - yellow-brown earth soils of the Ramiha silt loam are mapped on the interfluves of Physiographic Unit 1. Yellow-brown earth soils of the Korokoro hill soil s are mapped on Physiographic Unit 2 and yellow-grey earth - yellow-brown earth soils of the Tuapaka hill series and Shannon silt loam are mapped on the interfluves of Physiographic Units 3 and 4.

It should be noted that Soil Bureau Bulletin 33 does not describe any soils resembling Profile Groups D and F recognized in this detailed local survey. Similarly many profile classes described in this survey would remain undetected if reliance were placed solely on the descriptions given in Soil Bureau Bulletin 33. These differences are a direct reflection of the differences in scale of the respective soil surveys.

6.4.3 Soil Profile Classes Related to Soil Taxonomy.

Soil Profile Classes from the Local Soil Classification have been correlated* with the Soil Taxonomy Classification down to Great Group level, as follows:

Group A.**	Profile Group A.
A1	HAPLUMBREPTS
A2	"
A3	DYSTROCHREPTS
A4	HAPLUMBREPTS
A5	DYSTROCHREPTS
A6	FRAGIUMBREPTS
A7	HAPLUMBREPTS

* Provisionally

** Soils belonging to Group A and commonly falling within the Ramiha soil series commonly have an horizon or horizons in the upper 75 cm that has a bulk density $\leq$0.95 g per cc. At the subgroup level most would therefore be classified as Andic Haplumbrepts or Andic Dystrochrepts.

Group B	Profile Group B
B1	FRAGIAQUALFS
B2	"
B3	ALBAQUALFS
B4	HAPLUDALFS
B5	FRAGIOCHREPTS
B6	"
B7	[FRAGIAQUEPT-] FRAGIAQUALF

Group C	Profile Group C
C1	FRAGIOCHREPTS
C2	"
C3	"
C4	DYSTROCHREPT
C5	HAPLUMBREPT
C6	FRAGIOCHREPT

Group D	Profile Group D
D1	HAPLAQUEPTS
D2	HAPLUMBREPTS
D3	DYSTROCHREPTS

Group E	Profile Group E
E1	HAPLAQUEPTS
E2	"
E3	DYSTROCHREPTS
E4	"
E5	UDORTHENTS
E6	"
E7	DYSTROCHREPTS

Group F	Profile Group F
F1	DYSTROCHREPTS
F2	FRAGIOCHREPTS

Appendix 1. Range of profile features within Taxonomic Unit A1.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
O (possible)	6 to	10yr 3/4	-	silt loam	soft to firm	very weak and weak
Ah or Ap	11 to 13	10yr 4/4 7.5yr 4/3 10yr 3/4 5/6 (worm casts)	-	silt loam	firm to stiff	moderately weak to moderately firm.
AB		10yr 4/4, 4/6, 3/4 5/6 (worm casts)	-	silt loam	firm to stiff	moderately weak
BA	11 to 22	10yr 5/4, 5/6, 6/4 10yr 4/4 (few worm casts)	Very faint, fine 5yr 5/8 7.5yr 6/8 5yr 5/2, 6/2 patches in matrix.	silt loam to silty clay loam.	stiff	moderately (very) weak
Bw1 (or Bwg1)	34 to 41	10yr 5/4, 5/8, 6/4 6/6 7.5yr 5/4	Possible. Many fine, distinct 2.5yr 4/8 spots 2.5yr 8/2 7.5yr 6/8, 5y 5/2 6/2.	silt loam going to silty clay loam	very stiff	moderately weak to moderately firm.
2Bw2 (or 2Bwg2	21 to 26	10yr 5/6, 6/8 7.5yr 5/6 2.5y 6/4	spots 2.5y 8/2	sandy loam	very stiff to hard	moderately weak to very firm
Bw3 (Bwg3		10yr 6/4, 6/6 2.5y 6/4 2.5Gy 7/1	many, faint small to prominent, fine, abundant 10yr 5/6, 6/8 2.5y 8/2	silty clay loam	stiff to very stiff	moderately weak to moderately firm

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
slightly sticky	very plastic	weakly-strongly developed nutty, crumb	-	-	profuse, fine roots.
slightly sticky.	very plastic	moderately to strongly developed, coarse, medium & fine, nutty (crumb)	-	-	abundant, fine roots. Worm mixing noted. NaF reaction positive
slightly-moderately sticky	very plastic	moderately to strongly developed, coarse medium & fine nutty (crumb)	-	-	many, fine roots. Worm mixing noted. NaF reaction positive
slightly (mod) sticky	very plastic	moderately developed, coarse granular going to medium & fine nutty, crumb, becoming very coarse becoming coarse blocky-polyhedral with depth.	many, soft, fine 5yr 5/8 7.5yr 3/2	abundant, medium & thick, faint 7.5yr 5/6	many thinning to few fine roots. Incipient placic horizon possible at base of horizon, 2.5yr 3/6, 5yr 5/8. Worm mixing noted. NaF reaction positive.
slightly sticky	very plastic	moderately developed, very coarse and coarse blocky-polyhedral going to massive with depth.	Few 7.5yr 6/8 at upper boundary many, fine 7.5yr 3/2 Some, ½-1 cm diam., soft 10yr 6/6	abundant, fine, 7.5yr 5/8 Profuse, thick faint & distinct 7.5yr 5/6	Few worm casts in upper horizon. NaF reaction positive.
slightly sticky	very plastic	moderately developed, coarse blocky going to massive.	many, fine 7.5yr 3/2	abundant, thick 5yr 5/8,6/8 soaking into matrix Profuse, medium distinct 7.5 yr 4/6,5/6	Few old worm casts and old bush roots. NaF reaction positive, strong.
Slightly sticky	very plastic	massive and coarse and medium blocky breaking to fine blocky.	-	many, thick, 10yr 7/3 @ 136 cm	NaF negative

Appendix 2. Range of profile features within Taxonomic Unit A2.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
Ap	8 to 24	10yr 3/4	-	silt loam	soft to stiff	moderately weak to very weak.
AB	18 to 21	10yr 3/4, 4/4 5/4, 5/6	-	silt loam	firm to very stiff	moderately weak to moderately firm.
Bw1	20 to 38	10yr 5/4, 5/8 worm casts 3/3 4/4	-	silt loam to silty clay loam.	firm to very stiff	moderately weak to moderately firm
2Bw2 (or 2Bwg1	31 to 60	10yr 5/4, 6/4, 6/6 2.5y 6/4 - 6/6	many, distinct coarse (possible)	sandy clay loam	firm to very stiff	moderately weak to firm near base
Bw3 (or Bwg2)		10yr 6/4 2.5y 5/4, 6/4	matrix has 5y 7/3 in places, also many, distinct fine 2.5y 7/2	silty clay loam	stiff to very stiff	moderately weak to moderately firm.

Stick-iness	Plasticity	Structure	Concretions	Cutans	Miscellaneous
slightly sticky	very plastic	moderately-strongly developed, fine & medium nutty. Fine crumb around roots.	-	-	abundant fine roots. NaF reaction positive - strong.
slightly to moderately sticky	very plastic	moderately developed, coarse breaking to medium & fine, nutty-granular	-	-	worm mixing noted. Profuse fine roots. Possible old bush roots. NaF positive.
Slightly to moderately sticky	very plastic	moderately developed, coarse breaking to medium & fine blocky-polyhedral.	-	many to abundant, 5yr 6/6	worm mixing, less than in AB horizon. NaF reaction positive.
slightly to moderately sticky	very plastic	weakly to moderately developed, very coarse and coarse blocky breaking to medium & fine blocky, possibly becoming massive with depth.	possible incipient placic horizon, 5yr 3/6 also large, coarse near or at lower boundary 2.5y 8/3,8/8	abundant, thick, prominent, 7.5yr 4/6 10yr 4/6 2.5yr 3/1, 2/1 7.5yr 8/8 5yr 4/6 3/6	black speckles on on peds with cutans. 2.5yr 2/1, 3/1. Few fine roots. NaF reaction, positive, strong.
slightly to moderately sticky	very plastic	weakly-moderately developed very coarse & coarse breaking to medium & fine blocky.	many, soft 5yr 3/1 Pinhead, soft 5yr 5/8 @ 150 cm.	very faint on peds and in relict root channels. 5yr 6/8	NaF reaction negative. Old bush roots.

Appendix 3. Range of profile features within Taxonomic Unit A3.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
Ap (Ah)	7 to 18	10 yr 4/4, 5/4	-	silt loam	very stiff	moderately weak to very firm
AB or BA	16 to 22	10yr 5/6 and 10yr 4/4, 5/4 worm casts	-	silt loam	very stiff	moderately weak to very firm
Bw1	26 to 28	10yr 5/8 6/8 few worm casts 10yr 5/4	-	silt loam going to silty clay loam	stiff to very stiff	moderately weak
2Bw2	14 to 17	10yr 5/8 6/8	-	sandy loam	very stiff	very weak to moderately firm.
Bw3		10yr 6/3 6/4	-	silty clay loam	stiff to very stiff	moderately weak to moderately firm.

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
slightly sticky	very plastic	moderately to strongly developed. Fine medium and coarse nutty.	-	-	abundant, fine roots. Worm mixing noted. NaF reaction positive.
slightly to moderately sticky.	very plastic	moderately to strongly developed medium and coarse nutty	-	few, very faint, on peds	many, fine roots. NaF reaction positive - strong. Worm mixing noted.
slightly to moderately sticky	very plastic	weakly to moderately developed, coarse going to medium blocky, becoming massive with depth.	-	many, on peds 5yr 4/8 6/8 7.5yr 5/8	many, fine roots. NaF reaction positive, strong.
slightly sticky	moderately plastic	massive and blocky, platey in places.	discontinuous incipient placic horizon at lower boundary & concretions 7.5yr 5/6 5/8	many, on peds 7.5yr 6/8 10yr 4/6 5yr 4/4 5.6,5.8 spots 5yr 2/1	many to few fine roots NaF reaction positive, very strong.
slightly to moderately sticky	very plastic	massive	profuse, soft 2.5yr 3/3 3.4 (2mm in diameter)	profuse, medium thickness in relict fine root channels 2.5yr 4/8 5/8 2.5y 7/2	NaF reaction positive but very weak. no roots.

Appendix 4. Pedological description of profile 11, representing Profile Class A4.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	23	10yr 3/4	-	silt loam	soft	moderat-ely firm.
AB	16	10yr 4/6 3/4 (worm casts)	-	silt loam	stiff	moderat-ely weak to mod-erately firm.
2Bw	27	10yr 5/6 and patches of 7.5y 6/2	-	sandy clay loam	stiff	moderat-ely weak
Bwg	40	10yr 7/3 7.5yr 5/6	faint, coarse, profuse	silty clay loam	stiff to very stiff	moderat-ely weak
3Cg		10yr 7/6 matrix	distinct, fine, abundant 7.5yr 7/8 rotting rock 10yr 6/8	bouldery silty clay	stiff to very stiff	moderat-ely firm

Stick-iness	Plasticity	Structure	Concretions	Cutans	Miscellaneous
slightly sticky	very plastic	moderately developed, fine & medium nutty.	-	-	NaF reaction positive. abundant fine roots.
slightly sticky	very plastic	weakly developed, medium crumb.	-	-	NaF reaction positive, strong. Worm mixing noted. Abundant fine roots.
slightly sticky	moderately plastic	massive	Pinhead in grey patches 2.5yr 3/2	-	NaF reaction positive, strong. Many fine roots. Old bush roots.
moderately sticky	very plastic	weakly developed coarse blocky-polyhedral	many, pinhead 2.5y 3/2 with 2.5y 4/4 centres.	-	NaF reaction positive, very weak. Few, fine roots.
		weakly developed, medium, blocky-polyhedral.	many, pinhead, 2.5yr 3/3 with 2.5yr 4/4 centres.	-	old bush roots. negative

Appendix 5. Pedological description of profile 16, representing Profile Class A5.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah1	8	10yr 4/3	-	silt loam	firm	moderat-ely strong
Ah2	14	10yr 5/4	-	silt loam	very stiff	moderat-ely strong.
AB	16	10yr 5/4 5/6	-	silt loam to silty clay loam	very stiff	very firm
Bw1	22	10yr 5/8	-	silty clay loam	very stiff	moderat-ely firm
Bw2	42	10yr 5/8	-	silty clay loam	very stiff	moderat-ely firm.
2Cg		10yr 5/8	-	bouldery silty clay loam	very stiff	moderat-ely weak

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
slightly to moderately sticky	very plastic	moderately developed, very fine, nutty.	-	-	profuse, fine roots. NaF reaction negative.
slightly to moderately sticky	very plastic	moderately developed, fine and medium, nutty	-	-	abundant, fine roots. NaF reaction negative.
moderately sticky	very plastic	moderately developed, medium, nutty	few, soft 5yr 4/6	-	NaF reaction positive. Worm mixing noted. A few rock fragments noted. Abundant fine roots.
moderately sticky	very plastic	moderately developed, fine going to coarse polyhedral.	few, soft 5yr 4/6	many, abundant thick, 5yr 4/6 7.5yr 5/8, 6/8	NaF reaction positive. Worm mixing noted. Rock fragments present. Few, fine roots.
moderately sticky	very plastic	moderately developed, coarse blocky breaking to medium and fine crumb.	some small, hard 5yr 4/6 pinhead throughout matrix 7.5yr 1.7/1	abundant, thick, 5yr 4/6 7.5yr 5/6 5/8	NaF reaction negative. Rock fragments present. Very few, fine roots.
			profuse, pinhead 7.5yr 1.7/1 7.5yr 4/6 7/8		rotting greywacke in matrix.

Appendix 6. Pedological description of profile 7, representing Profile Class A6

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	10	7.5yr 3/3	-	silt loam	soft	moderately weak to moderately firm
AB	12	7.5yr 4/3 10yr 5/4 worm casts	-	silt loam	very stiff	moderately weak
BA	18	10yr 4/3, 5/4, 5/6 5yr 4/8 worm casts	few, medium faint, more notable in lower horizon	silt loam	very stiff	moderately weak
Bwg	15	10yr 4/3, 5/3 veins: 7.5yr 5/8 5yr 4/8 2/4, 3/4	abundant, profuse, medium, distinct.	silty clay loam going to sandy loam at base of horizon	very stiff	moderately weak
2Cg	16	10yr 5/4, 6/4 going to 7.5yr 6/8 at base.	profuse, coarse, distinct prominent	sandy loam	very stiff	moderately weak
BCxg	19	10yr Gy 8/1 7.5yr 5/6 2.5yr 5/8	abundant, profuse, coarse, prominent	silt loam	very stiff	moderately weak to moderately firm.
Cxg		10Gy 8/1 7.5yr 5/8 6/8	abundant, profuse, coarse, prominent	silt loam		

Stickiness	Plasticity	Structure	Concretions	Cutans	Miscellaneous
slightly sticky	very plastic	moderately developed, medium and coarse, nutty.	-	-	NaF reaction positive. Abundant, fine roots.
very sticky	very plastic	moderately developed, medium, nutty.	-	-	NaF reaction positive. Material from underlying BA horizon in worm casts. Abundant fine roots.
moderately sticky	very plastic	moderately developed, medium and coarse, nutty.	-	-	NaF reaction positive, strong. Worm casts notable. Many fine roots.
slightly sticky	moderately to very plastic	moderately developed, very coarse, angular crumb.	in veins 5yr 4/8 2/4 3/4	thick to very thick	seepage pronounced at lower boundary. Many going to few fine roots.
slightly sticky	moderately plastic	massive, platey in places.	7.5yr 5/8 5y 4/8 2.5yr 3/4 3/6 2/4		NaF reaction positive, very strong.
very sticky	very plastic	moderately developed, coarse, blocky.	pinhead, as spots 5yr 3/3	thick, particularly in upper horizon 2.5yr 5/6 5yr 5/8 spots: 5yr 3/3	NaF reaction strong in upper horizon but weak with depth.
		massive			

Appendix 7. Range of profile features within Taxonomic Unit A7.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
O	9	10yr 3/3 4/3	-	silt loam	very stiff	moderately firm
Ah	18 to 20	10yr 3/2 3/4	-	silt loam	stiff to very stiff	moderately firm
AB	19 to 21	10yr 3/2, 3/4 5/6) } worm 7/6) } casts	-	silt loam	stiff to very stiff	moderately firm
Bwg1 (or Bw1)	24 to 38	10yr 5/8 6/6 7.5yr 6/8 2.5y 6/4 7/4 8/3 spots: 2.5y 7/3	possible, abundant, medium, faint	silt loam going to silty clay loam	very stiff	moderately weak to moderately firm
Bwg2 (or Bw2)		10yr 5/6, 6/6 7.5y 7/2 2.5y 8/3	possible, abundant, medium, faint	silt loam to silty clay loam	stiff to very stiff	moderately weak to moderately firm

Stickiness	Plasticity	Structure	Concretions	Cutans	Miscellaneous
slightly sticky	very plastic	strongly developed, fine, nutty.	-	-	profuse, fine roots.
slightly to very sticky	very plastic	moderately to strongly developed, fine, medium and coarse, nutty.	-	-	NaF reaction positive. Profuse - abundant fine roots.
moderately to very sticky	very plastic	moderately developed, coarse, nutty and medium blocky breaking to crumb.	-	few, faint, on peds and in fine root channels	worm mixing noted. NaF reaction positive. abundant fine roots.
slightly to moderately sticky	very plastic	moderately developed, medium and coarse blocky-polyhedral, breaking to fine and medium rumb.	many, pinhead 5yr 3/3 Incipient placic horizon 2.5y 3/3 surrounded by matrix 5y 5/8 and many, pinhead concretions 10yr 3/2	abundant, thin 7.5yr 5/8 6/8	NaF reaction positive. Little worm mixing. Few fine roots.
slightly to moderately sticky	very plastic	weakly developed, very coarse and coarse blocky breaking to fine & medium crumb.	profuse, pinhead, soft. 10yr 3/2 many, pinhead hard 5yr 3/3	abundant, thin, 7.5yr 5/8 6/8	NaF reaction positive, very weak. Few fine roots.

Appendix 8. Range of profile features within Profile Class B1.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
Ah	6 to 29	10yr 4/2, 4/4, 5/3 6/3, 6/4 7.5yr 4/2, 4/3 5yr 3/2; possible shades of 7Gy 6/1	-	silt loam	firm to very stiff	very weak to moderately firm
E		2.5y 5/2 5y 7/1, 7/3	abundant, fine faint; 7.5yr 5/8, 6/8;10yr 6/6, 6/8, 7/3			
Eg	6 to 30	2.5y 7/1, 7/2,7/3 7/4 5y 7/1, 7/2 10yr 6/6	abundant-many fine, medium faint to distinct; prominent in lower horizon	silt loam	firm to very stiff	very weak to moderately firm
AE		10yr 6/2 7.5yr 4/2,5/2,6/2	none or many, fine, faint. (10yr 6/6) (7.5yr 6/8)			
AEg		10yr 6/2 2.5 7/2 7.5yr 6/8	abundant, medium & coarse prominent.			
Btg1	13 to 49	7.5yr 5/8, 6/8 5y 7/1, 7/2 2.5y 7/1, 7/2 7.5y 7/1, 7/2 possible shades of 5B 7/1	profuse to abundant, fine to coarse prominent	silty clay loam	(firm) stiff (very stiff)	moderately weak to moderately firm
Btg2	17 to 55	7.5yr 5/8, 6/8 5y 7/1, 7/2 2.5y 7/1, 7/2 7.5y 7/1, 7/2	profuse to abundant fine medium, coarse prominent	silty clay loam	firm to very stiff	moderately to very firm
Cxg		7.5yr 5/8, 6/8 5yr 4/8 5y 7/1 2.5Gy 7/1	abundant, coarse prominent	silt loam	very stiff	very firm to moderately strong

Stick-iness	Plasticity	Structure	Concretions	Cutans	Miscellaneous
moderately to very sticky	very plastic	weak to moderately developed, fine to very coarse granular-crumb	possible pinhead	-	rust colour in fine roots. 5yr 4/6, 4/8, 5/8. Truncated Ah horizon with slope, in some instances. Many fine roots.
slightly to very sticky	very plastic	(weak), moderately developed, (very coarse), coarse medium & fine, granular-crumb, possibly going to coarse blocky-polyhedral with depth.	pinhead, profuse 7.5yr 1.7/1, 2/2, 2/3, 4/4. 5yr 2/2, 2/3 2/4, 3/6, 4/8 7.5yr 4/6 concretions coarser in lower horizon (<5mm).	possible in lower horizon 2.5y 5/3	worm mixing in upper horizon 10yr 6/3; lower horizon 10yr 7/8 7.5yr 6/8; rust in fine root channels. Possible old bush roots. Seepage at base of horizon. Many fine roots.
slightly to very sticky	very plastic	weakly, moderately & strongly developed, medium to very coarse, blocky breaking to moderately developed, coarse granular-crumb	soft & hard, in mottles, & at lower boundary, 5yr 2/2	on peds. 2.5y 5/3 7.5yr 4/6 10G 7/1	worm casts. Old bush remains. Many to few, fine roots.
slightly to very sticky	very plastic	weakly, moderately developed, medium to very coarse, blocky, breaking to moderately developed coarse granular-crumb - becoming massive. Possible at lower boundary 7.5yr 3/4	mottles going to concretions also profuse, small & large 5yr 2/1, 2/2 3/4	on peds, as above.	few fine roots. A lot of seepage at upper boundary.
slightly	very	massive. Grey veins			

Appendix 9. Range of profile features within Profile Class B2.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	9 to 25	10yr 4/2,4/3,4/4 5/3 10yr 6/3, 7/3 5Gy 6/1 near lower boundary.	-	silt loam	soft, going to firm	moderately weak to moderately firm.
AEg	15	10yr 5/2,5/3,6/2 few spots 7.5yr 6/8 (worm casts)	many to abundant, fine, medium, distinct to to prominent, faint to distinct.	silt loam	firm to stiff	very weak to moderately firm
Eg	14 to 34	2.5y 5/2,6/2,6/3 2.5Gy 7/1 5Gy 7/1 spots 7.5Gy 7/1 mottles 7.5yr 5/8 10yr 6/6				
Btg1	21 to 42	10yr 6/8, 7/3, 7/4 7.5yr 5/8,6/8, 7/8 2.5yr 6/1,7/1, 7/2 7/3 5y 7/1	profuse to many, fine, medium & coarse distinct to prominent.	silty clay loam	firm, stiff and very stiff.	moderately firm to very firm
Btg2	28 to 34 (where Cxg present)	10yr 6/8 7.5yr 5/8,6/8,7/8 2.5yr 6/1,7/1,7/2, 7/3 going to 10y 7/1 7.5y 7/1 5y 7/3	profuse to many, medium & coarse, distinct to prominent (larger coarser mottles than above)	silty clay loam or silty clay loam to to fine sandy clay loam to fine sandy loam (where Cxg horizon absent below)	firm to very stiff	moderately firm to very firm
Cxg		as above		silt loam		

Stick-iness	Plasticity	Structure	Concretions	Cutans	Miscellaneous
very sticky	very plastic	weakly developed to moderately developed. Fine, medium & coarse crumb & coarse nutty.	pinhead concretions near boundary 7.5yr 4/4	thick, on peds in lower horizon 5yr 7/3	many fine roots
moderately to very sticky	very plastic	very weak to moderately developed, fine, medium coarse & very coarse nutty or crumb becoming moderately developed medium blocky with depth	profuse to many, pinhead 5yr 2/4,5/8 few fine, hard 5yr 2/3, 4/8	-	many fine roots. Possible worm mixing.
slightly, moderately and very sticky	very plastic	weakly to strongly developed, moderate, coarse and very coarse blocky.	mottles going to soft concretions, pinhead, 7.5yr 4/8. also 7.5yr 3/3, 3/4 near lower boundary.	thick on peds in lower horizon 5y 7/3	many to few, fine roots down structural peds.
slightly to very sticky.	very plastic	weakly to moderately developed, coarse and very coarse blocky-polyhedral or massive where fine sand content high.	in lower horizon forming from mottles where Cxg horizon present below 7.5yr 3/3,3/4 concretions absent where Cxg horizon absent.	on peds 5y 7/3 5B 7/1	few to none fine roots.
		massive			sand component significant at 130-145 cm where Cxg horizon present.

Appendix 10. Pedological description of profile 41, representing Profile Class B3.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
Ah	22	10yr 5/3 10yr 3/3 boundary: 7.5yr 4/2, 6/8	-	loam	soft-firm	moderately weak
AEg	28	10yr 7/1, 6/2	10yr 6/8 to 7.5yr 6/8 many-abundant fine. distinct prominent	fine sandy clay loam to fine sandy loam	firm	moderately firm
Btg	Ca 100	5y 7/1 7.5yr 6/8	abundant, medium & coarse, prominent.	sandy clay loam.	stiff	moderately weak

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
Very sticky	very plastic	weakly-moderately developed, fine medium & coarse, crumb.	-	-	rust in fine roots. Many fine roots.
very sticky	very plastic	moderately developed, very coarse, polyhedral-blocky.	mottles going to concretions soft. 5yr 4/8, 5/8	-	worm mixing 10yr 5/2 Weeping from upper boundary and horizon. Many to few fine roots.
very sticky	very plastic	moderately developed very coarse, blocky.	-	on peds 10yr 5/4 6/3	Seepage. Weeping AEg-Bwg boundary and from horizon many to few fine roots.
					Sand @ >150 m.

Appendix 11. Range of pedological features within Taxonomic Unit B4.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	15 to 26	10yr 5/2 7.5yr 4/2, 4/3 2.5y 5/3	-	silt loam to loam	firm	moderat-ely weak to mod-erately firm
AE	10 to 15	10yr 6/6 7.5yr 4/2, 4/3 5y 7/3, 7/4 2.5y 5/2, 6/4 7/3, 7/4		silt loam to loam	firm to stiff	moderat-ely weak to mod-erately firm
Eg	10 to 14	10yr 5/8 7.5yr 5/2, 5/8, 6/8 2.5y 6/4,7/3,7/4	profuse to many, prominent to distinct fine & medium			
Btg	27 or to 75*	10yr 7/3 7.5yr 5/3, 5/8, 6/8, 7/2 5yr 5/8, 6/8 2.5y 6/3,7/1,7/3 Shades of 5G 7/1 7.5y 3/4, 5/3 to 6/3	abundant, medium and coarse, distinct to prominent	silty clay loam to fine sandy loam with depth	stiff to very stiff	very weak to mod-erately firm at base of horizon with 2C horizon
Bwg (where pres-ent)	14	10yr 7/3 7.5yr 3/4, 7/2 5yr 5/8, 6/8	abundant, medium, prominent	fine sandy loam	stiff to very stiff	moderat-ely weak
2C		10yr 6/8 with streaks 10yr 3/4 and worm casts 5yr 4/4		fine sand loam to fine sand	very stiff	

*27 cm where Bwg horizon present.

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
slightly to moder-erately sticky	very plastic	moderately developed very coarse breaking to fine, granular crumb.	-	-	rust in fine root channels. many, fine roots.
moderat-ely to very sticky	very plastic	moderately developed coarse and very coarse, medium and nutty crumb		-	
			pinhead, throughout Eg, 5yr 3/4 also many, large & pinhead, hard & soft 10yr 2/2		many, fine roots.
slightly to very sticky	very plastic	weakly to mod-erately dev-eloped, very coarse and coarse blocky.	on peds	-	Incipient iron pan near base of hor-izon in some prof-iles. 5yr 4/8,5/8. Few old worm casts filled with dark material. Pebbles & few stones in some profiles. Few, fine roots.
moderat-ely sticky	very plastic	weakly devel-oped, coarse blocky.	-	-	few, fine roots. Rotting rock in matrix.
		single grain			some fine clay present from translocation.

Appendix 12. Pedological description of profile 38, representing Profile Class B5.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	11	7.5yr 4/2	-	silt loam	stiff	moderately weak to moderately firm
AE	34	10yr 5/2, 6/2 7.5yr 5/8 5y 6/2 at base.	some, fine distinct.	stony silt loam	very stiff	moderately firm
Bwg	34	10yr 6/2 2.5y 6/2 7.5yr 5/8 10Gy 6/1	abundant, fine, medium and coarse, prominent	silty clay loam	stiff, going to very stiff at base	very firm
BCxg	26	10yr 6/2 7.5yr 5/8 10y 7/1 5y 7/1 spots of 10Gy 7/1	abundant, coarse, prominent	silty clay loam	very stiff	very firm
Cxg						

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
very sticky	very plastic	weakly dev-eloped, fine and medium crumb	-	-	abundant, fine roots.
very sticky	very plastic	weakly dev-eloped, medium nutty going to medium and coarse, blocky.	-	-	many, fine roots.
very to moderat-ely sticky	very plastic	moderately developed, coarse blocky	-	-	many fine roots down peds.
moderat-ely sticky	very plastic	moderately developed, coarse and very coarse blocky	In association with rotting rock 10yr 7/8 7.5yr 5/8	-	

Appendix 13. Pedological description of profile 55, representing Profile Class B6.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
Ah	10	7.5yr 4/2	-	silt loam	soft	moderately weak
AE	11	10yr 3/3 10yr 6/2, 7/2 worm casts	many, fine faint, possible worm casts from below	stony loam	very stiff	moderately weak to moderately firm
Bwg	30	7.5yr 5/8, 6/8	abundant, fine and medium, distinct.	fine sandy clay loam	very stiff	moderately firm
BCxg	39	7.5yr 6/8 going to 5/8 5y 7/2 shades of 5B 7/1	abundant, coarse, prominent	fine sandy clay loam to sandy loam	very stiff	moderately firm

Stick-iness	Plasticity	Structure	Concretions	Cutans	Miscellaneous
very sticky	very plastic	moderately developed, medium and coarse, nutty-crumb	-	-	many, fine roots.
very sticky	very plastic	weakly developed, coarse and very coarse crumb	pinhead, many 7.5yr 4/6, 5/8	-	many, fine roots.
moderately sticky	very plastic	weakly developed coarse, blocky	as above	-	many, fine roots.
slightly sticky	very plastic	weakly developed coarse blocky going to massive	concretions in mottles	-	few, fine roots.

Appendix 14. Range of profile features within Taxonomic Unit B7.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	18 to 28	7.5yr 3/4, 4/4 lower horizon, merging to 10yr 4/3,5/3,6/3, 6/4 and 10yr 7/6 worm casts	-	silt loam	soft going to firm, with depth	very weak to moderat-ely weak
E	18	5y 6/2 merging to 10yr 7/6 in lower horizon	-	silty clay loam	firm to stiff	moderat-ely weak to mod-erately firm
Eg	20	5yr 5/1 2.5y 7/3 10yr 7/1 10yr 5/8	many, fine and medium, distinct			
BCxg	51	7.5yr 5/6, 6/8 7.5 7/1 5yr 5/8, 7/1, 8/1	profuse medium, coarse and very coarse	silty clay loam	stiff to very firm	moderat-ely firm
Cxg			gley veins between peds			

Stick-iness	Plasticity	Structure	Concretions	Cutans	Miscellaneous
slightly to moderately sticky	very plastic	moderately developed, fine, medium and coarse, nutty-crumb	possible, small, soft 5yr 4/8 with centres 5yr 5/1	-	many, fine roots. Possible worm mixing in lower horizon.
moderately sticky	very plastic	weakly to moderately developed, medium polyhedral.	profuse, pinhead 5yr 3/6 and many, small soft & hard associated with mottles in Eg.	-	many, fine roots.
slightly to moderately sticky	very plastic	very coarse, blocky going to massive, columnar.	profuse, soft, pinhead.	-	few, fine roots. Grey in old bush root channels.

Appendix 15. Range of pedological features within Taxonomic Unit C1.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
Ah	20 to 32	10yr 4/2, 4/3, 5/3 5/4 going to 6/3, 6/4 7.5 yr 4/4 worm casts in lower horizon 10yr 4/2, 5/2	possible, abundant to many, faint, fine and medium (7.5yr 5/6) (5yr 5/8)	silt loam	firm to very stiff	moderately firm
Bwg	11 to 24	10yr 5/3, 6/3, 6/4 6/8, 7/3 mottles: 7.5yr 4/6, 5/3,5/6 5/8, 6/3, 6/4, 6/8	profuse to abundant, coarse, medium & fine distinct to prominent.	silty clay loam	firm to very stiff	moderately firm to very firm
BCxg	13 to 39	10yr 5/8, 6/3, 6/6 6/8 7.5yr 5/8, 6/8 5yr 6/8 7.5y 8/2 5y 6/8 2.5y 6/3, 7/1,7/2	profuse to abundant, coarse, medium and fine, prominent. grey veins in matrix	silty clay loam	firm to very stiff	moderately firm to very firm.
Cxg		7.5yr 5/8, 6/8 2.5y 6/3, 7/1, 7/2 7/3 5y 7/1 to 10yr 7/2 possible shades of 10Gy 7/1, 6/3 in grey veins.	as above grey veins	silty clay loam to silt loam	very stiff	very firm to moderately strong.

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
slightly to very sticky	very plastic	moderately to strongly developed, fine, medium coarse and very coarse nutty-crumb	possible, associated with mottles near lower boundary 5y 3/6, 4/8 5/8. Few large 7.5yr 2/2	-	worm mixing near lower boundary many, fine roots.
slightly to very sticky	very plastic	weakly to strongly developed, fine medium and coarse, blocky-polyhedral	few to profuse, pinhead and larger, soft 5y 3/6, 4/8 Mottles associated with concretions, small, hard & soft, 7.5yr 2/3,6/8 5yr 4/8	possible, on peds 10yr 6/4	worm mixing noted Darker material from Ah down root channels joining up with grey veins in BCxg horizon. Few pebbles, many, fine roots
slightly to very sticky	very plastic	strongly developed, medium, coarse and very coarse, blocky-polyhedral going to columnar.	possible, 5yr 3/6 7.5yr 5/8 going to 2.5yr 3/2,3/3 Many soft & hard, below upper boundary.	possible, on peds 10yr 5/4, 6/4 possibly associated with spots. 10Gy 7/1	vertical grey veins. Few pebbles. Few, fine roots.
slightly to very sticky	very plastic	strongly developed, coarse and very coarse, blocky-polyhedral going to massive.	possible, in mottles 5yr 4/8	possible, on peds, 10yr 5/4	some rotting rock.

Appendix 16. Range of pedological features within Taxonomic Unit C2.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	19 to 33	10yr 3/2, 3/4 7.5yr 4/3 worm casts: 10yr 4/2,5/8,6/3, 6/8 7.5yr 6/2	possible many, fine, faint.	silt loam	firm to very stiff	moderat-ely firm
AB	6 to 19	10yr 4/3, 5/3, 5/4 6/4, 6/6 worm casts: 10yr 6/8	possible, many, medium faint to distinct	silt loam	firm to very stiff	moderat-ely weak to very firm.
Bwg	20 to 24	7.5yr 5/8, 6/8 10yr 4/2, 6/3, 6/4 2.5y 5/2, 6/2, 7/2 going to 2.5y 7/1 at base.	profuse to abundant, fine, medium and coarse faint to prominent	silty clay loam	firm to very stiff	moderat-ely weak to very firm
BCxg	25 to 35	2.5y 7/1 5y 6/1, 7/1, 7/2 10y 6/1, 7/1 7.5yr 6/8, 7/1	abundant, coarse and medium, prominent	silty clay loam	firm	moderat-ely to very firm
Cxg				silt loam		

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
moderately to very sticky	very plastic	strongly developed, fine, medium and coarse nutty-crumb.	possible, soft in upper horizon	-	old bush roots. Few angular stones. Worm mixing noted. Rust in fine roots. Abundant fine roots.
moderately to very sticky	very plastic	moderately to strongly developed, very coarse and coarse breaking to very fine, nutty-polyhedral.	possible, pinhead in upper to small hard, 5yr 2/2	-	abundant to many, fine roots.
slightly to very sticky	very plastic	strongly developed, coarse and very coarse, blocky polyhedral, breaking to medium & fine nutty.	possible, many large, 7.5yr 4/6,5/6	possible, on peds 10yr 6/3	many to few fine roots down peds.
slightly sticky	very plastic	moderately to strongly developed, coarse and very coarse, blocky-polyhedral	possible, soft & hard, in upper horizon.	very faint, 10yr 6/3 10Gy 7/1 thick in old bush root channels 7.5yr 6/8 going to 4/6	many to few fine roots down peds.
		massive-columnar			fine sandy component at 150<m.

Appendix 17. Pedological description of profile 73, representing Profile Class C3.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	25	10yr 6/3, 6/4 worm casts: 10yr 4/2	-	silt loam	very stiff	moderat-ely weak
Bwg	20	10yr 7/2, 7/3 10yr 6/8, 7/8 worm casts: 10yr 5/2	abundant, fine, going to medium, faint going to distinct.	silt loam	very stiff	moderat-ely firm
BCxg	20	7.5yr 6/8 2.5y 6/3 worm casts: 10yr 5/2	abundant, fine, medium and coarse, prominent.	loam	very stiff	moderat-ely firm
Cxg		10yr 6/8 5y 8/3 going to 7.5y 5/8, 6/8 5y 8/3 worm casts: 5y 6/2	abundant, medium and coarse, prominent	fine sandy clay loam to fine sandy loam	very stiff	very firm

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
very sticky	very plastic	moderately to strongly developed, medium, coarse and very coarse, nutty-crumb	-	-	abundant, fine roots. Rotting rock.
very sticky	very plastic	moderately developed, coarse and very coarse, blocky-columnar.	-	-	many, fine roots.
very sticky	very plastic	strongly developed, coarse and very coarse, blocky-columnar.	-	cutans on peds, as below.	many, fine down peds.
	very plastic	massive-columnar (fragipan)	pinhead, 5y 4/8	thick 10yr 6/3 going to 4/4, 4/6	few, fine roots.

Appendix 18. Range of pedological features within Taxonomic Unit C4.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	15 to 25	10yr 4/3	-	silt loam to loam	firm	moderately weak to moderately firm
ABg BAg	15 to 27	10yr 4/3 5/8 6/6 7/8	abundant, medium and coarse, distinct	silt loam to loam	stiff to very stiff	moderately weak to very firm
Bwg1	18 to 22	10yr 6/4, 6/8,7/8 7.5yr 6/4, 6/8 2.5y 7/2 worm casts: 10yr 5/3	abundant, medium, prominent	fine sandy clay loam	very stiff	moderately to very firm
Bwg2	23 to 30	10yr 6/8, 7/8 7.5yr 5/3, 5/8, 6/8 2.5y 7/2	profuse, coarse, prominent	fine sandy loam	very stiff	moderately weak to moderately firm
2Cg		10yr 6/8, 7/8 worm casts: 10yr 5/3		loamy sand to loose sand.	very stiff	moderately weak

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
very sticky	very plastic	weakly to strongly dev-eloped, fine to coarse, nutty-crumb	few, hard 7.5yr 4/6,5/8 5yr 5/8 soft and hard.	-	some rotting rock.
very sticky	very plastic	weakly to strongly dev-eloped, coarse blocky-polyhedral	possible, pinhead, many 7.5yr 5/8	possible, on peds 10yr 5/4	few rounded pebbles, 3-4 mm diameter.
slightly sticky	very plastic	moderately to strongly dev-eloped, blocky-columnar.	-	possible, on peds 10yr 5/4	rust in fine roots.
slightly sticky	moderat-ely plastic	weakly devel-oped, very coarse blocky going to massive.	many, 10yr 8/1 5y 8/3 and near lower boun-dary many hard. 10yr 4/4 7.5yr 4/6	possible on peds 10yr 5/4	rotting rock fragments.
slightly sticky	moderat-ely plastic	single grain			

Appendix 19. Pedological description of profile 56 representing Profile Class C5.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	39	7.5yr 4/3 worm casts: 10yr 7/6	-	sandy loam	firm	moderately weak
AC	7	7.5yr 4/3, 4/4 10yr 7/8	few, 7.5yr 6/8	sandy loam	firm	very to moderately weak
2C		upper (above 14) 10yr 6/8, 7/8 worm casts: 10yr 7/2 lower 10yr 7/6 going to 2.5y 7/4, 7/6 10yr 6/8 worm casts: 10yr 7/6		loamy sand sandy clay loam pan at 100 cm	very weak	slightly plastic very plastic at 100cm

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
moderat-ely sticky	moderat-ely plastic	moderately developed, fine and medium crumb	-	-	worm mixing noted.
moderat-ely to slightly sticky	moderat-ely to slightly plastic	as above	-	-	worm mixing notable.
slightly sticky	slightly plastic	single grain	soft, just above clay pan at 90 cm 5yr 4/8,5/8 and 5yr 1.7/1 at 116 cm	-	

Appendix 20. Pedological description of profile 5, representing Profile Class C6.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
Ah	12	7.5yr 4/4	-	silt loam	soft	moderately weak
AB	20	7.5yr 4/3 and 10yr 6/4 worm casts from below.	-	silt loam	very stiff	moderately weak to moderately firm
BA	16	10yr 6/4 and 10yr 3/4 10yr 6/4 worm casts from lower horizon.	-	silty clay	stiff	moderately weak
Bwg	27	10yr 6/4, 6/6,6/8 10yr 7/2	abundant, medium, prominent.	silty clay loam	stiff to very stiff	moderately weak
BCxg		10yr 7/6, 7/8 10yr 7/2 to 2.5y 7/1 grey veins.	profuse, coarse, prominent	silty clay loam	stiff to very stiff	moderately weak

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
slightly sticky	very plastic	moderately developed, fine and medium crumb	-	-	profuse to abundant fine roots.
slightly sticky	very plastic	moderately developed, fine and medium nutty	-	-	many to abundant fine roots. Few angular stones, <4 cm
slightly sticky	very plastic	weakly developed, coarse nutty.	very few, up to 3mm hard 5yr 3/6 soft 7.5yr 5/8	-	few, fine roots. Few stones. Worm casts concentrated near lower boundary
slightly sticky	very plastic	weakly developed, medium blocky-polyhedral going to massive.	extensive, hard, throughout horizon 7.5yr 2/1 with centres 10yr 5/6	-	few, fine roots. Old bush roots.
slightly sticky	very plastic	massive-columnar	as above 10yr 7/6	-	

Appendix 21. Range of pedological features within Taxonomic Unit D1.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
Ah	12 to 26	10yr 4/3, 5/3, 6/3 6/8 7.5yr 5/1, 5/2, 7/8 worm casts: 2.5y 6/2, 7/1	many, fine, faint, in lower horizon (7.5yr 7/8)	silt loam	firm to stiff	moderately weak to moderately firm
Bg or Bwg	30 to 48	10yr 6/8 7.5yr 5/2, 5/8, 6/8, 7/8 5yr 5/8 7.5y 5/1 5y 6/2, 6/3, 7/2, 8/3 2.5y 7/4 2.5Gy 6/1	profuse to many fine, medium and coarse, faint, distinct and prominent (7.5yr 5/8, 7/8)	silt loam (Bg) or silty clay loam (Bwg)	firm to very stiff	moderately weak to moderately and very firm
2R		2.5y 5/8, 6/8 5y 7/3, 8/1 10y 8/2 veins in rock 10yr 6/2, 6/3 2.5y 6/2				

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
very sticky	very plastic	weakly to moderately devoped, fine, medium, coarse & very coarse nutty-crumb	pinhead, profuse, especially in lower horizon 5yr 4/8,5/8 7.5yr 4/6, 5/6, 7/8 at lower boundary soft and hard 5yr 5/8	-	abundant fine roots.
moderately to slightly sticky	very plastic	weakly to strongly developed, coarse and very coarse blocky.	small to coarse (2 cm diameter) 10yr 4/6,6/8, 7/8 5yr 4/4	on peds 10yr 6/3, 6/4 7.5yr 5/2	many fine roots. Rotting pebbles. Lower boundary with rock uneven
					Rotting stones in siltstone. Thin grey veins in rock material. Few fine roots in cracks in rocks.

Appendix 22. Pedological description of profile 57 representing Profile Class D2.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	19	10yr 5/3, 6/3	-	silt loam	firm	moderat-ely weak
Bw	16	10yr 6/3 going to 10yr 7/3 and 2.5y 7/3 (lower horizon) 10yr 6/6 worm casts: 10yr 4/2, 5/2	many, fine, faint, in lower hor-izon (10yr 6/6)	silt loam to loam	firm to stiff	moderat-ely weak
Bwg	21	10yr 7/3, 6/8 7.5yr 6/8 2.5y 7/3 (worm casts in upper horizon 10yr 4/2, 5/2)	abundant, coarse with some medium distinct (10yr 6/8) (7.5yr 6/8)	stony sandy clay loam	firm	moderat-ely weak
2Cg		2.5 7/3 (matrix)		very stony sandy loam	stiff	

Stick-iness	Plasticity	Structure	Concretions	Cutans	Miscellaneous
very sticky	moderately plastic	moderately developed, very coarse breaking to medium and fine blocky breaking to crumb	-	-	many, fine roots. Rust in root channels 7.5yr 4/6
moderately sticky	very plastic	weakly to moderately developed, very coarse, crumb.	many, fine, faint, in lower horizon 10yr 6/6	lower horizon	many, fine roots.
moderately sticky	very plastic	moderately developed, coarse, blocky-polyhedral	abundant, coarse (some medium) distinct 10yr 6/8 7.5yr 6/8	-	few fine roots. Marine gravels from the 2Cg horizon extending into the lower Bwg horizon
slightly sticky	moderately plastic				Rotting marine gravels.

Appendix 23. Range of pedological features within Taxonomic Unit D3.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	10 to 20	10yr 4/2, 4/3, 4/4, 5/4 7.5yr 4/4	-	silt loam, loam & sandy loam	firm to very stiff	moderately weak to moderately firm
2C		10yr 5/4, 5/6, 6/3, 6/4, 6/8 7.5yr 5/6, 6/8 2.5y 6/4, 7/4	-	very stony fine sand, very stony, fine loamy sand. very stony, fine sandy loam.	very stiff	moderately weak to moderately firm

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
slightly to very sticky	moderat-ely to very plastic	moderately developed. fine to very coarse, nutty-crumb.	-	-	abundant to many fine roots.
non-sticky to very sticky	non-plastic to very plastic		-	-	many to few fine roots. Old bush roots.

Appendix 24. Pedological description of profile 13 representing Profile Class E1.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	20	10yr 4/1	-	silt loam (rock fragments in matrix)	soft	very weak
Ec	27	10yr 6/3	-	silty clay loam	stiff	very weak
BCg	23	7.5yr 6/8 5y 8/3	abundant, medium, prominent (7.5yr 6/8)	stony silty clay	soft to	moderately firm
Cg			matrix 5y 7/1	very bouldery silty clay		

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
slightly sticky	very plastic	weakly to moderately developed, fine, crumb	-	-	profuse, fine roots. Root mat - 9 cm. Few angular & rounded gravels - 2 mm diameter. Worm mixing in lower horizon 10yr 6/3
slightly to moderat-ely sticky	very plastic	moderately developed, fine, medium and coarse nutty.	large, hard, up to 2 cm 10yr 1.7/1 and also small soft 7.5yr 6/8	-	many going to few, fine roots. Worm mixing in upper horizon, 10yr 4/1 Concretions very numerous, increas-ing in lower half of horizon - fine and pinhead in upper horizon to coarse in lower horizon.
slightly sticky	very plastic	moderately developed coarse blocky	-	-	
					Rotting greywacke

Appendix 25. Pedological description of profile 37, representing Profile Class E2.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
Ah	25	10yr 4/4	-	slightly stony silt loam	stiff	moderately to very weak
E	19	10yr 6/2	-	very bouldery silt loam to silty clay loam	firm	moderately weak
Bwg	41	10yr 7/1, 7/2 7.5yr 6/8 to 10yr 7/8 with depth	profuse, prominent, coarse above 54 cm, merging to abundant, distinct, coarse with depth.	stony silty clay	firm to very stiff	
Cg		5y 8/1 to 2.5y 7/1 at 150 cm. 10yr 7/8 5yr 6/6, 6/8 at 150 cm.		very bouldery silty clay		

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
moderat-ely sticky	very plastic	moderately developed, fine and medium, nutty	-	-	many small angular gravels
slightly to mod-erately sticky	very plastic	weakly devel-oped, fine and medium, nutty and crumb	-	-	worm casts 10yr 4/4 Boulders not severely rotted some pebbles and stones.
moderat-ely sticky	very plastic	massive	-	-	smaller stones and boulders than above, severely weathered.
					Rotting rock

Appendix 26. Range of pedological features within Taxonomic Unit E3.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
O + Ah	22 to 29	10yr 3/3, 4/3, 4/4, 5/4 shades of 7.5yr 4/3, 10yr 6/4 at boundary	-	silt loam to slightly stony silt loam	soft to very stiff	very weak to moderately firm
Bw		10yr 6/6 going to 2.5y 6/4		slightly stony to stony	very stiff to hard	moderately weak to moderately firm
Bwg	22 to 33	10yr 6/6 10yr 6/8 7.5yr 6/8 worm casts: 10yr 4/4	many to abundant, medium, distinct	silty clay		
BCg	27 to 30	10yr 5/8, 6/6, 6/8,7/1,7/2,7/8 7.5yr 5/8, 6/2 6/8, 7/1 5yr 4/8 2.5y 6/2, 7/3 5y 8/2	many to profuse coarse, medium distinct to prominent.	bouldery or very bouldery silty clay	stiff to hard	moderately to very firm
Cg				very bouldery silty clay		

Stick-iness	Plasticity	Structure	Concretions	Cutans	Miscellaneous
slightly to moderately sticky	very plastic	moderately to strongly developed, very fine, fine, medium and coarse, nutty and crumb	possible, many 10yr 6/8 (may be rotting rock particles)	-	abundant fine roots.
slightly to moderately sticky	very plastic	moderately developed. medium and coarse blocky-polyhedral breaking to medium and fine nutty	many to abundant 10yr 4/4 7.5yr 6/8 Rotting rock associated with concretions	possible, faint in lower horizon 2.5yr 4/3 also 7.5yr 4/6 6/8	worm mixing noted. Many fine roots.
slightly to moderately sticky	very plastic	weakly coherent, massive, breaking to coarse blocky-polyhedral & fine nutty.	many to abundant, coarse, distinct, associated with rotting rocks 10yr 5/8, 6/8 7/8 7.5yr 6/8, 7/8	in relict and existing root channels 10yr 4/6 5yr 3/4	grey forming into veins. Few fine roots. Old bush roots noted.

Appendix 27. Pedological description of profile 66, representing Profile Class E4.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	31	10yr 5/3 7.5yr 5/3 plus in lower horizon 10yr 6/6, 7/6 7.5yr 6/8 possibly due to worm mixing.	in lower horizon, associated with worm mixing. Many, fine faint to distinct.	fine gravelly silt loam (many very small rock fragments noted)	firm (firmer near base)	moderat-ely firm
Bwg	25	7.5yr 6/8 2.5y 6/4 down old root channels 2.5y 6/3	abundant to profuse, medium, prominent.	silty clay loam	stiff	moderat-ely firm
BCg	> 31	5y 7/2 7.5y 8/1 7.5yr 5/8	abundant, coarse, prominent	stony silty clay	stiff	moderat-ely firm
R						

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
very sticky	very plastic	moderately developed, coarse and very coarse, crumb.	-	-	considerable worm mixing below 17 cm. Much fine grit and rock fragments. Abundant fine roots.
slightly sticky	very plastic	moderately to strongly developed, very coarse blocky	-	in lower horizon 2.5y 6/3	many fine roots.
slightly sticky	very plastic	moderately developed, very coarse blocky	-	in upper horizon 2.5y 6/3	few to none, fine roots.

Appendix 28. Pedological description of profile 26, representing Profile Class E5.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
O	8	10yr 3/4	-	silt loam	firm	moderately firm
Ah	22	10yr 6/6 to 10yr 6/4 at base	-	slightly stony silt loam	very stiff	very firm
2Cg	27	Rotting rock plus 10yr 4/6 (worm casts) 7.5yr 6/8 5yr 3/6	abundant, coarse, distinct	bouldery silty clay loam		
2R						

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
slightly sticky	very plastic	moderately developed, medium, nutty and fine crumb	-	-	root mat 8 cm
slightly sticky	very plastic	moderately developed coarse and medium, nutty and fine crumb.	-	-	angular greywacke stones 2-6 cm in diameter.

Appendix 29. Pedological description of profile 27, representing Profile Class E6.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
Ah	16	10yr 4/3, 5/3	abundant, pinhead 5yr 5/8	silt loam	firm	very to moderately weak
E	11	10yr 5/3 merging to 2.5y 6/3	-	silt loam to silty clay loam	stiff	moderately weak
Bwg		10yr 6/8 2.5y 6/4 in the upper horizon merging to 7.5yF 6/8 and 7.5y 7/1 below 53 cm.	many, fine going to medium, prominent with depth.	stony silty clay	stiff. softer above 53 cm and harder in lower zone.	very to moderately weak

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
slightly sticky	very plastic	weakly developed, fine and medium, crumb.	-	-	many, fine roots.
moderately sticky	very plastic	weakly developed, very coarse nutty going to fine crumb.	-	-	many, fine roots.
moderately sticky	very plastic	weakly developed, coarse blocky going to weakly coherent massive in lower horizon	mottles going to soft concretions	-	few roots in softer material above 53 cm, with fewer below this in old bush roots.
					Grey more prominent with depth, more gravels struck with auger at 110 cm.

Appendix 30. Profile Description of profile 2, representing Profile Class E7.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
Ah	12	7.5yr 5/3	-	silt loam	firm	moderat-ely weak
2C	38	5yr 5/4 2.5yr 5/4	-	bouldery silt loam to sandy loam	very stiff	moderat-ely weak
3C				very stony silt loam to sandy loam		
4R						

Stick-iness	Plast icity	Structure	Concretions	Cutans	Miscellaneous
slightly sticky	very plastic	weakly to moderately developed, fine, medium and coarse crumb.	-	-	many, fine roots.
slightly sticky	moderat-ely plastic	as above	-	-	Greywacke boulders not severely weathered. Many to few, fine roots.
					Greywacke boulders strongly weathered.

Appendix 31. Pedological description of profile 24, representing Profile Class F1.

Horizon	Thickness	Colour	Mottles	Texture	Penet-ration	Cohesion
O	9	7.5yr 4/3	-	silt loam	soft	moderat-ely firm
Ah	15	7.5yr 4/3 and 10yr 5/4 worm casts prominent in lower horizon	-	silt loam	very stiff	moderat ely firm
BAc	24	10yr 4/6, 5/4, 5/6, 5/8 7.5yr 5/6, 5/8	-	silty clay loam	very stiff	moderat-ely weak
2Bwc	44	7.5yr 5/6, 6/6	2.5y 7/3 staining in matrix going to mottles 7.5yr 5/8 and 5y 7/4, at base of horizon. Fine and faint.	sandy clay loam (sandy textural component from rock fragments)	very stiff	moderat-ely weak
2BCg		5yr 4/8 2.5yr 4/8, 5/8 7.5y 7/3	abundant, coarse, prominent	bouldery sandy clay loam (as above)	very stiff	
3R						

Stick-iness	Plasticity	Structure	Concretions	Cutans	Miscellaneous
slightly sticky	very plastic	moderately developed, medium and fine crumb and nutty.	-	-	profuse, fine roots.
slightly sticky	very plastic	moderately developed, coarse, nutty.	-	-	profuse to abundant, fine roots.
slightly sticky	very plastic	moderately developed, medium and coarse nutty	profuse, pinhead, 5yr 5/8		many, fine roots. considerable worm mixing noted at lower horizon boundary.
slightly sticky	moderately plastic	weakly developed, coarse, blocky.	hard, 7.5Gy 6/1,7/1 7.5yr 1.7/1 surrounded by 5yr 5/8 2.5yr 3/6	possible in upper horizon 7.5yr 5/8	few fine roots. Rust staining prominent above 70 cm. Some pieces of angular rotting rock above 70 cm. Below 70 cm, much less rotting rock and distinct concretions.
slightly sticky	moderately plastic	massive	mottles going to concretions 5yr 6/8	-	

Appendix 32. Pedological description of profile 40, representing Profile Class F2.

Horizon	Thickness	Colour	Mottles	Texture	Penetration	Cohesion
O	8	10yr 4/3, 5/3	-	silt loam	firm	moderately weak
Ah	22	10yr 5/3, 6/6	-	silt loam	stiff	moderately firm
BA	15	10yr 5/3, 6/6 7.5yr 6/8	many, fine, faint, in lower horizon	silt loam	very stiff	moderately firm
2Bwg	47	10yr 6/4 7.5yr 5/8, 6/8 5y 7/2	as above, concentrated at lower boundary	silty clay loam	UPPER: (above 62 cm) very stiff. LOWER: stiff	moderately firm
2BCxg		7.5yr 5/8, 6/8 5y 7/1	many, fine and medium, prominent	silty clay	very stiff	

Stick-iness	Plasticity	Structure	Concretions	Cutans	Miscellaneous
moderately sticky	very plastic	weakly developed, fine and medium crumb.	-	-	
very sticky	very plastic	strongly developed, coarse, nutty	-	-	
moderately sticky	very plastic	moderately developed, fine and medium blocky-polyhedral	few with gley spots near lower boundary	-	
moderately to very sticky	very plastic	UPPER: (above 62 cm) weakly developed blocky-polyhedral. LOWER: weakly developed, coarse blocky-polyhedral breaking to fine crumb.	above 62 cm 5yr 2/3 surrounded by faint mantle of rust colour grey patch 2.5y 6/3	UPPER: (above 62 cm) thin, faint, abundant 2.5yr 6/4,6/6 LOWER: as above 7.5yr 5/6	below 69 cm, material wetter and softer.
very sticky	very plastic	massive			

Appendix 33. Sampling Depths.

Sampling was carried out on the horizons of the nominated profiles at the following depths down the profile:-

Profile 18	Horizon	Sampling depth (cm)
	*Ah1	2 - 8
	*Ah2	14 - 20
	BA	47 - 53
	Bw1	78 - 84
	2Bw2	97 - 103
	Bw3	112 - 118

(* - Note: Ah1 horizon is the Ah horizon above 9 cm;
Ah2 horizon is the Ah horizon from 9 to 20 cm.)

Profile 7	Ah	2 - 8
	AB	13 - 19
	BA	28 - 34
	Bwg	47 - 53
	2Cg	58 - 64
	BCxg	78 - 84
	Cxg	90 - 96
Profile 50	Ah	1 - 7
	Eg	16 - 22
	Btg1	41 - 47
	Btg2	68 - 74
	Cxg	85 - 90
Profile 1	Ah	5 - 11
	AE	19 - 25
	BEg	33 - 39
	Btg	52 - 58
	Bwg	72 - 78
	2C	80 - 82

	Horizon	Sampling depth (cm)
Profile 70	Ah	11 - 17
	Bwg	37 - 43
	BCxg	61 - 67
	Cxg	79 - 85

Appendix 34. Glossary.

Landscape body - where the maximum lateral rate of change of landscape characteristics is used as the boundary criterion.

Soil landscape body - where the maximum lateral rate of change of soil characteristics is used as a boundary criterion.

(Schelling, 1970)

BIBLIOGRAPHY

ADKIN, G.L. 1912: The discovery and extent of former glaciation in the Tararua Ranges, North Island N.Z. *Trans. N.Z. Inst.*: *44*, 308-316.

AQUINAS, T. Summa Theologica I, Q 85, 2 vol. 4, (trans. Fathers of English Dominican Province, 1911), Burns, Oates & Washbourne, London, 372p.

AVERY, B.W. 1973: Soil Classification in the Soil Survey of England and Wales. *The Journal of Soil Science, Vol. 24, No.3*: 324-338.

AVERY, B.W. 1980: Soil Survey. Technical Monograph No. 14. Soil Classification for England and Wales (Higher Categories). Adland & Son Ltd., Bartholemew Press, Dorking, England. 67p.

BALL, D.F. & Williams, W.M. 1968: Variability of Soil Chemical Properties in two Uncultivated Brown Earths. *Journal of Soil Science, Vol. 19:* 379-391.

BARGH, B.J. 1976: A study of the hydrological and sedimentological characteristics of two catchments of contrasting land use. Thesis M.Agr.Sc., Massey University.

BECKETT, P.H.T. 1967: Lateral changes in soil variability. *Journal Aust. Inst. Agric. Sci. 33:* 172-179.

BECKETT, P.H.T. & Bie, S.W. 1976: Reconnaissance for soil survey (II). Pre-survey estimates of the intricacy of the soil pattern. The *Journal of Soil Science 27:* 101-110.

BECKETT, P.H.T. & Burrough, P.A. 1971: The relation between cost and utility in soil survey (IV). Comparison of the utilities of soil maps produced by different survey procedures and to different scales. The *Journal of Soil Science, 22: No. 4:* 466-480.

BECKETT, P.H.T. & Webster, R. 1971: Soil Variability: a review. *Soil Fertilizer, 34:* 1-15.

BIE, S.W. & Beckett, P.H.T. 1971: Quality Control in Soil Survey. Introduction I: Choice of mapping unit. The *Journal of Soil Science 22, No. 1:* 32-49.

BREWER, R. 1964: Fabric and Mineral Analysis of Soils. John Wiley & Sons, Inc., New York, London & Sydney, 470 p.

BOWLER, D.G.1980: (personal communication.)

BRINKMAN, R. 1979: Ferrolysis, a soil forming process in hydromorphic conditions. Wageningen Centre for Agricultural Publishing & Documentation, 105p.

BRONOWSKI, J. 1977: A Sense of the Future. The MIt Press, Massachusetts & London, 286p.

BURINGH, P., Steur, G.G.L. & Vink, A.R.P. 1962: Some techniques and methods of soil survey in the Netherlands. *Netherlands Journal of Agric. Sci., 10:* 157-172.

BURROWS, C.J. 1978: The Quaternary Ice Ages in New Zealand. A framework of Biologists. *Mauri Ora 6:* 69-96.

BUTLER, B.E. 1964: Assessing the Soil Factor in agricultural production. *Journal Aust. Inst. Agric. Sci. 30:* 232-240.

BUTLER, B.E. 1980: Soil Classification for Soil Survey. Oxford, Clarendon Press. 129p.

BUTLER, B.E. 1982: A new system of soil studies. The *Journal of Soil Science, 33:* 581-595.

CLINE, M.G. 1949: Basic Principles of Soil Classification. *Soil Sci. 67:* 81-92.

COFFEY, G.N. 1912 : A Study of the Soils of the U.S. *U.S. Dept. Agric. Bureau of Soils Bulletin, 85.* 114p.

COLE, J.W. & Lewis, K.B. 1981: Evolution of the Taupo-Hukurangi subduction system. *Technophysics 72:* 1-21.

COTTON, C.A. & Te Punga, M.T. 1955: Solifluxion and periglacially modified landforms at Wellington, N.Z. *Trans. R. Soc. N.Z. 82 (5):* 1001-1031.

COWIE, J.D. 1964a: Loess in the Manawatu District of New Zealand. Soil Bureau Publ. *N.Z. Journal Geol. Geophys. 7:* 389-396.

COWIE, J.D. 1964 b: Aokautere Ash in the Manawatu District, New Zealand. *N.Z. Journal Geol. Geophys. 7:* 67-77.

COWIE, J.D. 1978: Soils and Agriculture of Kairanga County. *N.Z. Soil Bureau Bulletin 33.*

COWIE, J.D., Fitzgerald, P. & Owers, W. 1967: Soils of the Manawatu-Rangitikei Sand Country. *N.Z. Soil Bureau Bulletin 29.*

COWIE, J.D. & Rigkse, W.C. 1977: Soils of Manawaty County, North Island, N.Z. *N.Z. Soil Survey Report 30.*

CUTLER, E.J.B. 1977: Soil Resource survey interpretations and applications. Lincoln College Press, Lincoln College, Canterbury, N.Z. 272p.

DE BAAKER, H. 1970: Purposes of Soil Classification. *Geoderma, Vol. 4 No. 3:* 195-208.

DE SIGMOND, A.A.J. 1938: The Principles of Soil Science. Thomas Murby & Co., London. 362p.

DOKUCHAIEV, V.V. 1886: 1. (Russian) Data for valuation of the soil of Nishny-Nargorad. In *Soil Survey Staff, 1960.*

ELLIS, J.H. 1932: A field classification of soil for use in Soil Survey. *Sci. Agric.* (now found under *Canadian Journal of Agric. Sci.) Vol. XII No. 6:* 338-345.

ESLER, A.E. 1978: Vegetation. *Soil Bureau Bulletin 33:* 19-21.

FAIR, E.E. 1968: Structural, Tectonic and Climatic Control of the Fluvial Geomorphology of the Manawatu River West of the Gorge. Thesis M.Sc., Massey University.

FAO/UNESCO 1974: Soil Map of the World. Vol. I. Legend. UNESCO Press, Paris.

FIELDES, M. & Perrott, K.W. 1966: The Nature of Allophane in Soils, Part 3. Rapid field and laboratory tests of Allophane. *N.Z. Journal of Science 9:* 623-629.

FLEMING, C.A. 1953: The Geology of Wanganui Subdivision. *Bulletin Geol. Surv. N.Z. 5 (52):* 1-360.

FRANKLIN, D.A. 1967: The synecology of the Tararua indigenous forests. *Forest Research Inst. Tech. Paper No. 53.* N.Z. Forest Service.

GILSON, E. 1950: 'The Spirit of Medieval Philosophy'. (Gifford Lectures, 1931-32). Sheed & Ward, London. 490p.

GLASS, A.N. 1957: Soil Conservation on North Island Hill Country. *N.Z. Journal Agric. Vol. 95, No.4:* 378-392.

GLAZONSKAYA, M.A. 1966: Principles of Classifying Soils of the World. *Soviet Soil Sc. 8:* 857-877.

GRANT, P.J. 1981 a: 'Major periods of erosion and sedimentation in the Ruahine Range since the 13th Century.' In 'Erosion in the Ruahines.' Booklet issued for International Conference on Soils with Variable Charge, Massey University: 18-24.

GRANT, P.J. 1981 b: 'Notes on some effects of several Erosion periods in the West Tamaki Basin, Ruahine Range.' In Booklet issued for International Conference on Soils with Variable Charge, Massey University, 40-42.

HALLSWORTH, E.G. 1965: The relationship between experimental pedology and Soil Classification. In Experimental Pedology. E.G. Hallsworth & D.V. Crawford (eds.), Butterworths, London, 354-374.

HEERDEGEN, R.G. 1972: Landforms of the Manawatu. In The geography of the Manawatu. Miscellaneous Papers No. 2. Dept. of Geography, Massey University.

JENNY, H.J. 1941: Factors of Soil Formation. A system of Quantitative Pedology. McGraw & Hill Book Co. Inc., New York & London, 281 p.

JENNY, H.J. 1961: Derivation of State Factor Equations of Soils and Ecosystems. *Soil Sc. Soc. of America Proc. 25:* 385-388.

JENNY, H.J. 1980: The Soil Resource, Origin and Behaviour. Ecological Studies 37. Ed. W.D. Billings, Durham (U.S.A.), F. Golley, Athens (U.S.A.), O.L. Lange, Wurzburg (F.R.G.), J.S. Olson, Oak Ridge (U.S.A.), K. Remment, Marlburg (F.R.G.). Springer-Verlangs, New York. 377 p.

KEAR, B.S., Gibbs, H.S. & Millar, R.B. 1967: Soils of the Downs and Plains, Canterbury and North Otago. *N.Z. Soil Bureau Bulletin 14.*

KINGMA, J.T. 1957: The Tectonic Setting of the Ruahine-Rimutaka Range, N.Z. *N.Z. Journal of Sci. & Technol. B38:* 858-861.

KINGMA, J.T. 1969: The Tectonic History of New Zealand. *N.Z. Journal of Geol. Geophys. 2 (1):* 1-55.

KIRKMAN, J. 1977: The Formation of Allophane and Halloysite from Rhyolitic and Andesitic Tephras. In Summaries of Papers presented at N.Z. Soc. of Soil Sc. Jubilee Conference.

KIRKMAN, J. & Pullar, W.A. 1978: Halloysite in late Pleistocene Ryolitic Tephra Beds near Opotiki, Coastal Bay of Plenty, North Island, N.Z. *Aust. Journal of Soil Research 16:* 1-8.

KNOX, E.G. 1965: Soil Individual and Soil Classification. *Soil Sc. Soc. America Proc. 29:* 79-83.

KOVDA, V.A., Lobova, Y.E. & Rozanov, B.G. 1967: A Classification of the World's Soils, general considerations. *Soviet Soil Sc. 4:* 427-441.

KUBIENA, W.L. 1953: The Soils of Europe. Illustrated Diagnosis and Systematics. Murby & Co. London. 317p.

LEVY, E.B. 1970: Grasslands of New Zealand. 3rd Edition. Government Printer, Wellington, N.Z.

LILLIE, A.R. 1953: The Geology of the Dannevirke Subdivision. *N.Z. Geol. Surv. Bulletin 46:* 146p.

McCRAW, J.D. 1975: Quaternary Airfall Deposits in New Zealand. In: Suggate, R.P. & Cresswell, M.M. (eds.) Quaternary Studies. *Roy. Soc. of N.Z. Bulletin 13.* Wellington, 35-44.

McLINTOCK, A.H. (ed.) 1959: A Descriptive Atlas of New Zealand. Government Printer, Wellington.

MARBUT, C.F. 1921: The Contributions of Soil Surveys to Soil Science. *Soc. for the Promotion of Agric. Sci. Proc. 41:* 116-142.

MARBUT, C.F. 1922: 'Soil Classification.' *American Assoc. Soil Survey Workers Bulletin 3:* 24-32.

MARBUT, C.F. 1927: The Great Soil Groups of the World and their Development. (Translation from German) Thomas Murby & Co. London. 235p.

MEAD, A.D. 1936: Notes on the Structure of Tararua Ranges near Mangahao. *N.Z. Journal of Sci. & Technol. 18:* 12-23.

MEW, G., Webb, T.H., Ross, C.W. & Adams, J.A. 1975: Soils of Inangahua Depression, South Island, New Zealand. *N.Z. Soil Survey Report 17.*

MEW, G. 1980: Soils, Forestry and Agriculture of the Grey Valley, South Island, New Zealand. *N.Z. Soil Survey Report 46.*

MILNE, J.D. & Smalley, I.J. 1979: Loess Deposits in the Southern Part of the North Island of New Zealand. An Outline Stratigraphy. *Acta Geologica Academiae Scientiarum Hungaricae, Tomus 22 (1-4):* 197-204.

MULLER, P.E. 1887: Studien uber die Naturlichen Humusformen. Sprunger, Berlin. In: Concept of the Soil, Simonsen, R.W. 1968.

N.Z. Soil Bureau. 1954: General Survey of the Soil of the North Island, New Zealand. *Soil Bureau Bulletin 5.*

N.Z. Soil Bureau. 1968 a: 'Soils of New Zealand'. *Soil Bureau Bulletin 26 (1-3).*

N.Z. Soil Bureau. 1968 b: General Survey of the Soil of the South Island New Zealand. *Soil Bureau Bulletin 27 (1, 2).*

NORTHCOTE, K.H. 1979: Factual Key for the Recognition of Australian Soils. Rellim Tech. Publication, Adelaide, South Australia. 124p.

NORTHCOTE, K.H. 1981: Morphology, Distribution and Classification. In: 'Red Brown Earths of Australia'. J.M. Oates, D.G. Lewis & K. Norrish (eds.), Waite Agricultural Research Institute, University of Adelaide, and C.S.I.R.O. Div. of Soils, South Australia, 11-28.

ONGLEY, M. & Williamson, J.H. 1931: A Note of the North End of the Tararua Range, New Zealand. *Geol. Survey, 25th Annual Report,* p12.

PALMER, R.W.P., Neall, V.E. & Pollok, J.A. 1981: Soils of Egmont and part Taranaki Counties, North Island, New Zealand. *N.Z. Soil Survey Report 64.*

POHLEN, I.J. 1972: Influence of Rainfall on the Morphology of some Humid and Subhumid zonal soils in New Zealand. *N.Z. Journal of Science 16:* 101-112.

POLLOK, J.A. 1975: A Comparative Study of Certain New Zealand and German Soils Formed from Loess. Published Ph.D. Thesis, University of Bonn, 312p.

PULLAR, W.A. 1962: Soils and Agriculture of Gisborne Plains, New Zealand. *Soil Bureau Bulletin 20.*

PULLAR, W.A., Birrell K.S. & Heine, J.C. 1973: Named Tephra and Tephra Formations Occurring in the Central North Island. Work Notes on derived Soils and Paleosols. *N.Z. Journal of Geology & Geophys. 16:* 497-518.

RAESIDE, J.D. 1964: Loess Deposits of the South Island, New Zealand and Soils formed on them. *N.Z. Journal of Geology & Geophys. 7:* 811-838.

RAGG, J.M. & Henderson, R. 1980: A Reappraisal of Soil Mapping in an area of Southern Scotland. Part I. The reliability of soil mapping units and the morphological variability of their dominant taxa. *Journal of Soil Sc. 31, No. 4:* 559-572.

RICH, C.C. 1959: Late Cenozoic Geology of the Lower Manawatu Valley. Unpublished Ph.D. Thesis, Harvard University. Microfilm lodged at Massey University Library.

RICKARD, D.S. 1960: The Occurrence of Agricultural Drought at Ashburton, New Zealand. *N.Z. Journal of Agric. Research 3:* 432-441.

RIICKEN, F.F. 1963: Some aspects of Soil Classification in Farming. *Soil Sci. 96:* 49-61.

ROBINSON, G.W. 1949: Soils, their Origin, Constitution and Classification. Thomas Murby & Co., London. 573p.

ROBINSON, G.W. 1950: Philosophical approach to Soil Classification. The *Journal of Soil Science Vol. 1, No.2:* 150-155.

ROBINSON, N.G. 1975: Personal communication to Bargh, B.J. in 'A Study of Hydrological and Sedimentological Characteristics of Two Catchments of Contrasting Land Use. Appendix 1D. Thesis M.Ag.Sc., Massey University.

SCHELLING, J. 1970: Soil Genesis, Soil Classification and Soil Survey. *Geoderma 4, No.3:* 165-193.

SELBY, M.J. 1976: Loess. *N.Z. Journal of Geography, 61:* 1-18.

SIMONSEN, R.W. 1962: Soil Classification in the United States. *Science, 137:* 1027-1034.

SIMONSEN, R.W. 1964: The Soil Series as used in the U.S.A. Transactions of the 8th International Congress of Soil Science, Bucharest, Roumania, Vol. 5: 17-24.

SIMONSON, R.W. 1968: Concept of Soil. *Advances in Agronomy 20:* 1-47.

SOIL SURVEY STAFF, 1951: Soil Survey Manual. U.S.D.A. Handbook, Government Printer, Washington D.C.

SOIL SURVEY STAFF, 1960: Soil Classification: a comprehensive system; 7th approximation. U.S. Soil Conservation Service, U.S.D.A., 265p.

SOIL SURVEY STAFF, 1975: Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. U.S.D.A. Handbook, Government Printer, Washington D.C. 754p.

SOONS, J.M. 1976: Late Quaternary Environments in the South Island, New Zealand. p.511 In: Abstracts, 25th International Geological Congress, Vol. 12, Sect. 12. Sydney, Australia.

STEPHENS, C.G. 1947: Functional Syntheses in Pedogenesis. Transactions Royal Soc. 71: 168-181.

STEVENS, G.R. 1957 a: Geomorphology of the Hutt Valley, New Zealand. *N.Z. Journal of Sci. & Technol. B38:* 297-327.

STEVENS, G.R. 1957 b: Solifluxion phenomena in the Lower Hutt Area, New Zealand. *N.Z. Journal of Sci. & Technol. B38:* 279-296.

TAYLOR, N.H. 1948: Soil Map of New Zealand. 1:2,027,520. N.Z. Soil Bureau, D.S.I.R.

TAYLOR, N.H. & Mars, G.T. 1979: Economics of Hill and High Country Production. Proceedings of 1979 Hill & High Country Seminar, Tussock Grassland & Mountain Lands Inst., Lincoln College Special Publ. 16: 283-309.

TAYLOR, N.H. & Pohlen, I.J. 1962: 'Soil Survey Method'. *Soil Bureau Bulletin 25.* 242p.

TE PUNGA, M.T. 1952: The Geology of the Rangitikei River Valley. M.E.M. Geol. Survey N.Z., 8.

VAN WAMBEKE, A. 1966: 'Soil Bodies and Soil Classification'. In: *Soil Fertilizers 29:* 507-510.

VISSER, W.C. 1949: Over de Methodiek van schattem van de waarde van de grond. *Landbouwk TIJDSCHR 61:* 381-399.

WALLACE, R.C. & Neall, V.E. 1982: Sand and silt mineralogy of the Tokomaru silt loam at Massey University, Manawatu in New Zealand. *Soil News 30, ~~Vol~~ no. 5:* 128-129.

WATT, J.P.C. (ed.) 1972: Loess soils and problems of land use on the Down lands of the South Island, New Zealand. Otago Catchment Board Publ. No. 4. 138p.

WEBB, T.H. 1976: Pedological Studies of the Tekapo Set in East Lake Pukaki Region, South Canterbury, New Zealand. Thesis M.Agr.Sc., Lincoln College.

WEBSTER, R. & Beckett, P.H.T. 1968: 'Quality and Usefulness of Soil Maps'. *Nature, London, 219:* 680-682.

WELLMAN, H.W. 1948: 'Tararua Range Summit Height Accordance.' *N.Z. Journal of Sci. & Technol. B30:* 123-127.

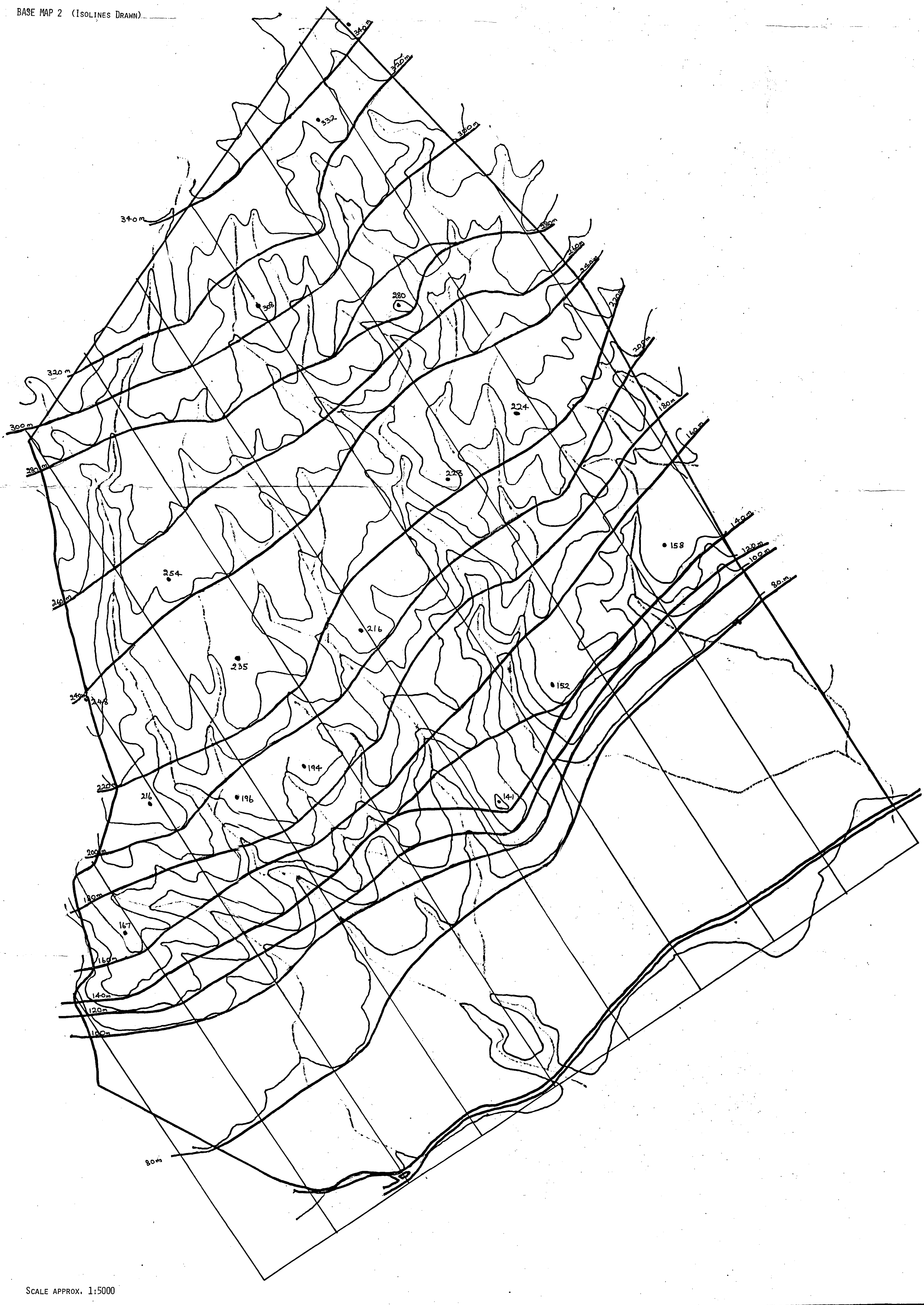
WILLETT, R.W. 1950: The Pleistocene Snowline, climatic conditions and suggested biological effects. *N.Z. Journal of Sci. & Technol. B32:* 18-48.

WILDE, H. 1983: (personal communication.)

BASE MAP 1 (PROFILE LOCATIONS)

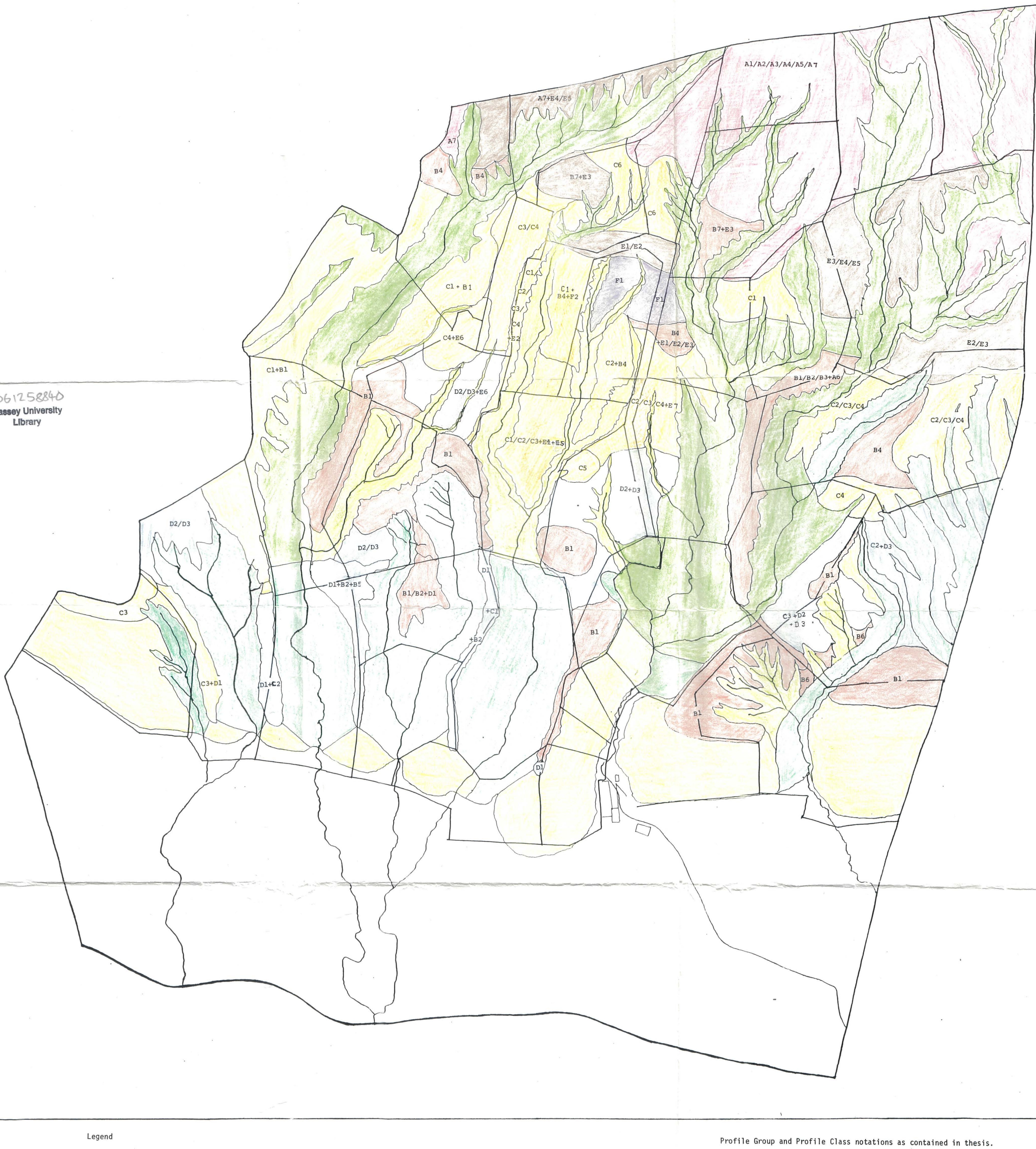
SCALE APPROX. 1:5000

BASE MAP 2 (ISOLINES DRAWN)



SCALE APPROX. 1:5000

TUAPAKA SOIL MAP



Legend

- Profile Group A
- Profile Group B
- Profile Group C
- Profile Group D
- Profile Group E
- Profile Group F
- Halcombe hill soil.
- Halcombe steepland soil
- Makara steepland soil
- / Symbol separating Profile Classes present in an erosional sequence
- \+ Symbol separating Profile Classes from different Profile Groups present in an unresolved 'complex'.

Profile Group and Profile Class notations as contained in thesis.

Mapping Units colour-coded after the Profile Group of the dominant Profile Class(es).

SCALE 1:5000