THE DISTRIBUTION AND PROPERTIES OF SOILS IN RELATION TO EROSION IN A SELECTED CATCHMENT OF THE SOUTHERN RUAHINE RANGE, NORTH ISLAND, NEW ZEALAND

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

Carolyn Hubbard
1978

FRONTISPIECE

A view of the south-eastern fault-controlled front of the Ruahine Range. Car Park Creek, a subcatchment of the West Tamaki River, is seen in the centre of photo. In the foreground, fertile floodplains are seen. These are threatened by the inundation of erosion products which are carried out of the mountainland by the rivers, during storm periods.

ABSTRACT

The soils of a selected subcatchment of the Southern Ruahine Range have been mapped at a scale of 1:5,000. The soil mapping units have been further characterised by measurement of a number of soil physical and chemical properties, together with an investigation of their sand and clay mineralogies.

The erosion history since 20,000 yrs B.P. when the Aokautere Ash was deposited in the West Tamaki River catchment, has been partially reconstructed for this catchment. It is one of erosive periods and resulting aggradational gravel deposits, alternating with more stable periods with soil development and vegetation growth. Studies of a histosol (organic soil) on the summit plateau of the Southern Ruahine Range, at the head of the catchment, suggests that this soil is approximately 4600 years old, and prior to this time the summit plateau was stripped by erosion.

Present erosion occurs predominantly: (1) on convex creep slopes, just below the summit plateau, and (2) on the steep valley-sides. In the former zone, where Takapari hill soils exist, deep-seated creep and mass movements occur. In the latter zone, where Ruahine steepland soils exist, superficial soil and rock slips are more common.

An investigation of the soil-water relationships for each soil mapping unit indicates that a number of factors render the Takapari hill soils and Ruahine steepland soils particularly susceptible to erosion. A comparison of soil properties which affect the erosion susceptibilities of each soil mapping unit has enabled an ordering of the units with respect to erosion risk. Thus, areas of high, medium and low risk to erosion in the West Tamaki River catchment have been delineated. Many of the deep-seated erosion surfaces occur in the high risk area. Thus, if stabilisation of these sites is possible, by intensive revegetation programmes, the result will be a decrease in the amount of gravels carried out of the mountainland by rivers onto the surrounding fertile floodplains.

ACKNOWLEDGEMENTS

My course of study in New Zealand has been both beneficial and enjoyable. I would like to express my sincere appreciation to the following, who have helped to make it this way:

Drs. V.E. Neall and J.A. Pollok for supervision of my study, and for many pleasurable times together.

Drs. D. Scotter and J.H. Kirkman, Messrs D.G. Bowler and R.B. Stewart for their assistance in various parts of the study.

Professor J.K. Syers and many other members of the Department for help and friendship throughout my course.

Mike Marden, my colleague, Keith McAuliffe and Mike Hedley for accompanying me in the field.

Messrs Rob Blakely, Dick Martin and Colin Michie (Manawatu Catchment Board) and Mr Peter Stephens (Ministry of Works and Development) for helping to acquaint me with the Ruahine situation. In particular, I would like to thank Mr Rob Blakely for arranging several reconnaissance trips, and for many stimulating discussions.

Rotary International, for their generous financial assistance; without whom I would have been unable to embark on this course.

N.Z. Forest Service for funding my second year of study; and especially to Mr A. Cunningham, for his interest and assistance throughout the study.

Judy for speedy and skilful typing of the text;

and, finally, my family for their unending support.

TABLE OF CONTENTS

CHAPTER I

CHAPTER 2

CHAPTER 3

DESCRIPTION OF THE STUDY AREA

CHAPTER 4

HISTORY OF EROSION IN THE WEST TAMAKI RIVER CATCHMENT page

CHAPTER 5

A PEDOLOGICAL INVESTIGATION OF THE SOILS IN CAR PARK CREEK SUBCATCHMENT

CHAPTER 6

AN INVESTIGATION OF SOIL PARAMETERS RELATED TO SOIL GENESIS AND ERODIBILITY

CHAPTER 7

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 REASONS FOR STUDY

The nature and distribution of the soils of the Southern Ruahine Range are largely controlled by erosion processes in an area of very high erosion rates. Few soil surveys have been conducted in this mountainland. However, soils have been mapped at a scale of 1:63,360 in the Dannevirke area by G.J. Smith (cited in Mosley, 1977) and in Woodville and Pohangina counties by Rijkse (1974, 1977). There is a paucity of detailed information on the soils of the Southern Ruahine Range, and knowledge of their parent materials, genesis and distribution pattern with reference to slope angles and erosion history is scarce.

Slope stability problems centre around the failure of the soil mantle and underlying bedrock with subsequent formation of both shallow and deep-seated erosion scars. The causes of this erosion in the Southern Ruahine Range are by no means well-established, and in the last ten years concern has mounted due to a commonly held belief that erosion rates have increased in recent decades. The apparent increased incidence of mass movements and slips, coupled with marked aggradation in river channels draining the Range has led to the possibility of flooding in adjacent lowland areas. These lowland areas are, in certain places, densely populated and are used for highly productive livestock farming.

1.2 OBJECTIVES OF STUDY

The objectives of the present study were to assess the soil resources of a selected study area with respect to:

(a) their relationship to the erosion history

(b) nature of parent materials

(c) their genesis and classification

(d) their relative erosion potential, involving measurement of a number of soil physical and mineralogical properties.

It was anticipated that this information would help to explain the erosion processes occurring in the study area, which are similar to those occurring throughout the Southern Ruahine Range.

1.3 CHOICE OF STUDY AREA

A number of reconnaissance trips to the Southern Ruahine Range were made to investigate the erosion problem and the range of soils which occur there. Information gathered on these trips was used to choose a study area, in which a detailed soil survey could be carried out.

A subcatchment of the West Tamaki River, Car Park Creek, was chosen as a suitable study area for the following reasons:

(a) the erosion problem, and range of soils, appeared to be typical of the erosion and soils encountered over much of the area of the Southern Ruahine Range,

(b) a considerable amount of background information is available for the West Tamaki River catchment, from work carried out by the Manawatu Catchment Board, Soil and Water Division of the Ministry of Works and Development and the New Zealand Forest Service.

(c) the West Tamaki River catchment provides the main water supply for the town of Dannevirke and is thus an important catchment in the Southern Ruahine Range,

(d) good access exists along vehicle and foot tracks at the top and bottom of the West Tamaki River catchment and Car Park Creek (the selected subcatchment). This was considered to be an important factor in enabling widespread ground observations to be made throughout the study area.

1.4 METHODOLOGY OF STUDY

(a) Fieldwork: Two major objectives of fieldwork studies were: an investigation of the erosion history of the West Tamaki River catchment, and an assessment of the soil resources of Car Park Creek subcatchment, at 1:5,000 scale. The former involved the identification and delineation of depositional surfaces in the main channel of the West Tamaki River catchment. This part of the study provides a picture of past erosion events in the catchment, and also shows the degree of soil development on varying aged surfaces. The soils on the more stable sites of the summit plateau were also investigated to provide a stratigraphic control to the record of erosion events, over the last few thousand years, on the unstable sites within the study catchment.

The latter involved a survey of the soils in Car Park Creek subcatchment. This entailed a detailed enquiry into the Ruahine steepland soils, a mapping unit used in previous surveys to describe the major portion of soils in the south-eastern Ruahine Range. Also, the relationships of soil distribution to vegetation pattern, slope, geomorphology and parent materials were noted, all of which are closely related to the erosion history.

Aerial photographs were used as an aid to fieldwork studies. Photographs at a scale of 1: 20,000, published by the Department of Lands and Survey were used as an aid in identifying erosional and depositional surfaces. A series of aerial photos of Car Park Creek, at an approximate scale of 1: 5,000, were flown by Mr D.G. Bowler of the Department of Soil Science, Massey University for use in the soil survey and for accurate determination of the extent of erosion scars in the subcatchment.

(b) Laboratory Investigations: Characterisation of the soils for classification involved measurement of a number of soil physical and chemical parameters to augment information obtained in the field, (i.e. organic matter, bulk density, pH in NaF, P retention).

Mineralogy studies (sand and clay fractions) were used to investigate the extent of weathering in these soils, as well as the nature of the soil parent materials.

Soil-water characteristics were investigated by measuring: the saturated hydraulic conductivity, macroporosity, total porosity, and 15 bar water retention (of moist and previously dried samples) values, in order to assess the susceptibility of the soils to erosion. In this way, factors involved in the erosion of soils within this area were defined, and these in turn revealed the units of the landscape which had maximum susceptibility to erosion processes.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW ON THE SOILS AND EROSION SITUATION OF THE SOUTHERN RUAHINE RANGE

2.1 INTRODUCTION

In recent years, the Southern Ruahine Range has been an area of intensive study, chiefly by governmental and quasi-governmental agencies, due to concern over large amounts of gravel and other debris which are transported from the eroding mountain range onto the adjoining farmland. This detritus chokes many river beds, and is threatening between 24,300 and 28,300 hectares of fertile, flood-free plains of the Manawatu, (Poole, 1973). A number of workers believe that erosion rates in this area have increased markedly during the last few decades (James, 1973; Stephens, 1975; Cunningham and Stribling, 1977; Grant, 1978). Stephens has shown that between 1946 and 1974, a 120% increase in area of eroded slopes occurred in the No. 1 and Raparapawai catchments, of the Southern Ruahine Range.

Brougham (1977) indicates that the Tamaki and Rokaiwhanga streams were probably narrow (10-20m wide) and meandering, prior to deforestation of the lower reaches. Following timber removal, tree stumps began to rot out in the 1920's and 1930's, and the streams became wide, braided channels, scouring through previously forested areas. This resulted in loss of productive floodplain, which continues today. He considers that bed levels rose by about 0.5m to 1.0m between 1910 and 1940; and again, by a similar amount since 1940. Since 1940, the lateral extent of these channels has increased by a factor of three to ten times.

Thus the problem of gravel extending over fertile floodplains in this region is not a new one. It was acknowledged by Cumberland (1944), who described "frost-bitten, windswept, golden scars of soil-stripped patches along the crestline of the ranges", which could be seen from a distance of 30 miles. Cumberland attributed the "induced" erosion to "the tread and grazing of animals - wild and domestic - and the use of the firestick". However, Colenso (1884) wrote of "very precipitous and broken hills and ridges", and "extensive landslips", before exotic wildlife or domestic animals were introduced; and when burning had only just commenced.

Mosley (1977) states that the precise nature, location and extent of the problem has been only vaguely specified. He considers soils as one of several factors of importance in the consideration of erosion in the Ruahine Range. Cunningham and Stribling (1977) consider the soil resources are a key factor in the Ruahine erosion situation, deserving close study.

2.2 LANDSCAPE EVOLUTION IN THE SOUTHERN RUAHINE RANGE THROUGH GEOLOGICAL TIME

2.2.1 Genesis of the Mountain Range

Sediments that accumulated in the New Zealand Geosyncline, parallel to the "supercontinent" of Gondwanaland (Fleming, 1975), are mapped today in the Ruahine and Tararua ranges as the Torlesse Supergroup, (Stevens, 1974). The sediments were deformed, and raised above sea-level, during the Rangitata Orogeny, in early Cretaceous times (Fleming, 1975; Kingma, 1959).

Peneplanation of the Ruahine Range occurred between the Upper Cretaceous and Palaeocene, when a marine transgression submerged the southern North Island (Kingma, 1959). Fleming (1962) suggests that this phase of peneplanation and quartoze sedimentation may be the only really stable phase in New Zealand's geological history since the Devonian.

The peneplanation resulted in a level surface now exhumed and dissected to form the marked summit accordance seen today in the Ruahine Range, and Tararua Range (Wellman, 1948).

The sediments of the New Zealand Geosyncline have suffered a second deformation episode, with uplift during the more recent Kaikoura Orogeny, which is continuing today (Bradshaw, 1975).

2.2.2 Landscape Evolution, During Plio-Pleistocene Times

A climatic cooling during the Pliocene was heralded by a change of vegetation in the mountain ranges of New Zealand, from *Nothofagus brassi* (Long-leafed Beech) in Waitotaran times, to *Nothofagus fusca* (Red Beech) and podocarps in the Lower Pleistocene, (Mildenhall, 1973).

Conditions were becoming more severe, and with tectonic uplift of the main ranges, increased erosion rates resulted, which are recorded by greywacke detritus of Nukumaruan age, on the surrounding lowlands. The Castlecliffian Stage contains abundant fossils of warm temperature flora and fauna (Fleming, 1973; Mildenhall, 1973), indicating a milder, more stable period in the mountainland, before the oncoming glacial of the Upper Pleistocene, the Waimaungan Stage. Milne (1973a), suggests that during this and the succeeding cold climate episodes, the mountainland was largely devegetated above the 900 metre contour line. He estimates a decrease in mean annual temperature of 5°C to 6°C during these cold climate episodes; with slightly lower rainfall and fewer high intensity rainstorms. However, Soons (1976) suggests that sea-level temperatures in the central South Island were lowered by not more than 4.5°C during the most severe glacial of the Otiran Stage. Thus, the decrease in temperature of 5°C to 6°C, suggested by Milne for the southern North Island may be an over-estimate.

Increased erosion, during the cold climate episodes, produced aggradational gravels, with subsequent wind removal of silt and fine sand particles, to form extensive terraces in some parts of the adjoining lowlands (Milne, 1973b) and associated loess deposits.

Leamy et al. (1973) studied a sequence of seven paleosols and associated loess units in the southern North Island, and concluded that the paleosols indicate interstadial periods of relative warmth and increased soil profile development compared with the stadial periods. The loess units associated with the stadial periods indicate a period of higher erosion rates with a retreat of vegetation down the mountain flanks.

2.2.3 Post-Glacial Climatic Changes

Since the last stadial (Ohakean Substage, of Milne, 1973c), the Post-glacial period in New Zealand (Aranuian Stage) has been characterised by a major warming between 14,700 and 6,300 years B.P., with only minor temperature oscillations since.

McGlone and Topping (1973) have shown, on the basis of pollen studies, that podocarp forests had established themselves in the central North Island before 13,800 years B.P., and consider the Aranuian Stage to have begun about 14,000 years ago. Molloy (1969) considers that there was a general rise in temperature about 10,000 years ago in New Zealand. The magnitude of this temperature rise is unproven and estimates are based primarily on evidence from the South Island, where podocarp forests began to spread over areas, formerly characterised by grassland and scrubland, (Moar, 1966; Walker, 1966). A general rise in temperature since 10,000 years ago, is substantiated by global evidence of a rapidly rising eustatic sea level (Shepard and Curray, 1967; Bloom et al. 1974; Thom, 1974).

Molloy (1969) details climatic oscillations believed to have occurred in Britain over the last 7,000 years, indicating a climatic optimum between 3000 and 5000 B.C., and a "Little Ice Age" between 1500-1850 A.D. Fleming (1963) and Wilson, Hendy and Reynolds (1973) discuss evidence for these two climatic oscillations in New Zealand. Wilson et al. (1973) using the oxygen isotope method for estimating paleotemperatures from speleothems (cave formations) estimate that temperature oscillations during the last millenia have been ± 2°C.

It is important to note that Molloy (1969) considers that any effect that these minor oscillations might have on landscape evolution would, in most cases, be less significant than modifications by natural catastrophes, such as fire, faulting, natural vegetational evolution and man's influences.

Grant (1965, 1966, 1978) gives evidence for 5 erosion phases in the Ruahine Range in the last 600 years. The Matawhero phase coincides with the "Little Ice Age" of ca. 1500-1850 A.D. These periods of increased erosion are attributed by Grant to periods of "increased storminess", and are outlined in Table 1, below.

TABLE 1: EROSION PHASES IN THE SOUTHERN RUAHINE RANGE

EROSION PHASE	TENTATIVE DATE (A.D.)	YEARS AGO(PRIOR TO 1970)
Waihirere	closed ca. 1400-1450	520-570
Matawhero	" " 1600	370
Wakarara	ca. 1780-1830	140-190
Early modern	1880's - 1890's	80-90
Modern	mid 1930's to present	0-40

(Grant, 1978)

2.3 PRESENT EROSION SITUATION OF THE SOUTHERN RUAHINE RANGE

2.3.1 Erosion Situation

Cunningham and Stribling (1977) outline the present erosion problem in the Ruahine Range as one of mountainland erosion, and transport of its products. They consider the main concern to be the accumulation of large quantities of gravel in the upper reaches of the rivers, which may be accelerating and posing a threat to areas downstream.

Schumm (1977) categorises the erosion and sedimentation into 2 types:

TYPE 1: erosion on the steep slopes and small tributary basins in the Range. This is the source of the sediment that forms floodplains, valley deposits and alluvial fans. A major contribution is from mass movement.

TYPE 2: bank erosion and remobilisation of TYPE 1 sediments that are stored in valley throats, floodplains and fans.

Schumm considers that TYPE 1 erosion has always occurred to varying degrees, and is inevitable; whilst TYPE 2 erosion has been acclerated by man's actions.

2.3.2 Erosion Types

Bedrock, soil and fluvial erosion processes are common throughout the Ruahine Range. Resultant erosion types have been reported by a number of workers (James, 1973; Stephens, 1975, 1977; Cunningham and Stribling, 1977; Mosley and Blakely, 1977). The landslide classification of Varnes (1958) is used in this study for naming erosion types. The classification is based on the type of material involved and type of movement. It also considers water content of flow-type landslides and takes into account a general range of velocity of movement of the landslide types. Thus, erosion types are explicitly defined (see Appendix I). Some forms of soil erosion such as soil creep and solifluction are not included in Varne's classification and these are included here using the classification of Campbell (1951), (cited in Land Use Capability Survey Handbook, Water and Soil Division, M.O.W.D., 1971).

Examples of debris slides, debris avalanches and slumps in the Southern Ruahine Range have been given by James (1973), Stephens (1975, 1977), Cunningham and Stribling (1977) and Mosley and Blakely (1977), who indicate that these particular erosion types are common in the Southern Ruahine Range. Mosley and Blakely (1977) describe a landslide (rotational slump) feature in Coppermine Creek, from which over 35,000 m^3 of shattered rock has been supplied to the stream. They consider that although this is one of the largest mass movement features in the south-eastern Ruahine Range, its form and sliding or flowing type of movement (depending on water content) is rather common. Also, the majority of erosion events supplying material to the streams occur on the walls of steep-sided, deeply-cut inner valleys.

There is a paucity of literature detailing forms of soil erosion in the Ruahine Range. Cunningham and Stribling (1977) consider that soil slips ("rapid sliding movements of soil and subsoil parallel to the slope", Campbell (1951)) are common on riparian sites throughout the Range, sometimes developing into "debris-falls". An example is given in the Southern Ruahine Range, in the headwaters of Coal Creek. Undercutting, by streams, of oversteepened valley-sides, commonly results in this type of erosion. They also note that creep and sheet erosion occur within the Range.

2.3.3 Causes of Erosion

The frequency of erosion has increased over the last few decades, as documented by various workers (see 2.1). Reasons to explain the increased erosion rates have differed. James (1973) considers that there has been some influence of *mammals*, particularly opposums, on mass movements in the Upper Pohangina River. He also considers increased storminess, in recent years, to be an important factor, but indicates that it is difficult to know what sort of interaction, if any, these two factors have in causing mass movements. Grant (1977), as previously stated, also considers that *increased storminess* is an important factor for periods of increased erosion rates. Heavy rains, associated with Cyclone Alison, in March 1975 were responsible for shifting a considerable amount of debris in certain catchments of the Southern Ruahine Range, thus providing visible evidence for this latter theory.

Elder (1965) provides evidence for vegetational changes in recent years, on the flanks of the Ruahine Range. He considers that these changes may be explained by a *climatic change*. Totara (*Podocarpus totara*), matai (*Podocarpus spicatus*) and rimu (*Dacrydiun cupressinum*) are failing to replace themselves under forest conditions. Also, pink pine (*Dacrydium biforme*) and cedar (*Libocedrus bidwillii*) communities show a consistent pattern of deterioration, which is most advanced in the south, whilst mountain beech (*Nothofagus solandri* var. *cliffortioides*) forests show a general deterioration, except toward the lower end of its range. In the Central Ruahine Range ring counts of mountain beech give evidence for a retreat in altitude and change in distribution pattern on slopes over the last 200 years, which suggests that conditions may have become wetter.

Stephens (1975) establishes a tentative relationship between *earthquakes* and erosion. An increased frequency of medium-sized earthquakes since 1939, may be associated with the creation of oversteepened slopes which are prone to erosion. Erosion subsequently occurs after a triggering action, most commonly rainstorms.

The main factor predisposing steep slopes to erosion in the Raparapawai and No. 1 catchments, is the instability of the densely faulted and shattered mélange-like bedrock, (the "Pohangina mélange" is mapped to the north, by Spörli and Bell (1976), and defined by Spörli (1974) as "a body of tectonically deformed rock, characterised by the inclusion of native and exotic blocks, in a pervasively sheared, commonly pelitic matrix"). Marden (1977) considers that important factors partly responsible for erosion in the West Tamaki River catchment both in the past and at present, are the steepness, faulting and structure of the bedrock.

Cunningham and Stribling,(1977) attribute erosion scars in the Northern Ruahine Range to burning and grazing. They consider that past burning and grazing may have initiated sheet erosion, which in some cases, develops into "debris-falls". They consider most "debris-falls" in the Range have developed at the sites of previous avalanches or slides, which are closely associated with high intensity rainfalls and soils which for some periods approach saturation.

Mosley (1977) and Schumm (1977) consider that significant fluctuations occur in erosion rates naturally, so that erosion in the mountainland may not be accelerated by any one factor or combination of factors, but is part of a natural cyclical process. Schumm (1975) proposes that stream behaviour does not change progressively through geologic time, but rather, relatively brief periods of instability and incision are separated by longer periods of relative stability.

Thus, according to Schumm (1975, 1977) it is possible to envisage that the present increased erosion rates in the Ruahine Range are accounted for as a normal stage in the very complex denudational history of the landscape. However, this does little to aid our understanding of how best to deal with the problem on hand.

2.3.4 Future Control of Erosion

The main aim of any erosion control plan appears to be preservation of floodplains downstream of the Range, which are in danger of being covered with gravel during larger floods.

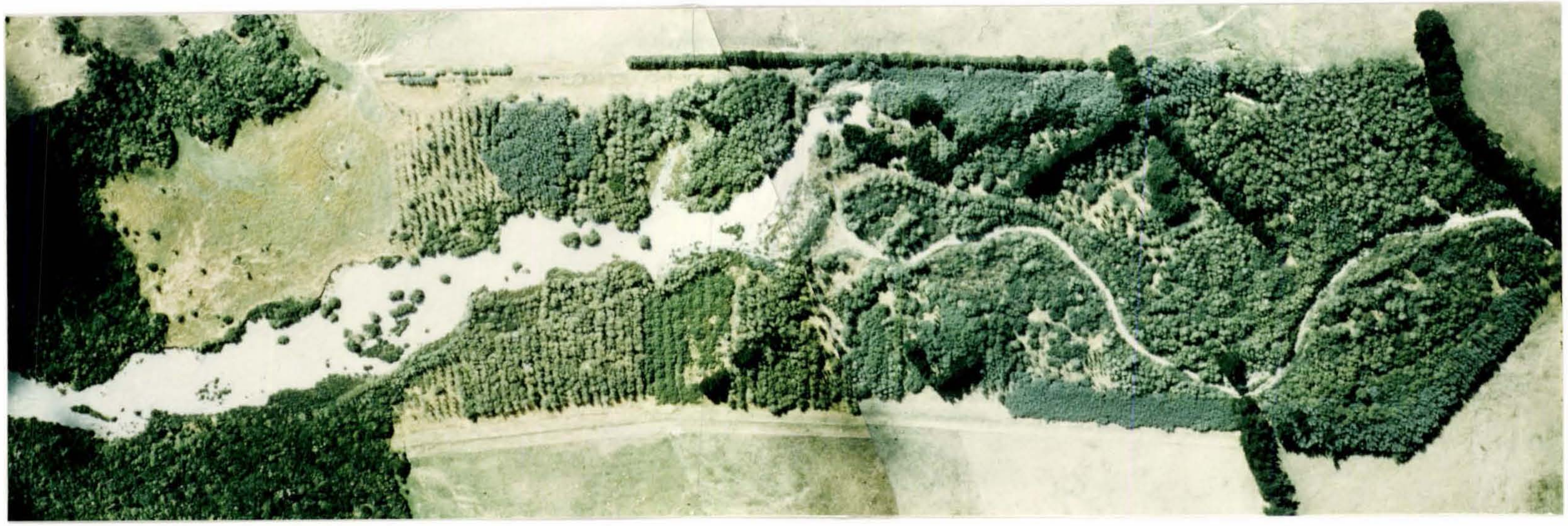
Two approaches to erosion control are discussed in the literature. Cunningham and Stribling,(1977) and Hathaway (1977) discuss animal control and revegetation schemes as a method of combating mountainland erosion. They emphasise the importance of controlling erosion in the steep mountainland area, and are referring to the TYPE 1 erosion of Schumm (1977), (see 2.3.1). Schumm considers that this type of erosion has always occurred to some extent, and is inevitable.

Indeed, Mosley and Blakely (1977) in discussing possible erosion control measures with respect to landsliding in Coppermine Creek, state that no management techniques are available that could have prevented the landslide, and to this extent support the concept of inevitability. Since landsliding the area has become more stable, and no action was deemed necessary by these authors to prevent further erosion at this site.

Blakely (1977), Mosley (1977) and Mosley and Blakely (1977) discuss erosion control in terms of the TYPE 2 erosion of Schumm, (1977) (see 2.3.1). This type of erosion, involving channel widening and remobilisation of gravels, has been enhanced by man's actions, so that a suitable management policy, aimed at restoring the situation to approximate its original state is considered to be the most desirable control method.

These workers suggest that sediment transport rates have been accelerated by deforestation of the former, natural deposition areas, at the foot of the Range, where the valleys broaden and become less steep (the valley "throats" of Mosley, 1977). Mosley and Blakely, (1977) consider that the most obvious course of action is:

FIGURE 1: KUMETI GRAVEL RESERVE



The reserve acts as a constricted natural fan area. It has been operative since the 1950's, when an area of about 20ha was planted in willows, poplars and pines. Previously, this natural deposition area had been deforested. This resulted in the scouring of materials further upstream with accelerated sediment transport rates.

Photo: D.G.Bowler

> "to enhance the natural tendency of the streams to store soil and rock eroded from the valley-sides in the valley bottom, by judicious use of structural and vegetative techniques".

This work should concentrate at valley "throat" areas. An example of a successful constricted natural fan area is Kumeti Gravel Reserve, discussed by Blakely (1977), and shown in Fig. 1.

These workers agree that the magnitude of river control work required at the foot of the Range can only be modified by animal control work, and maintenance of a good vegetative cover in the mountainland.

2.4 SOILS OF THE SOUTHERN RUAHINE RANGE

There is a paucity of information on the mountain soils of the Ruahine Range and Cunningham and Stribling (1977) have previously reviewed literature on this topic.

Pohlen et al. (1947) adopted a Ruahine series to describe soils of the Range, south of the Ngaruroro River. They mapped eroded complexes, where the eroded area exceeded 10% of the total area: i.e. a moderately eroded phase where eroded area is 10-30% of the total area, and a severely eroded phase, where eroded area is >30% of the total area.

They also describe a Ruahine light silt loam, with a characteristic light texture and high erodibility, which occurs in patches at the foot of the Range, between the Ngaruroro and Waipawa rivers. The different properties of this soil are attributed to a change in vegetation. However it seems likely that its "lightness" may be explained by a greater contamination of tephras from the central North Island.

In the General Survey of the soils of North Island, the mountain soils of the Southern Ruahine Range were mapped as the Ruahine stony silt loam soil set (N.Z. Soil Bureau, 1954). In 1968, they were referred to as

Ruahine-Rimutaka soils (N.Z. Soil Bureau, 1968), and classified as "related steepland soils to central yellow-brown earths". They are described as shallow, with colour B horizons (Bw using horizon designations of FAO/UNESCO, 1974) forming over weathering greywacke bedrock, with some volcanic ash contamination. At lower elevations, at the foot of the mountainland, yellow-brown earth - yellow-brown loam intergrade soils are mapped, e.g. Kopua and Dannevirke soils. On the western and southern slopes of the Range weakly clay illuvial central yellow-brown earths are mapped.

Pang (1969) describing the soils in the Woodville district, uses lithology of parent material and topography as a basis for soil mapping units. He notes that widespread occurrence of loess is a dominant feature, and considers that it is an indicator of largely stable sites; at least since the Last Stadial. Loess occurs on ridge crests and land of slopes less than 20°. In these areas he mapped the soils as Ruahine hill soils, which are considered to be less erosion-prone than the shallow and stony Ruahine steepland soils which occur on steep to very steep slopes. In naming the hill soils after their steepland counterparts, Pang infers that they are more closely related to the steepland soils than the soils of the rolling land (see Taylor and Pohlen, 1970, p.142).

Rijkse has mapped the soils of Woodville County (1974) and Pohangina County (1977) at a scale of 1:63,360, details of which are given in Table 2. He considers that with increasing elevation the soils become more leached and show the initiation of podzolisation. Thus, the Renata and Rimutaka soils are distinguished from the Ramiha and Ruahine soils on the basis of movement and segregation of iron, forming mottles and discontinuous iron pans within the profile. The Takapari peaty loam, and associated hill soils are mapped at the highest elevations, with the hill soils recorded as having only slight risk of slip erosion (see Table 2).

Mosley (1977) presents the most recent soil map for the south-eastern Ruahine Range at a scale of 1:63,360, which has been compiled by G.J. Smith.

TABLE 2: SOILS OF THE MOUNTAIN RANGE, IN POHANGINA COUNTY (RIJKSE, 1977)

SOIL NAME	SOIL SYMBOL	PARENT MATERIAL	RAINFALL (approx. mm)	DRAINAGE	ELEVATION RANGE (m)	SOIL DEPTH (cm)	EROSION POTENTIAL
Ramiha Silt Loam	Rm	loess on greywacke	1500-1800	well drained	300-500	40	-
Ramiha Hill Soils	RmH	loess and greywacke	"	" "	300-600	58	moderate scree and slip erosion
Ruahine Steepland Soils " " " Very Steep Phase	RuS RuVS	greywacke	"	" "	300-1100	30	severe slip and scree erosion
Renata Silt Loam	Rn	loess	1800-2300	moderately well drained	600-900	80	-
Renata Hill Soils	RnH	greywacke and loess	"	moderately well drained	"	30	moderate slip and scree erosion
Rimutaka Steepland Soils " " " Very Steep Phase	RkS RkVS	greywacke	"	well drained	600-1720	10	severe scree and slip erosion
Takapari Peaty Loam	Tp	peat and greywacke	>2300	poorly drained	1250-1300	70	-
Takapari Hill Soils	TpH	greywacke and peat	"	" "	1070-1370	46	slight slip erosion

Steepland soils are mapped in areas where most slopes are greater than 30°, and are subdivided on the basis of parent rock and climate. The mapping units of Rijkse (1974) have been adopted in this survey.

The soils on the floodplains, at the foot of the Range have a high potential for pastoral use; whereas the steepland soils have severe to very severe soil limitations for pastoral use. Such soils are best suited to protection forestry, (Rijkse, 1977).

2.5 SOIL PARAMETERS, RELEVANT TO EROSION STUDIES

2.5.1 Erosion Processes

The natural process of erosion comprises (1) weathering and (2) transporation of materials by water, gravity, ice and wind, (Ward, 1975). Transportation by water and gravity are considered to be of major importance to erosion studies in the Ruahine Range; although some erosion by ice and wind undoubtedly occurs, especially in the northern part of the Range.

All weathering processes require water (Leopald, Wolman and Miller, 1964) and involve the breaking down of rocks into small fragments, forming the parent material for subsequent soil development. Further weathering occurs within the solum, which is primarily chemical weathering of the primary minerals to produce secondary minerals. The weathering stage of erosion will be discussed more fully in the soil mineralogy section of this chapter.

Subsequent to weathering, transporation of materials occurs by mass movement of rock and/or soil and ultimately via the river channel. In this way, natural erosion processes occur within a catchment, sculpturing the landscape. In cases where increased or accelerated erosion occurs, the land-surface becomes degraded and soil is lost.

A number of workers have stressed the importance of the soil factor to erosion processes in a catchment area, together with climatic, topographic and vegetational factors (e.g. Meeuwig, 1971; Baver, Gardner and Gardner, 1972; Ward, 1975). Erosion processes with water as the primary eroding agent are affected by soil-water characteristics. Erosion processes with gravity as the primary eroding agent are affected by soil mechanical properties.

2.5.2 Soil Mineralogy

The initial stage in any erosion process is weathering. Weathering occurs, in situ, when physical, chemical and biological agencies break down the rock surface, contributing particles to the primary mineral assemblage of soils. Thus, in the case of a greywacke bedrock, quartz and feldspar are contributed to the mineral assemblage, together with minor amounts of mica and other accessory minerals. In steepland terrain, movement of materials downslope introduces materials from upslope, depositing colluvial materials at the base of a slope. Alternatively, material may be introduced aerially as (1) loess, from the surrounding bedrock, or (2) volcanic ash. Thus, the primary mineral assemblage, which may be investigated by viewing the sand mineralogy with an optical microscope, defines the nature of the parent material and indicates the extent of additions from other sources.

Study of the sand mineralogy also yields information on the proportions of major mineral constituents which provide evidence of the extent of weathering of both parent materials and soil. Thus, if the proportions of feldspars in the sand fraction of the soil is distinctly less than in the parent rock, it is probable that they have been chemically weathered.

The sand fraction is further weathered and comminuted to silt and then clay-sized particles. The soil clay mineralogy may thus be studied in conjunction with the sand mineralogy to investigate weathering processes within the soil. Argillation, the formation of clay minerals, is described by Keller (in Rich and Kunze, 1964) as a group of multiple interrelated processes, such as (a) solid state conversion-solution transition processes and (b) reaction with ground water, e.g. by hydrolysis, hydration, oxidation or chelation.

Quartz grains weather principally by solution, although the sand-sized grains are one of the most resistant minerals to weathering. Fieldes and Weatherhead (1966) indicate that for New Zealand soils, the 'sand fraction minus quartz', expressed as a percentage of the whole soil is regarded as the percent of weatherable minerals in the soil.

The heterogeneity of feldspar grains has a marked effect on their decomposition (Wilson, 1975). Their decomposition in the pedogenic environment is not fully understood, although it seems likely that in the initial hydrolysis stage continuous dissolution occurs, which is preferential at certain weak spots in the crystal lattice, producing etching of the grain (Wilson, 1975). Further weathering involves the formation of clay minerals such as illite (mica with intermixed expanded layers, Mehra and Jackson, 1959), and may proceed via an intermediate amorphous product (Parham, 1969). Vermiculite and montmorillorite also form either directly from feldspar or from associated mica (Wilson, 1975). The mica-vermiculite transformation is complex probably involving loss of potassium, accompanied by oxidation, substitution of hydroxyl for oxygen, and loss of octahedral iron and magnesium. Wilson (1975) suggests that mica-derived dioctahedral vermiculite is quite common in soil clays.

Pedogenic chlorite forms in soils, when interlayering of $Al-OH_2$ groups in the expandable vermiculite is complete (Bear, 1969). Under more extreme weathering conditions, mica (both biotite and muscovite) may convert to kaolinite, which may be formed directly, without a preceding sequence of mineralogical changes involving vermiculitization, (Wilson, 1975).

Rhyolitic and andesitic tephras weather to allophane, the former much less rapidly than the latter, and ultimately to halloysite (Kirkman, 1977a).

Differences in rate of formation and subsequent alteration of allophane in the two types of tephra is 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, 1977a).

The nature of clay minerals present in a soil influence the soil drainage, compressibility and reaction to changes in moisture (Sowers and Sowers, 1970), and therefore, have an indirect effect on slope stability studies. The presence of swelling clays in a soil is of particular relevance, as hydration, causing swelling, may produce a lateral pressure within the soil, increasing its shear stress, and susceptibility to movement downslope.

An allophane-rich clay-organic layer at a regolith-sandstone interface has been reported as one of the principal causes of instability on slopes in North Westland, New Zealand, (O'Loughlin and Pearce, 1976). Wells and Furkert (1972) also refer to the shearing tendency of allophane under increasing pressure. The amorphous structure of allophane results in a large and varying capacity for water retention. The possible effects of allophane on physical and chemical behaviour of soils deserves much closer attention (Furkert and Fieldes, 1968), however, there is little literature available on this subject.

2.5.3 Soil-Water Characteristics

Water erosion of soil is affected by the soil properties that control the rate with which rainfall enters the surface. These include (i) macroporosity of the soil surface,(ii) moisture content of the soil at the time of the rain, (iii) permeability and (iv) the resistance of the soil surface to dispersion and subsequent erosion during rainfall and runoff, i.e. the structural condition of the soil surface, and soil cohesion (which becomes very small as the soil becomes saturated). Soil erosion by water involves raindrop splash and surface runoff, which is manifested in sheet, rill and ultimately gully erosion, (Baver, Gardner and Gardner, 1972).

This traditional approach to soil erosion studies is explained by Horton's runoff model, which interprets surface runoff in terms of the infiltration theory. Horton (1933) considered that the infiltration capacity of soils in a catchment will decrease exponentially during a prolonged storm of constant intensity. He attributes this to factors operating at the soil surface such as compaction, structural change, and inwashing of fine particles. Eventually the infiltration capacity will decrease to a value below rainfall intensity, and at this point surface runoff (or overland flow) begins to occur, causing erosion of the surface layer of soil.

In recent years, with a greater amount of information available, workers have supported the Hewlett runoff model. This model, as described by Ward (1975), assumes that infiltration is seldom a limiting factor, and much of the water infiltrates into the soil, and moves through the soil as interflow. In this case, interflow may make a substantial contribution to storm runoff.

Thus in erosion studies it is important to consider movement of water laterally through the soil, as well as over its surface. Ward (1975) considers that the soil factors favouring interflow are:

1) when lateral hydraulic conductivity in the surface soil horizon is substantially greater than the overall vertical hydraulic conductivity, through the soil profile.
2) when a thin permeable soil overlies impermeable bedrock, with a markedly stratified soil profile e.g. a marked difference in horizon textures or extent of cementation.
3) where an iron pan occurs a short distance below the surface,
4) the presence of old root holes and animal burrows, and other subsurface pipes.

Observations in the Torlesse Range, South Island, New Zealand, by Hayward (1976) show that surface runoff seldom occurs, even after an intense rainfall of 165mm in 36 hours. The intensity of a one-year storm in the Ruahine Range, estimated for the West Tamaki River catchment is 60mm in 24 hours (Martin, pers. comm) considerably less than the intensity considered by Hayward. Thus it is unlikely that major surface runoff occurs in the Ruahine Range, unless there is some other limiting factor such as a compacted soil surface.

Debris avalanches occur on steep slopes when a mass of soil and rock begins to flow. Jackson (1966) comments on the occurrence of debris avalanches on forested slopes in Fiordland, New Zealand; and considers that movement is caused by a gradual increase in stress as the mass of forest anchored on the steep slope increases, in combination with climatic abnormalities such as heavy rainfalls, when interflow probably occurs. The soil properties: water acceptance and retention, soil structure and fissure formation are considered to be related to these erosion processes.

Loss of soil from high elevation rangeland in the intermontane region of south-western U.S.A. has been studied using multiple regression analyses, (Meeuwig, 1971). It was found that amount of cover and slope gradient were most closely related to erosion. Important soil parameters affecting erodibility were found to be: organic matter, antecedent moisture content of the surface soil, bulk density and capillary porosity.

The literature therefore indicates the importance of soil-water characteristics in erosion studies. The inter-relationship of water and gravity as agents initiating erosion processes is also of prime importance, and has been noted by many workers (e.g. Terzaghi, 1950; Jackson, 1966; O'Loughlin, 1974; Ward, 1975). Investigation of gravity, as an eroding agent, involves slope stability studies and measurement of certain soil mechanical properties (e.g. shear strength, stress and cohesion), which are discussed in the ensuing section.

2.5.4 Slope Stability Studies

Gravity is the primary operative force in mass movement of soil and rock on slopes. Mass movement occurs when the shear strength of a body of material is exceeded by its shear stress, over a relatively continuous surface, (Sowers and Sowers, 1970). Parameters contributing to change in soil shear strength or stress are listed by Sowers and Sowers (1970) and further detailed by Selby (1970), (see Table 3).

Slope stability studies have shown the importance of: (1) soil-water conditions, and (2) tree root depth and distribution, to stability of soil materials on a slope, (O'Loughlin, 1974; O'Loughlin and Pearce, 1976). These workers adopt the Infinite-Slope Model to examine movement-promoting and movement-resisting forces, operating on a steep slope. This model uses Coulomb's Law to describe a soil's shear strength, or resistance to failure as:

$$\underline{S = C + \tan \phi \, P}$$

where S = shear strength

C = cohesion

P = effective pressure normal to the shear plane

tan ϕ = coefficient of friction,

where ϕ is the angle of friction.

O'Loughlin (1974) applied the Infinite-Slope Model to data collected from a steep, clearfelled slope in southwest British Columbia, Canada, and concludes that:

(1) the main causative factor in landsliding is deterioration of the tree root system,

and (2) pore water pressures are of importance to soil stability and any changes inducing saturation of steep slopes should be avoided.

TABLE 3: FACTORS CONTRIBUTING TO MASS MOVEMENT IN SOILS

A. FACTORS CONTRIBUTING TO HIGH SHEAR STRESS

Types	Major Mechanisms
1. Removal of lateral support	i. Stream or water erosion. ii. Subaerial weathering, wetting, drying, and frost action. iii. Slope steepness increased by mass movement. iv. Manmade quarries and pits.
2. Overloading by	i. Weight of rain, snow, talus. ii. Fills, wastepiles, structures
3. Transitory stresses	i. Earthquakes ii. Manmade vibrations.
4. Removal of underlying support	i. Undercutting by running water. ii. Subaerial weathering, wetting, drying and frost action. iii. Subterranean erosion (eluviation of fines or solution of salts). iv. Mining activities.
5. Lateral pressure	i. Water in interstices. ii. Freezing of water. iii. Swelling by hydration of clay.

B. FACTORS CONBRIBUTING TO LOW SHEAR STRENGTH

Types	Major Mechanisms
1. Composition and texture	i. Weak materials such as volcanic tuff and sedimentary clays ii. Loosely packed materials. iii. Smooth grain shape.
2. Physico-chemical reactions	i. Cation (base) exchange, ii. Hydration of clay, iii. Drying of clays.
3. Effects of porewater	i. Buoyancy effects. ii. Reduction of capilliary tension. iii. Viscous drag of moving water on soil grains.
4. Changes in structure	i. Spontaneous liquefaction.

(Selby, 1970)

Application of the Infinite-Slope Model to a study area, although simplifying the real situation, provides an invaluable method of slope stability analysis.

Measurement of soil moisture tensions or pore pressures (which directly influence soil cohesion, and are thus related to shear strength of a soil, as shown by Coulomb's Law) during rainstorms has been used as an estimate of slope stability in New Zealand situations by Jackson (1966). Jackson considers that slope instability may be of a cyclical nature with a cycle of slipping, weathering and soil development followed by renewed slipping, thus supporting the idea that the period of increased erosion seen in the Southern Ruahine Range, at present, is part of a natural cyclical process.

2.6 SUMMARY

The literature indicates that the erosion problem in the Southern Ruahine Range is one of high erosion rates in the mountainland; with the threat of flooding of fertile plains, by the erosion products - gravel and other debris, which choke river beds downstream.

Concern has been shown by a number of government agencies in recent years to a generally accepted belief that erosion rates have increased since the 1930's.

Erosion rates in the Ruahine Range have varied markedly with geological time. During the Upper Pleistocene, they were considerably higher than they are today. At this time, besides periods of cold climate episodes (glacials) alternating with warmer episodes (interglacials), the Range was also subjected to uplift as the Kaikoura Orogeny approached its climax. Post-glacial erosion rates have probably been smaller; however important vegetational changes over the last few thousand years, (Elder, 1965) suggest that smaller climatic changes have occurred.

Today, causes of erosion in the Ruahine Range are reported to be many and varied. The majority of mass movements seem to occur from a number of causes existing simultaneously. The final cause is a "trigger", setting in motion a hillside already highly susceptible to erosion. The Ruahine Range is inherently unstable due in part to steepness, faulting and the nature of bedrock lithologies, (Marden, 1977).

Few soil surveys have been conducted in the Southern Ruahine Range. A number of workers have emphasized the widespread occurrence of loess overlying the basement greywacke at lower elevations (e.g. Pang, 1969). Rijkse (1977), in mapping the soils of Pohangina County,has provided the most comprehensive study to date. Cunningham and Stribling (1977) indicate that the soils are a key factor in erosion studies of the Ruahine Range. A number of soil parameters appear to be of importance to erosion potential in the mountainland. The soil acts as a medium which accepts and stores rainfall; and supplies it to the river channel. The rate of acceptance, throughflow and storage capacity are important factors to be considered.

Slope stability may be critically evaluated using the Infinite-Slope Model, (O'Loughlin, 1974). This enables an estimate to be made of

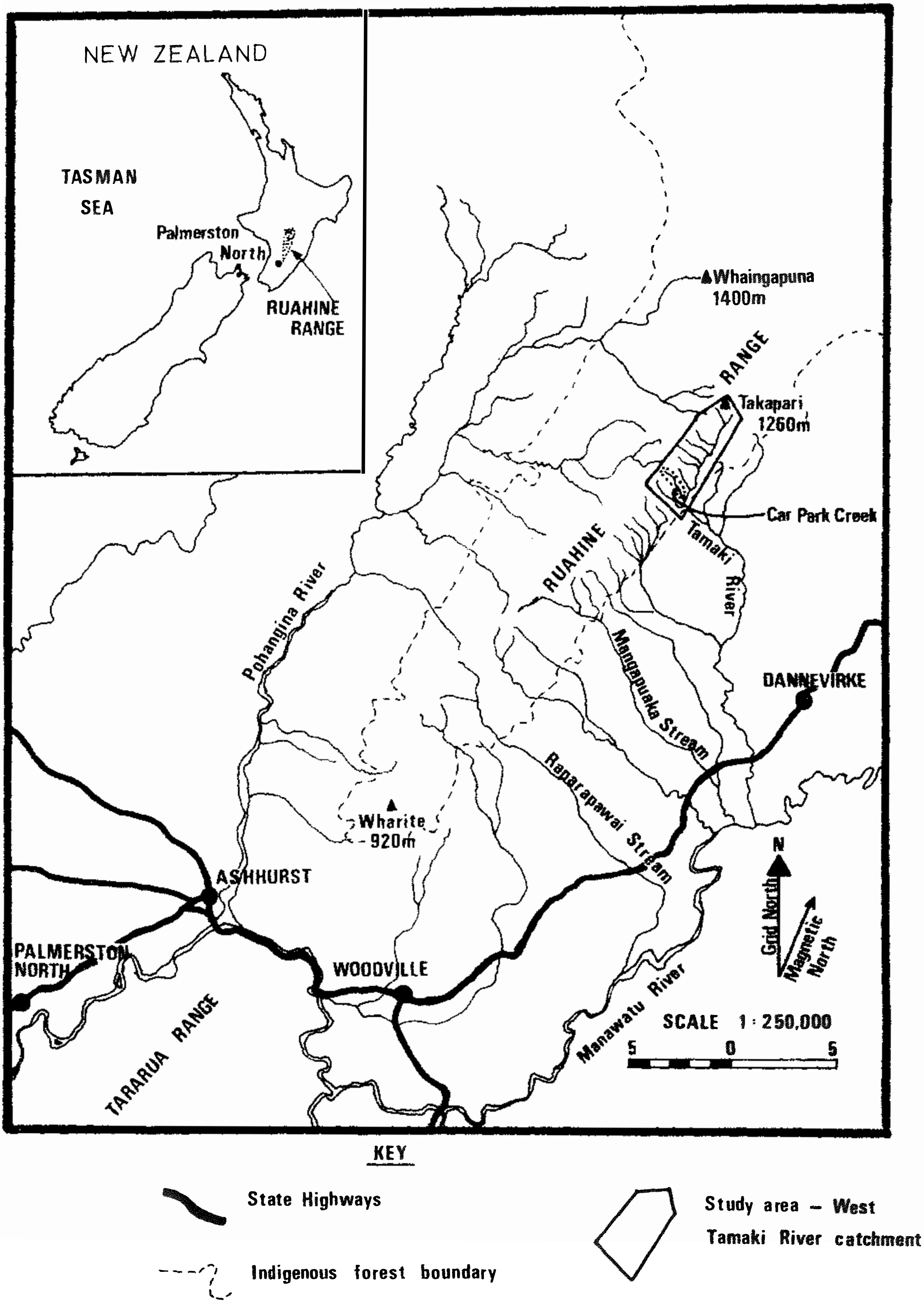
(1) susceptibility of slope material to movement,

and (2) the relevance of certain factors to stability, e.g. root distribution and soil saturation.

CHAPTER THREE

DESCRIPTION OF THE STUDY AREA

FIGURE 2: LOCALITY MAP OF STUDY AREA.



CHAPTER THREE

DESCRIPTION OF THE STUDY AREA

3.1 LOCATION

Fieldwork was conducted in the West Tamaki River catchment 13km northwest of Dannevirke, on the eastern flank of the Southern Ruahine Range, (see Fig. 2). The river extends 5km along the foot of the mountainland, in a N.N.E-S.S.W. direction. A detailed soil survey was carried out in one of the principal tributaries, Car Park Creek, which is approximately 650 metres upstream of the valley throat where a gravel control weir is located.

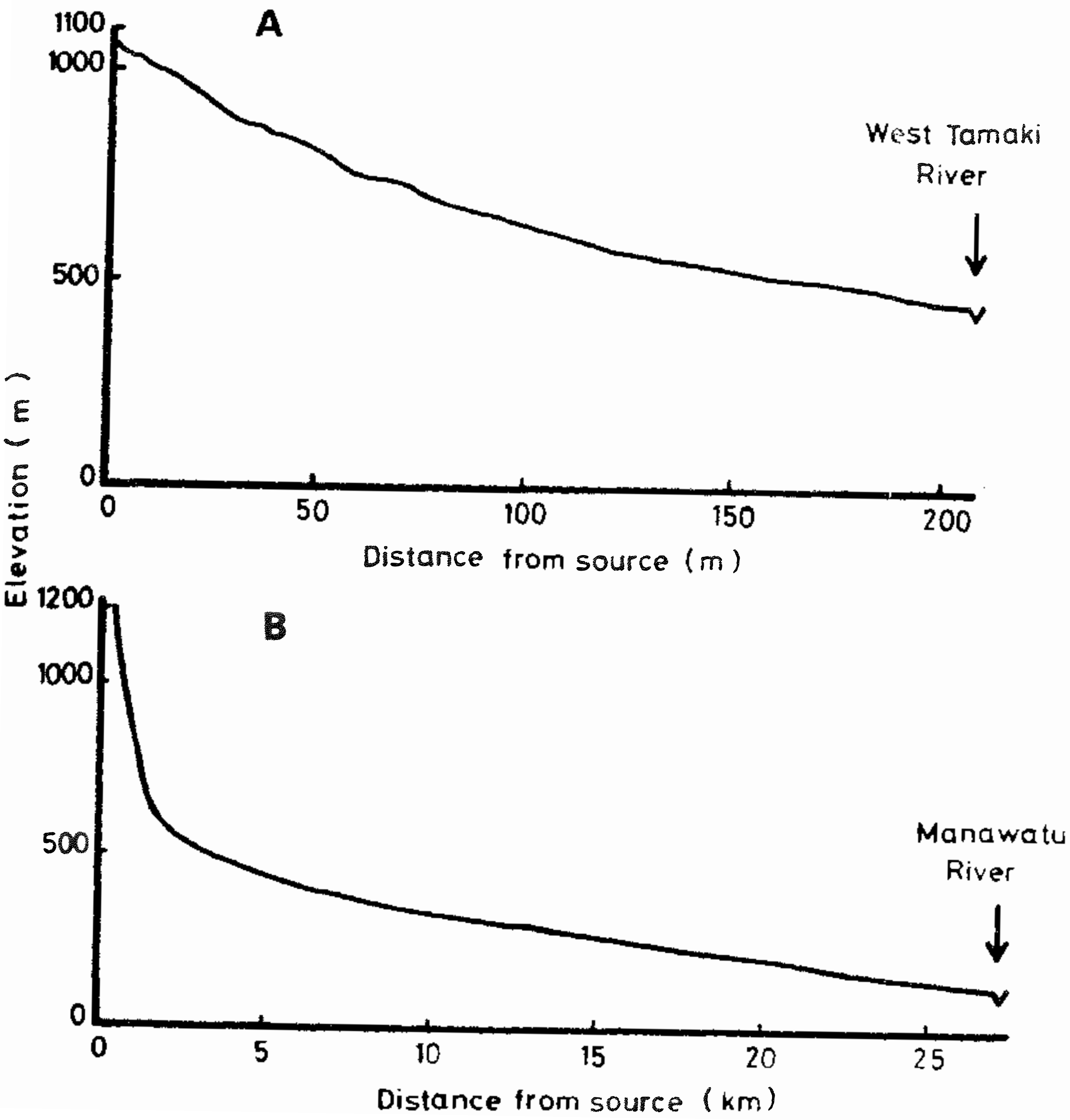
3.2 PHYSIOGRAPHY

Southern Ruahine Range

The Southern Ruahine Range is characterised by a steep eastern front, formed by uplift of this part of the Range along the western side of the Mohaka Fault. The summit plateau, which extends southwards as far as Mangapuaka Stream, is a remnant erosion surface, tilted to the west, (see 2.2.1). The western side of the Range slopes away less steeply, from this surface. The Southern Ruahine Range rises northwards from 914m at Wharite Peak in the south, to 1392m at Takapari, at the head of the West Tamaki River catchment and highest point in this part of the Range.

A number of rivers drain the eastern side of the Range. These characteristically have steep to very steep valley-sides, for example, the mean slope angle of valley-sides in the Raparapawai Stream is 30°, (Stephens, 1975). The longitudinalprofiles of these rivers, from their head to the Manawatu River is smoothly concave, on a large scale, (Mosley, 1977; see Fig. 3b). It is this form of profile which is associated with streams in equilibrium with their geologic and hydrologic environment, so that on a

FIGURE 3: LONGITUDINAL PROFILES OF: (A) CAR PARK CREEK; (B) WEST TAMAKI RIVER (from MOSLEY, 1977). (vertical exaggeration approximately X10)



broad scale the rivers have adjusted to carry their load.

West Tamaki River catchment

The course of the West Tamaki River runs parallel to the steep eastern front of the Range; with Holmes Ridge rising steeply on its east side, to a height of approximately 650m. Within its catchment, it is deeply incised; with eleven major subcatchments draining into it, from the west and north. These subcatchments are steep to very steep-sided. The slope of the valley-sides in Car Park Creek subcatchment is commonly between 30° and 45°. A longitudinal profile of Car Park Creek can be compared with that of the West Tamaki River (see Fig. 3). Its broad pattern is seen to be less obviously concave, indicating that the channel is not so well adjusted within its catchment. Slight humps in the curve indicate the presence of gravel waves.

The geomorphological units present in Car Park Creek seem representative of the subcatchments of the West Tamaki River catchment. Fig. 4 exemplifies a valley-side in the catchment to which the nine-unit landsurface model (NULM) of Conacher and Dalrymple (1977) has been applied (see Table 4). Specific examples from Car Park Creek are illustrated in Figs. 5 and 6.

In Fig. 5, unit 1 is the interfluve and of limited extent. Unit 2 is the seepage slope, characterised by a small angle of slope; whilst the convex creep slope (unit 3) occurs below it on slopes of up to 45°. This unit is defined as one in which soil creep predominates and terracettes occur. Large scale deep terracettes have been noted on unit 3 in Car Park Creek, which in places extend for about 100m across the hillslope (see Fig. 7), suggesting that active soil creep, together with creep of colluvial materials below the solum , is associated with this landsurface unit.
The fall-face, unit 4, is characterised by exposed rock, and is defined by "the response to the processes of fall and rockslide, with pressure release an important underlying process". Fig. 5 shows this unit in the sub-

FIGURE 4: An Idealised Diagram of the Landsurface Units Which Occur on a Valley-side in the West Tamaki River Catchment.

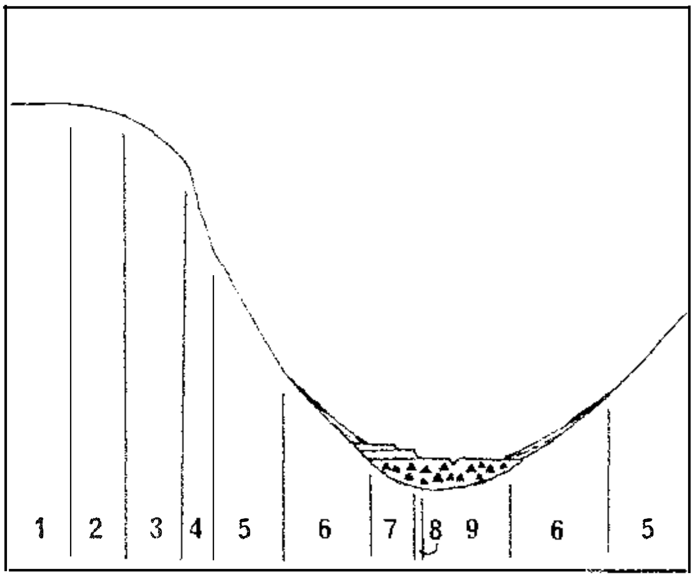


TABLE 4 CLASSIFICATION OF LANDSURFACE UNITS, ACCORDING TO THE NINE UNIT LANDSCAPE MODEL, OF CONACHER AND DALRYMPLE (1977)

LANDSURFACE UNIT NUMBER	LANDSURFACE UNIT NAME	DISTINGUISHING CRITERIA, RELEVANT TO THE PRESENT STUDY
1	Interfluve	soil development in situ, modal slope 0-1°
2	Seepage Slope	gleying above Fe pans; lateral subsurface soil water movement
3	Convex creep slope	soil creep; terracette formation; processes resulting from subsurface soil water movement
4	Fall face	soil formation restricted to lithosols (Entisols), fall and sliding features; slopes>45°
5	Transportational midslope	contrasting areas of deep and shallow soils, in an area of mass movements
6	Colluvial foot-slope	heterogeneous soil mantle containing additions from upslope; possible occurrence of paleosol horizons
7	Alluvial toe-slope	alluvial redeposition; frequent occurrence of paleosol horizons
8	Channel wall	intermittent regosol (Entisol) formation; corrasion, slumping, fall
9	Channel bed	no soil formation; transportation of material downvalley by stream action; periodic aggradation and corrasion

catchment, with a rockslide (to the right of centre) and two smaller debris slides contributing to gully erosion (in the left of photo). Unit 5, the transportational midslope is characteristically very susceptible to erosion. Several erosion scars may be seen in this zone on Fig. 6. Below this unit, a colluvial footslope (unit 6) sometimes occurs (Fig. 6), where the dominant process is redeposition of colluvial material from upslope, although some material is undoubtedly transported across this unit. Unit 6 is characterised by deeper colluvial soils.

Figure 4 indicates that the alluvial toeslope (unit 7) is of limited extent within the West Tamaki River catchment, in which Car Park Creek is located. However, this unit may be seen in Fig. 6, on the floodplains at the foot of the Range. Unit 8, the channel wall occurs in the catchment, but only over short, discontinuous sections of the river channel where some downcutting occurs. Unit 8, together with units 7 and 9 (the channel bed) are most extensive on the adjacent lowland area as shown in Fig. 6.

In Car Park Creek, unit 9 is choked with gravel to depths of between 2.5-4.5m (Lewandowski, cited in Mosley, 1977), and probably to greater depths in certain localities, where gravel waves occur. This unit acts as a gravel storage zone, due to aggradation; with intermittent transportation of material downstream, during and after intense rainstorm events. In the case of Hut Creek, another subcatchment of the West Tamaki River (Fig. 8), a large amount of debris was supplied to the channel bed (unit 9) during Cyclone Alison (a 40 year storm event; R. Martin, pers. comm.). Although some material was undoubtedly transported further downstream, the large bulk of the detritus accumulated in the channel bed with the net result of aggradation. Since March, 1975, when the Cyclone occurred, downcutting has taken place, so that today a channel wall (unit 8) is seen in this subcatchment.

The erosion processes in the West Tamaki River catchment determine the type and extent of landforms, which are adequately described by the N.U.L.M.

Fig. 5: Landsurface Units at the Head of Car Park Creek

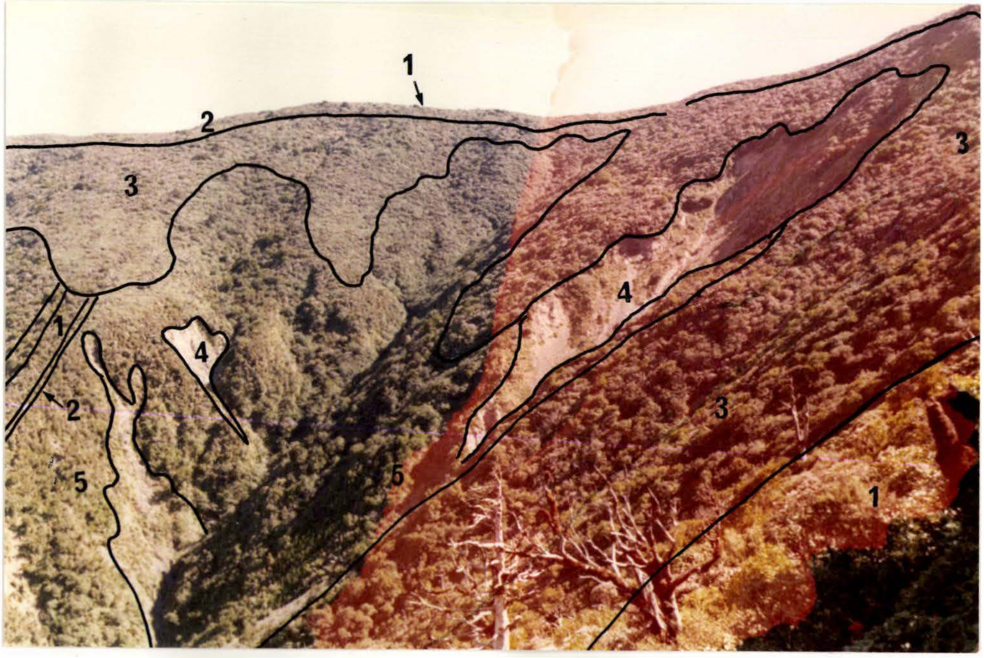


Fig. 6: Landsurface Units of a Valley-side in Car Park Creek

concept of Conacher and Dalrymple, (1977).

3.3 GEOLOGY

Southern Ruahine Range

The Ruahine Range has been described as a horst having faults, with vertical and dextral transcurrent movement, on both sides, (Kingma, 1959). The uplifted mass is intensely deformed and consists of indurated basement rocks of the Torlesse Supergroup, (Stevens, 1974).

The lithology of the eastern Ruahine Range consists of 3 tectonically concordant structural belts, trending north-east (Spörli and Bell, 1976). The three belts consist of coherent and disrupted sequences of greywacke (low grade metamorphosed sandstone) with argillite bands, cherts and spilites.

Mapping of the bedrock geology along the eastern front of the Southern Ruahine Range indicates 2 lithotypes, (Hubbard et al. 1978). The easternmost consists of massive alternating sequences of sandstone, siltstone and argillite; and the westernmost is an assortment of sedimentary and volcanic rocks, "floating" in a matrix of black argillaceous material.

Significant accumulations of greywacke loess occur in some localities, deposited during the periglacial conditions of the Upper Pleistocene (Milne, 1973b; Rhea, 1968). This loess contains tephric components in many cases.

Thus geologically, the Ruahines are a relatively young mountain range, with intense faulting and shattering of already folded strata. Their rate of uplift is rapid, being approximately 1.14mm per year for the west flank, over the last 0.8 million years, (Boellstorf and Te Punga, 1977). These effects on the landscape evolution of the Southern Ruahine Range are discussed in the Literature Review (2.2). They suggest that the geological situation in the Southern Ruahine Range today is one inherently prone to erosion.

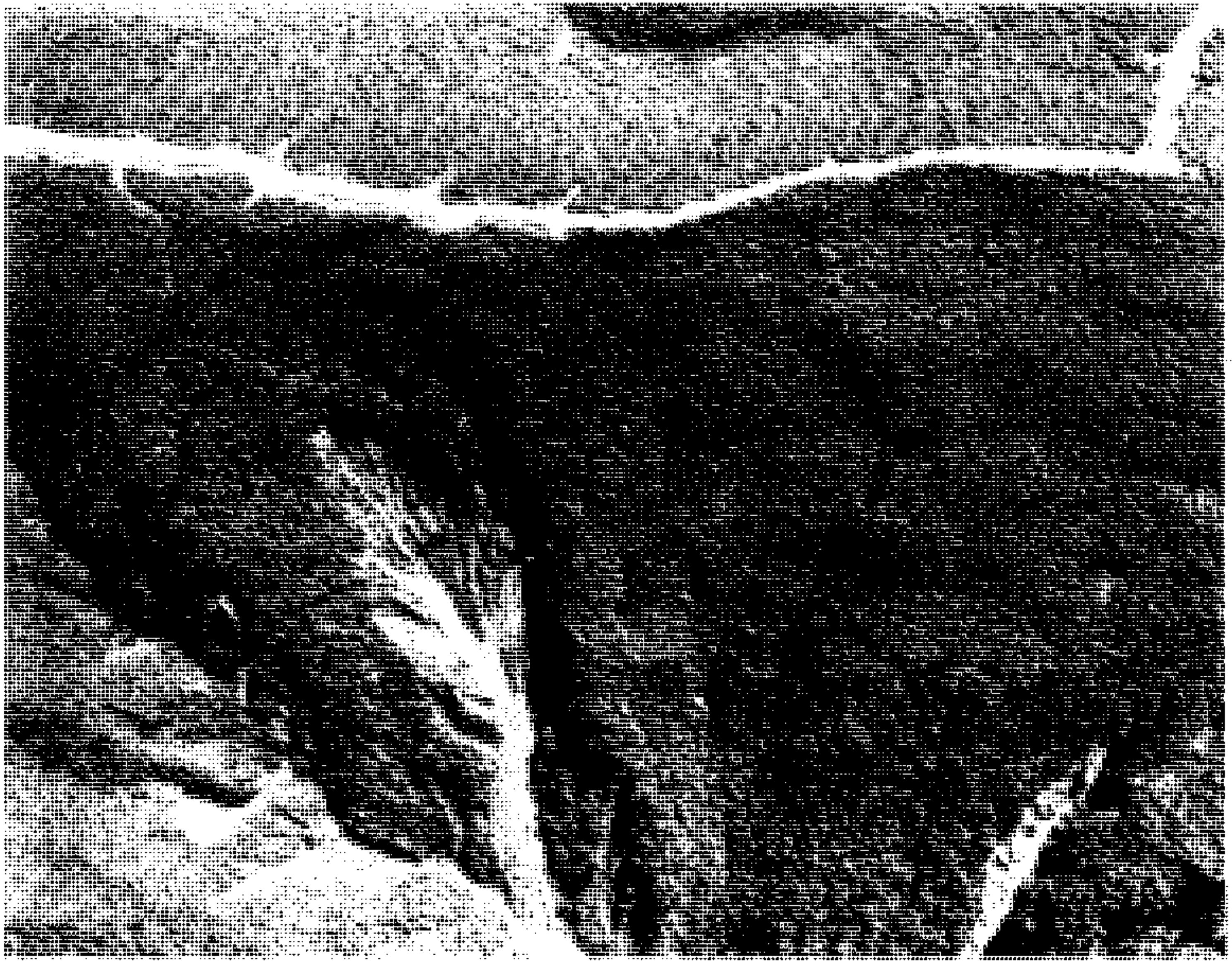


FIGURE 7: A ROCKSLIDE AND DEEP TERRACETTE FEATURES (dashed line) ON THE CONVEX CREEP SLOPE OF CAR PARK CREEK.

Photo: D.G.Bowler

West Tamaki River catchment

Within the West Tamaki River catchment, the main lithologies exposed are indurated sandstone, siltstone and argillite. No spilites, sedimentary conglomerates or microbreccias have been found, (Marden, 1977).

Structurally, the strata are steeply dipping and overturned to the west, with the bedrock strike parallel to the Range. The structure together with the fractured and faulted nature of the bedrock renders the greywacke lithotype prone to erosion (Hubbard et al. 1978).

A series of crush zones along the general line of the catchment provide evidence for a 1.5km wide Mohaka Fault zone, (Marden, 1977). At least 2 crush zones occur in Car Park Creek. Well preserved fault scarps in the West Tamaki River suggest that these faults have been active during the late Quaternary, (Marden, 1977).

3.4 SOILS

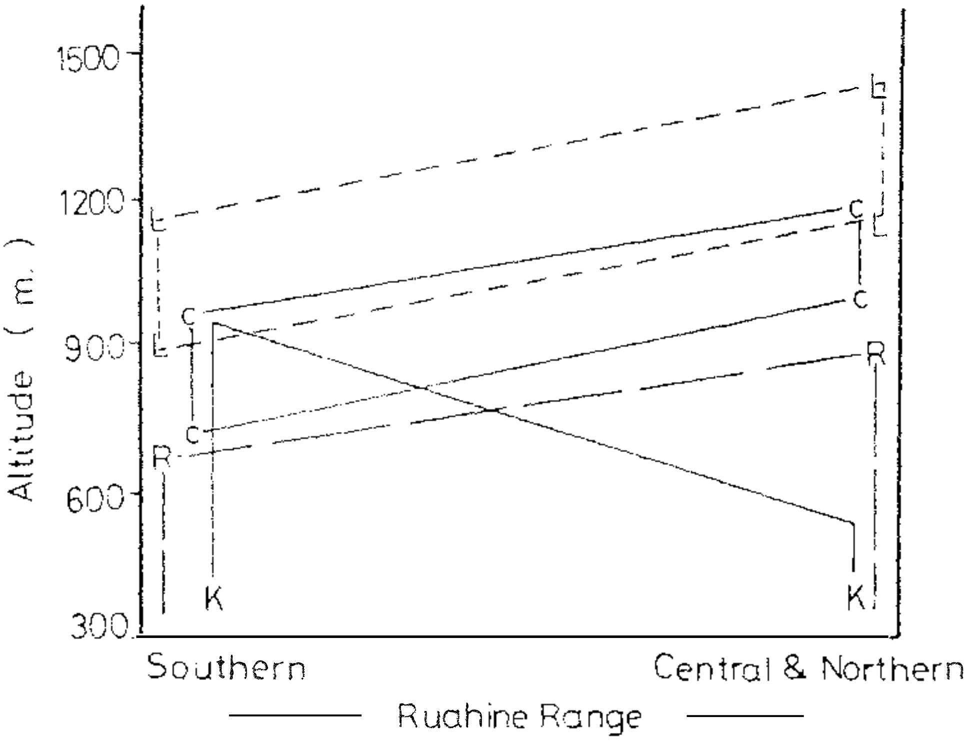
Southern Ruahine Range

Most previous soil surveys have described the soils of the Southern Ruahine Range at a reconnaissance survey level, with little investigation of soil variability within the broad steepland soil mapping units. Previous survey reports, which are detailed in the Literature Review (2.4), suggest that the soils pattern is largely related to parent materials, climate and age, in this area.

West Tamaki River catchment

The most detailed soil survey of this catchment has been produced by G.J. Smith (cited in Mosley, 1977), at a scale of 1: 63,360. This survey maps approximately 84% of the catchment as Ruahine steepland soils, with 12% mapped as Rimutaka steepland soils at higher elevations, and 4% mapped as Kopua stony silt loams at the mouth of the catchment. A pedological investigation of a selected subcatchment in the study area, carried out as part of the present study, is described in Chapter 5.

FIGURE 9: ALTITUDINAL DISTRIBUTION OF FOUR VEGETATIONAL SPECIES IN THE SOUTHERN RUAHINE RANGE, COMPARED WITH THEIR DISTRIBUTION FURTHER NORTH.



KEY

L- - - - -L	Leatherwood	(*Olearia colensoi*)
C———C	Cedar	(*Libocedrus bidwillii*)
R— —R	Rimu	(*Dacrydium cupressinum*)
K———K	Kamahi	(*Weinmannia racemosa*)

(adapted from Elder, 1965)

3.5 VEGETATION

Southern Ruahine Range

The vegetation of the Southern Ruahine Range occurs in three main altitudinal zones: i) podocarp-hardwood forest, ii) kamahi forest, and iii) leatherwood scrub, with vestiges of cedar forest and snowgrass tussock (Elder, 1965). A vegetation map, at a scale of 1: 250,000 also summarises the principal vegetation types of the Range (Nicholls, 1970).

Figure 9 shows that certain vegetation species show a definite drop in their upper limit in the Southern Ruahine Range by approximately 300m (i.e. rimu, cedar and Olearia colensoi) in comparison with the vegetation of the Range further north, (Elder, 1965). This suggests that conditions are more adverse in the south for the upper limit of plant growth in each zone. Reasons for this are most likely: 1) climatic stresses (see 3.6), and 2) unstable sites for adequate tree root establishment.

Thus, climatic and physiographic features of the Southern Ruahine Range may hinder the normal development of vegetational zones.

In recent years a deterioration in the forest stand has been noted by several workers (Cunningham and Stribling, 1977). Forest deterioration results in greater erosion susceptibility of the land surface, due to:

(1) less water intake and transpiration by plants, so that soil waterlogging is more likely, and

(2) decreased root distribution, which provides a significant decrease in slope stability (e.g. O'Loughlin, 1976).

Cunningham (1977) considers that the forest deterioration in the Southern Ruahine Range is primarily attributed to effects of introduced wildlife. Stephens (1975) considers that kamahi death is due largely to climatic changes, but Strand (1977) suggests that a number of factors are operative, and at present the widespread collapse that is visible is, perhaps, part of a normal cycle.

Fig. 8: Downcutting in Hut Creek, since Cyclone Alison, of March, 1975

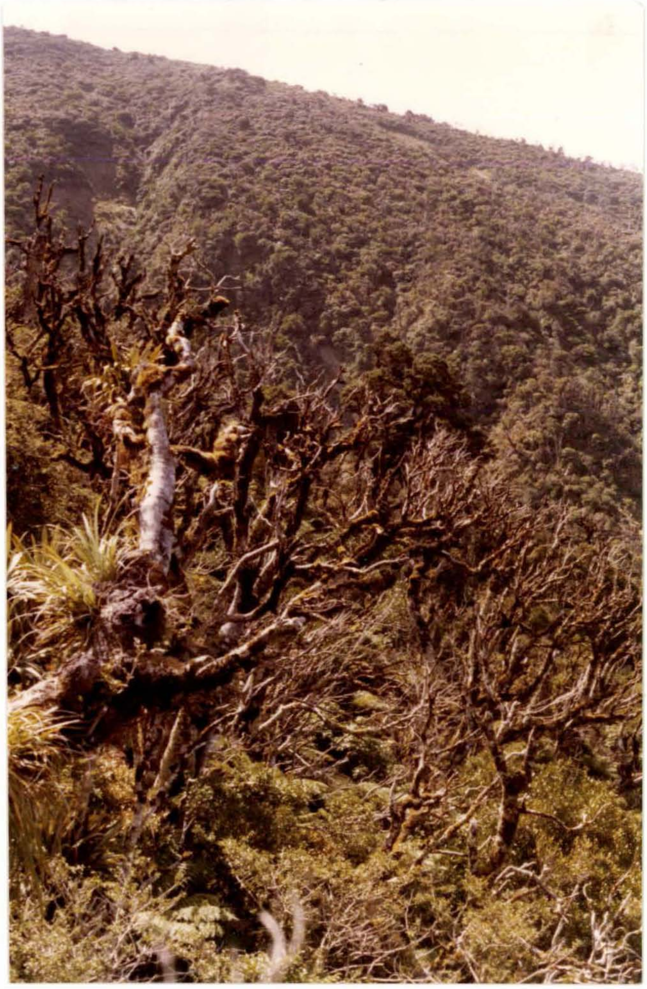


Fig. 10.
The Kamahi forest in Car Park Creek.
(note many dead kamahi trees in foreground)

West Tamaki River catchment

The broad altitudinal vegetation zones of the Range, all occur in this catchment. Strand (1977) has provided a comprehensive list of vegetational species occurring within the catchment. He notes that the lower podocarp-hardwood forest occurs at elevations up to approximately 600m altitude, although there is considerable overlap between the three broad zones.

In localities where a climax community exists, such as the podocarp-hardwood forest or kamahi forest, the vegetation is commonly in a state of degeneration (Fig. 10). However, the vegetation is at many sites controlled by erosion, and is in various seral stages of development (Fig. 11). Vegetation growth on the steep valley-sides is affected by adverse natural conditions of slope, soil depth and unstable strata, as shown in Fig. 12. This figure shows that where the slope angle decreases at the foot of the slope, there is a relatively dense vegetation growth. Here conditions are more stable, colluvium tends to accumulate and deeper soils are developed.

Natural colonisation of bare surfaces by native species is initially dominated by toetoe, rangiora, nettles, pepperwood and ferns. In 1969, the New Zealand Forest Service began a revegetation programme with exotic species, aimed at stabilising slip faces and consolidating banks and channel water courses. Colonisation of these sites, primarily by pines in the former case, and poplars and willows in the latter case, has been relatively successful.

3.6 CLIMATE

Southern Ruahine Range

The Ruahine mountainland experiences a cool climate and high annual rainfalls. Water is probably the most important single agent of erosion in this mountain range; the relationship between mass movement and heavy rainfalls in New Zealand being well established (e.g. Jackson, 1966; Grant, 1966). Water, therefore, plays an important role in soil erosion and fluvial erosion processes. Information on the distribution and

Fig. 11: Gully erosion in Car Park Creek (the vegetation is in a range of seral stages, being largely controlled by the erosion processes).

Fig. 12: Vegetation on a Slope in Car Park Creek (Note (i) the relatively dense vegetation at base of slope, where slope angle decreases, (ii) the presence of podocarps on the very steep slopes adjacent to an erosion surface, suggesting that stable sites do exist on this landsurface unit).

intensity of rainfall in the Range is consequently of much importance to erosion studies.

The Ruahine Range receives intense rainstorms at times, predominantly from the south or south-east, probably affecting the southern part of the range most of all. Other climatic stresses on the vegetation of the Southern Ruahine Range include:

i) Wind - Wharite Peak is one of the windiest places in New Zealand, recording exceptionally high wind speeds;

ii) cloud cover - sun-days in the southern part of the range are approximately 30% less than in the northern part, and 20% less than in the central part of the range;

iii) drought.

iv) heavy snows,

v) low humidities, and;

vi) freeze-thaw processes.

The latter four factors probably only have a minor effect on erosion in the Southern Ruahine Range, in most years.

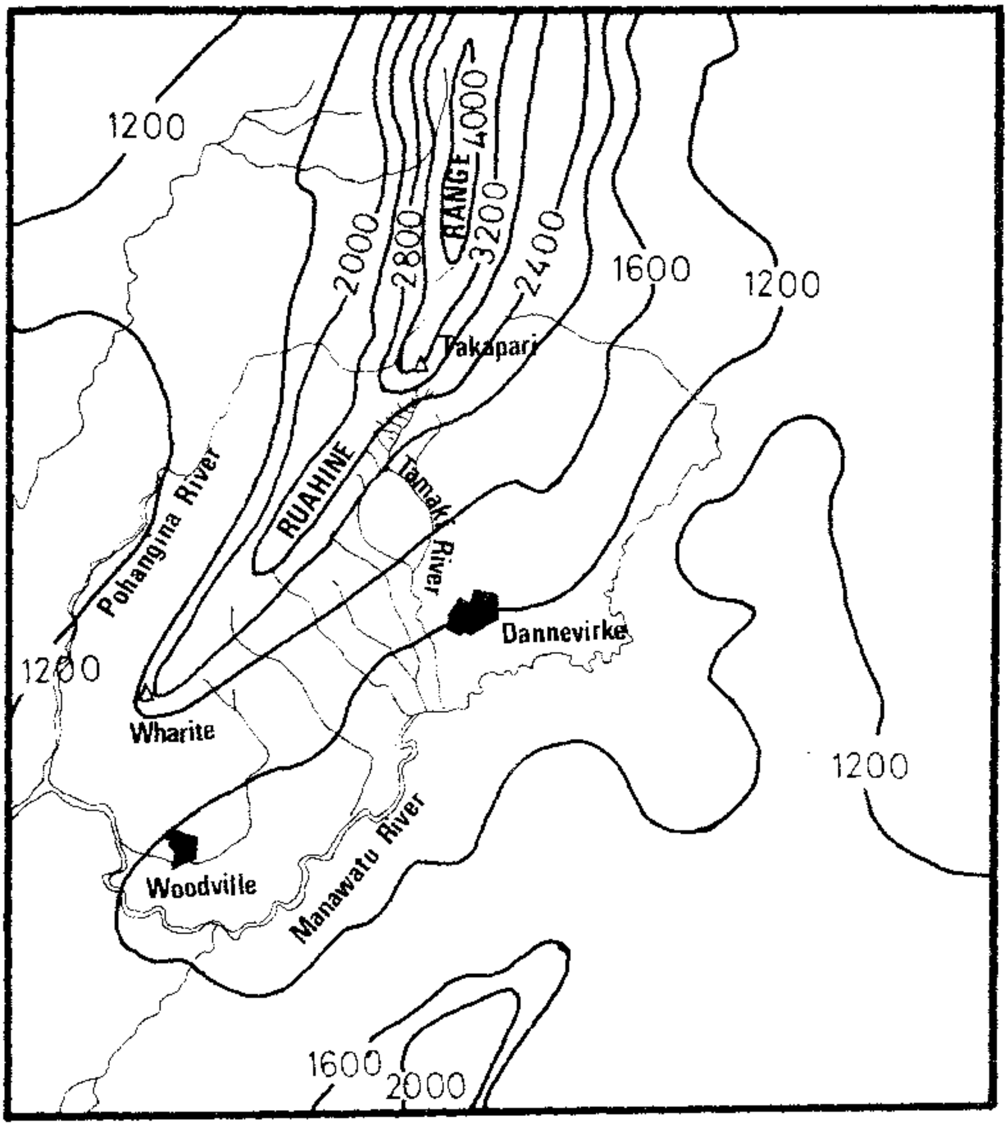
Effects of climatic changes on erosion rates have been previously discussed in the Literature Review. Grant (1965, 1966), discussing climatic data for the Tukituki River catchment and eastern Hawke's Bay, suggests that there have been significant variations in rainfall over the past few centuries. He states that "the climate is seldom constant for long", and attributes much of the present vegetation damage and erosion to high rainfall intensities associated with stormy periods.

West Tamaki River catchment (see Fig. 13)

This catchment experiences a high annual precipitation, which increases significantly with elevation from 2000mm to 2800mm, as does the amount of cloud cover.

The catchment exemplifies the effects of an intense rainstorm, Cyclone Alison, a 40 year event, which occurred in March, 1975 and caused

FIGURE 13: RAINFALL MAP FOR THE TAMAKI RIVER AREA, SOUTHERN RUAHINE RANGE.



(Official New Zealand Metereological Office data, 1941 - 1970)

ISOHYETS (mm)

1200
1600
2000
2400
2800
3200
4000

NOTE: In mountainous areas where there are very few stations and often large rainfall gradients, the isohyets only indicate the general pattern of the rainfall distribution. In such areas they cannot be used to obtain an accurate estimate of the rainfall.

a large amount of erosion throughout the catchment. Today, terraces resulting from this event are still preserved upstream of Stanfield Hut in the main channel, and in Hut Creek.

Many of the eroded areas in the upper reaches of the subcatchments are associated with permanent or periodic water channels indicating that fluvial erosion and incision, clearly governed by rainfall intensity, may play an important role in rejuvenation of slope erosion processes.

Needle ice has been observed at the higher elevations in the catchment, indicating that freeze-thaw processes contribute to minor erosion during the winter months, on the small areas of bare soil in the catchment. Many wind-thrown trees have been noted in the catchment, indicating high wind velocities have occurred on many occasions in the past.

After a long, dry spell during the Summer of 1977-1978, soils at higher elevations in the catchment were still very moist. A significant organic accumulation on the soil surface, especially in the leatherwood zone enables soils to retain much of their moisture. It seems probable that, in most cases, droughtiness will only affect vegetation growth at lower elevations, where there is less accumulation of organic litter on the surface, and rainfall is decreased.

3.7 INTRODUCED WILDLIFE

Southern Ruahine Range

The New Zealand landscape evolved without any native ground-dwelling mammals. On arrival, Europeans introduced a number of mammals into the mountainland. Pigs and goats were introduced over 200 years ago. Red deer were liberated in the Northern Ruahine Range in the late 1800's; and by the early 1900's all three were present in the Southern Ruahine Range, (Logan, 1978). Opossums were probably widespread in the Southern Ruahine Range by 1940 (Cunningham and Stribling, 1977), and other introduced wildlife includes sika deer, rabbits, rats and mice, ferrets and stoats.

There is little dispute in the literature that the introduced wildlife in the Southern Ruahine Range has had an adverse effect on the forest canopy, due to browsing and grazing of the understorey, as well as many other effects, for example, bark rubbing, soil compaction and changes of micro-climate due to opening up of the canopy. However, there is disagreement on the relative effects introduced wildlife has had as a triggering mechanism of erosion.

Cunningham (1977) considers forest deterioration in recent decades is primarily the effect of deer, goat and opossum, which has in turn led to slope instability. Grant (1965) and Jones (1973) consider that the impact of wild animals on vegetation damage and erosion may have been considerably less than the effects of increased storminess in recent decades. Mosley (1977) has provided evidence of canopy damage in the Mangapuaka Stream in the 1920's to 1930's which is, he considers, before introduced wildlife could have played a significant role in vegetation modification.

However, concern about the effects of introduced wildlife on vegetation damage, and resulting slope instability, has been sufficiently great to prompt many animal control operations in the Southern Ruahine Range, since 1938; with expenditure in the last 4 years (1974-77) being about $700,000, (Logan, 1978).

West Tamaki River catchment

The catchment was surveyed in 1975-76 by the New Zealand Forest Service, to assess the condition of vegetation and relative effects of animal population densities. It was concluded from this survey that deer control operations should concentrate on the cedar vegetation belt, and that special attention should be paid to opossum control, with regards to kamahi damage, (Strand, 1977). However, an exclosure plot set up within the catchment indicates that the unhealthy nature of kamahi can be attributed to exposure as well as to opossum browsing, (Strand, 1977). It is evident in the lower reaches of the catchment, that trampling by cattle and sheep has also had a marked effect on deterioration of the forest understorey.

The presence of fuschia, normally a highly palatable species to opossum, has been noted at elevations between 900m and 1000m on the western slopes of the catchment. It commonly appears at the heads of gullies, and is in a healthy condition. Its survival may be due to its occurrence at altitudes above which opossums browse, or possibly that these plants are an unpalatable variety.

3.8 EROSION

Southern Ruahine Range

The erosion situation in the Southern Ruahine Range has been reviewed in Chapter 2.3. Much of the erosion occurs in the form of mass movement, and there are many examples of debris slides and avalanches, slumps and rockslides (using the terminology of Varnes, 1958) in this area. Creep erosion of soil and/or screes also occurs, as does superficial movements of soil, i.e. soil slips, (Water and Soil Division, MOWD, 1971). These soil slips may develop into more deep-seated erosion types, especially if revegetation of the erosion scar is hampered by browsing animals, so that the eroded surface does not become sufficiently stabilised before the next intense rainstorm.

West Tamaki River catchment

The majority of deep-seated erosion sites occur in a zone along the upper reaches of the subcatchments of the West Tamaki River. This zone, corresponding to an altitude of between about 700m and 1000m is characterised by debris slides, debris avalanches, rock slides and gully erosion.

In Car Park Creek, deep-seated erosion types are largely gully erosion (Fig. 11), debris slides and rock slides (Fig. 7). Fig. 11 shows gully erosion producing a deeply incised V-shaped valley. With undercutting of the valley-sides debris slides are produced which become integrally associated with the gully erosion. When the gully becomes a watercourse, during wet winter periods, removal of detritus and fluvial undercutting of these slides occurs, during active erosion. Fig. 7 is a vertical aerial photograph of a rockslide, named Cats Paw Scar, in Car Park Creek. This rockslide is also evident in aerial photos taken in 1946, where it is visible as a prominant erosion feature. Here, erosion has begun with shear failure along a zone of weakness, either in the solum or along a bedding plane in the greywacke. Large scale terracettes (approximately 100m in width) can also be seen in Fig. 7, to the right of Cats Paw Scar, on the convex creep slope. It seems likely that not only soil creep, but a larger scale creep of all surficial materials and weathered bedrock may be occurring in this region.

At lower elevations in the catchment, on steep to very steep slopes, surficial erosion scars are developed, generally in the form of soil and earth slips (using the terminology of Water and Soil Division, MOWD, 1971). These occur at points on the oversteepened inherently weak basement rock, where vegetation is unable to stabilise the soil (e.g. Fig. 6, Fig. 12). Field observations, and study of past aerial photographs suggest that these features occur repeatedly at the same vulnerable sites, with intermediate stages of regrowth attained before the next slip occurs. These slips tend to occur predominantly on the north-east facing sides of subcatchments in the West Tamaki River catchment, indicating that aspect may be an important causal factor.

The West Tamaki River catchment has many examples of fluvial erosion deposits preserved in its channel bed. Fluvial erosion processes have gradually developed the channel profile, widening its banks, and sometimes forming terrace, fan and gravel wave deposits. Bank erosion is particularly evident where it is undermining gravel terraces and fans, and probably only occurs in periods of high water flow, when high erosion velocities are reached.

(Erosion velocity is defined as "the critical velocity when particles of a given size begin to move by rolling or sliding on the stream bed, or are lifted into suspension", Strahler, 1971). Rates of bank erosion are highly variable not only over time, but also from one reach to another. However, an average annual rate of channel widening in the bush-clad areas of the mountainland is estimated to be of the order of 0 to 0.5m yr^{-1} (Martin, pers. comm.). Current rates of channel widening increase by about two-fold in the lowland area, at the foot of the Range, (Martin, pers. comm.).

CHAPTER FOUR

HISTORY OF EROSION IN THE WEST TAMAKI RIVER CATCHMENT

CHAPTER FOUR

HISTORY OF EROSION IN THE WEST TAMAKI RIVER CATCHMENT

4.1 INTRODUCTION

The erosion history of the West Tamaki River catchment is complex and only partially preserved. Today, a number of discontinuous depositional surfaces occur in the main river channel each representing at least one erosion event. The degree of soil profile development and vegetation maturity, on each of these surfaces enables a tentative ordering of the deposits and thus the previous erosion events. Dating of erosion events in the catchment, has been aided by the presence of 3 tephras (Aokautere Ash, Waimihia Lapilli, Taupo Pumice) as well as radiocarbon dating and dendrochronology, (Grant, cited in Stephens, 1977).

It is apparent that two major factors have contributed to erosion events in the catchment, in the past. Theyare:

a) the creation of the steep eastern front of the Southern Ruahine Range by vertical faulting movements, which have governed the high slope gradients, and;

b) heavy rainstorms. e.g. Cyclone Alison of March, 1975, and earlier events as catalogued by Grant (1978).

4.2 METHOD OF STUDY

A number of methods were used to reconstruct the erosion history of this catchment:

a) mapping of depositional surfaces, within the catchment,

b) description of soil profiles on these surfaces; and observation of the maturity of vegetation stands,

c) estimation of the organic matter content of the soils described.

(It is considered that, in the initial stages of soil formation, organic matter accumulation increases with time, and is therefore an aid to a chronological ordering of events. Stevens (1968) also used this technique when studying a chronosequence of soils, in the Franz Josef Glacier region),

d) use of dates provided by radiocarbon dating, dendrochronology and tephrochronology,

e) mapping the thickness of one fan and terrace deposit to produce an isopach map,

f) use of aerial photographs, spanning the last 34 years, to estimate relative proportions of eroded areas.

4.3 EROSION HISTORY

Chapter 2 reviews literature, concerned with reconstructing the landscape evolution of the Ruahine Range through geological time. As the Range has been uplifted it has been subjected to erosive episodes probably interrupted by more stable periods, which have been largely controlled by major climatic fluctuations. Within the West Tamaki River catchment, during each erosive event, aggradational gravel deposits have formed in the river channel. During a subsequent more stable period, soil development and vegetation growth occurs on these surfaces as the river becomes incised within them to form a channel. A partial reconstruction of erosion events is outlined below.

4.3.1 Deposits of the Last Stadial (Ohakean Substage)

Recognition of the Aokautere Ash (erupted 20,500 yrs. B.P.)

A tephra bed, 25-40cm in thickness was discovered on the main channel valley-side, at T23/682163. A field description is given with Fig. 14. The tephra occurs as a silty-sandy lens, containing high proportions of rhyolitic glass, as well as minor amounts of quartz, magnetite, hypersthene, augite and rare hornblende. Using transmission electron microscopy, the

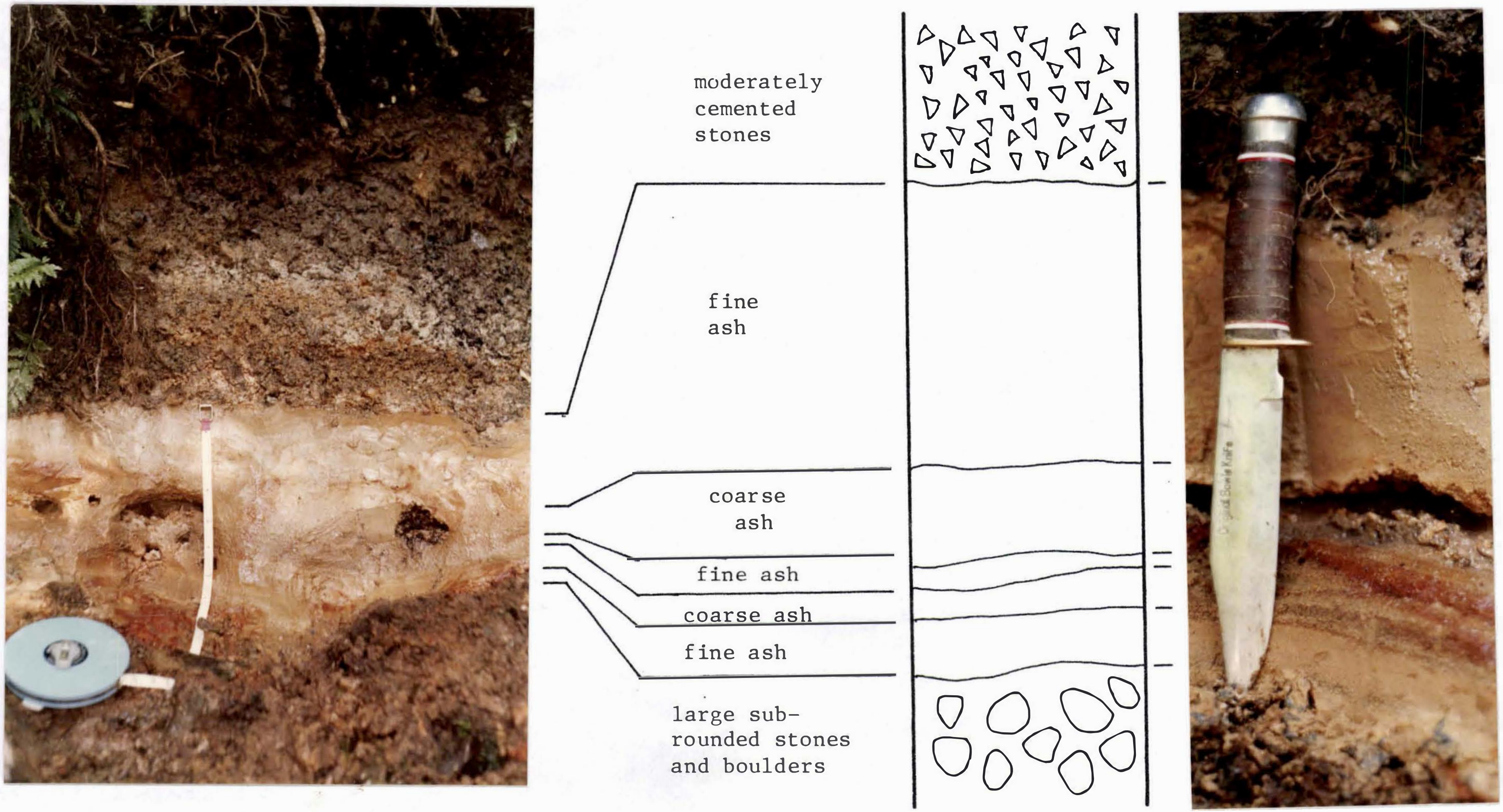


FIGURE 14: Illustrations and Field Description of the Aokautere Ash as it occurs in the West Tamaki River catchment.

<1μm fraction is seen to be a siliceous gel, with a fibrous matrix (see Fig. 55, 6.3.2).

The Aokautere Ash is believed to have been erupted from the Taupo Volcanic Centre about 20,500 years B.P. (McCraw, 1973). It extends as far south as Amberley in North Canterbury, South Island (Neall, pers. comm.,) and on the Tararua and Ruahine Ranges it is confined to flattish or gently rolling slopes, up to an altitude of about 400m (Cowie, 1964). Rhea (1968) describes the occurence of the Aokautere Ash throughout the Dannevirke district. The field and laboratory data indicate that the tephra located in the study area is the Aokautere Ash.

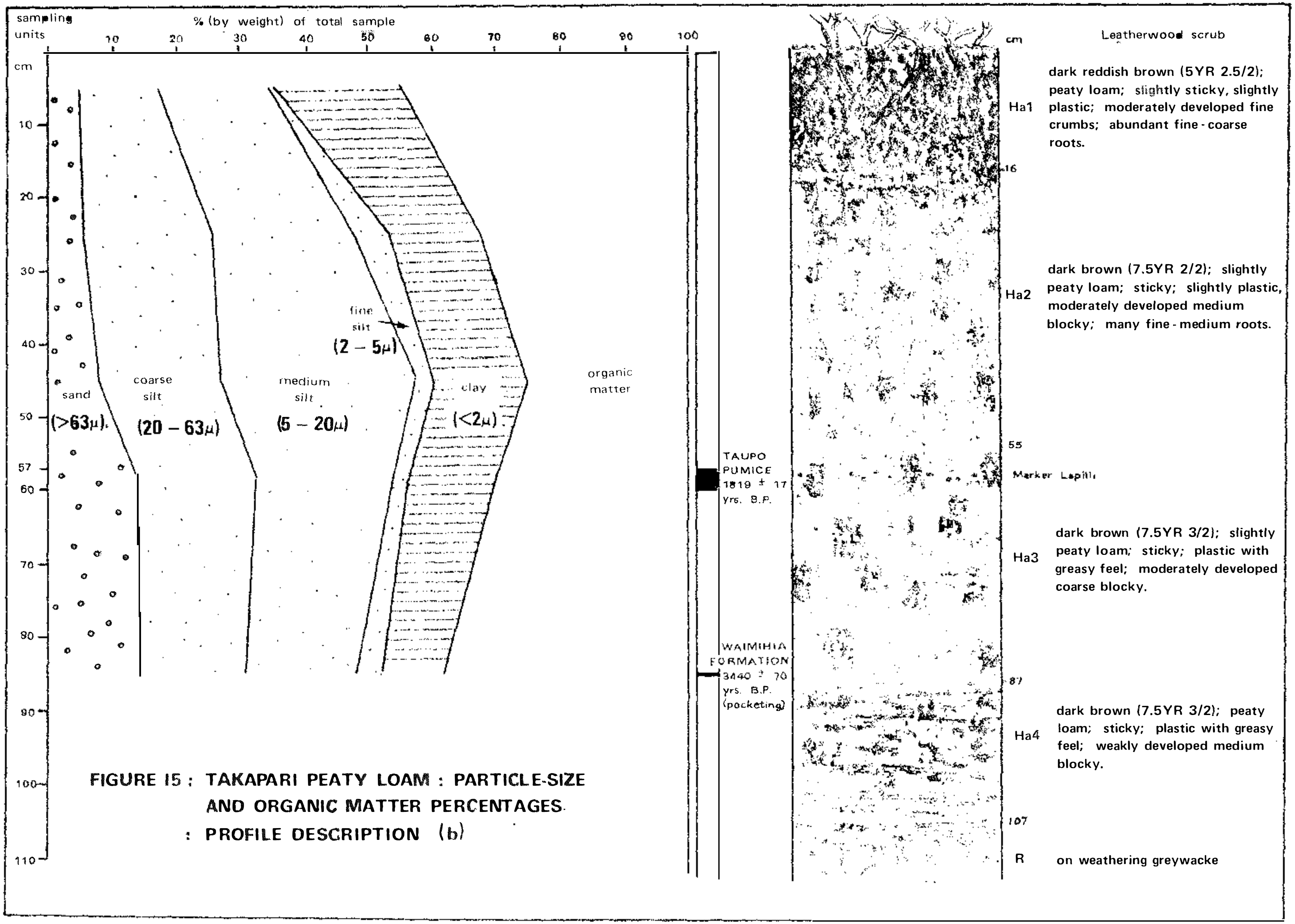
Interpretation

The Aokautere Ash occurs on the side of the main West Tamaki river channel, overlying large boulders, with at least 10m of stones above it. On the surface of these stones, 190cm of loess has accumulated in which a friable, yellow-brown soil has developed.

The presence of the Aokautere Ash at this locality, indicates that about 20,500 years ago, i.e. during the last stadial (which extended from approximately 25,000 years to 15,000 years B.P.) gravels were no higher than this point in the river bed. The tephra is today, found 10.1 metres above the level of the present river channel. The loess presumably accumulated upon the gravels toward the end of the last stadial (Ohakean Substage), and during Post-glacial (Aranuian Stage) times.

4.3.2 Tephrostratigraphy of the Takapari Peaty Loam, and Erosion History of the Summit Plateau

This soil occurs along the western boundary of the catchment on the summit plateau of the Ruahine Range. A deep profile, thicker than the modal profile, was studied to provide a stratigraphic control to the record of events involved in the genesis of this soil. A profile description, particle-size and organic matter analyses are given in Fig. 15. This soil



Ha1 dark reddish brown (5YR 2.5/2); peaty loam; slightly sticky, slightly plastic; moderately developed fine crumbs; abundant fine - coarse roots.

Ha2 dark brown (7.5YR 2/2); slightly peaty loam; sticky; slightly plastic, moderately developed medium blocky; many fine - medium roots.

Ha3 dark brown (7.5YR 3/2); slightly peaty loam; sticky; plastic with greasy feel; moderately developed coarse blocky.

Ha4 dark brown (7.5YR 3/2); peaty loam; sticky; plastic with greasy feel; weakly developed medium blocky.

R on weathering greywacke

FIGURE 15 : TAKAPARI PEATY LOAM : PARTICLE-SIZE AND ORGANIC MATTER PERCENTAGES : PROFILE DESCRIPTION (b)

has developed as organic matter has slowly accumulated under a dense leatherwood (Olearia colensoi) vegetation.

Within a profile studied of the Takapari peaty loam, a thin layer of continuous coarse ash (0.063-2mm) and fine lapilli (2-8mm) was found at approximately 60cm depth, and a thin discontinuous layer of coarse ash at 87cm depth, (Fig. 15).

Macroscopically, the upper band appears as ovate pumice pieces with elongate vesicles. This band shows up clearly in many cuttings along the Delaware Ridge track, which runs along the crest of the Range. It is particularly noticeable as a band of small, white grains, when the profile has dried out somewhat during the summer months. The lower band also consists of pumiceous grains, generally smaller and less distinct. The mineralogy of both bands shows large amounts of rhyolitic glass, with embedded augites and hyperstheres. Minor amounts of hornblende and feldspar were also noted.

Moar (1961) describes the presence of the Taupo Pumice and Waimihia Lapilli in the westernRuahine Range and Elder (1965) mentions the presence of 7-8cm of Waimihia Lapilli in the northern Ruahine Range. Pullar and Birrell (1973) discuss the presence of Taupo Pumice in the northern half of the Ruahine Range.

On the basis of macroscopic evidence, mineralogy and isopach maps (Pullar and Birrell, 1973), the upper tephra band, found within the Takapari peaty loam, is identified as the Taupo Pumice. This was erupted 1819±17 years B.P., during a sequence of eruptions, centred on Lake Taupo. It is considered that the lower band is part of the Waimihia Formation, erupted 3420±70 years B.P. from a centre east of Taupo.

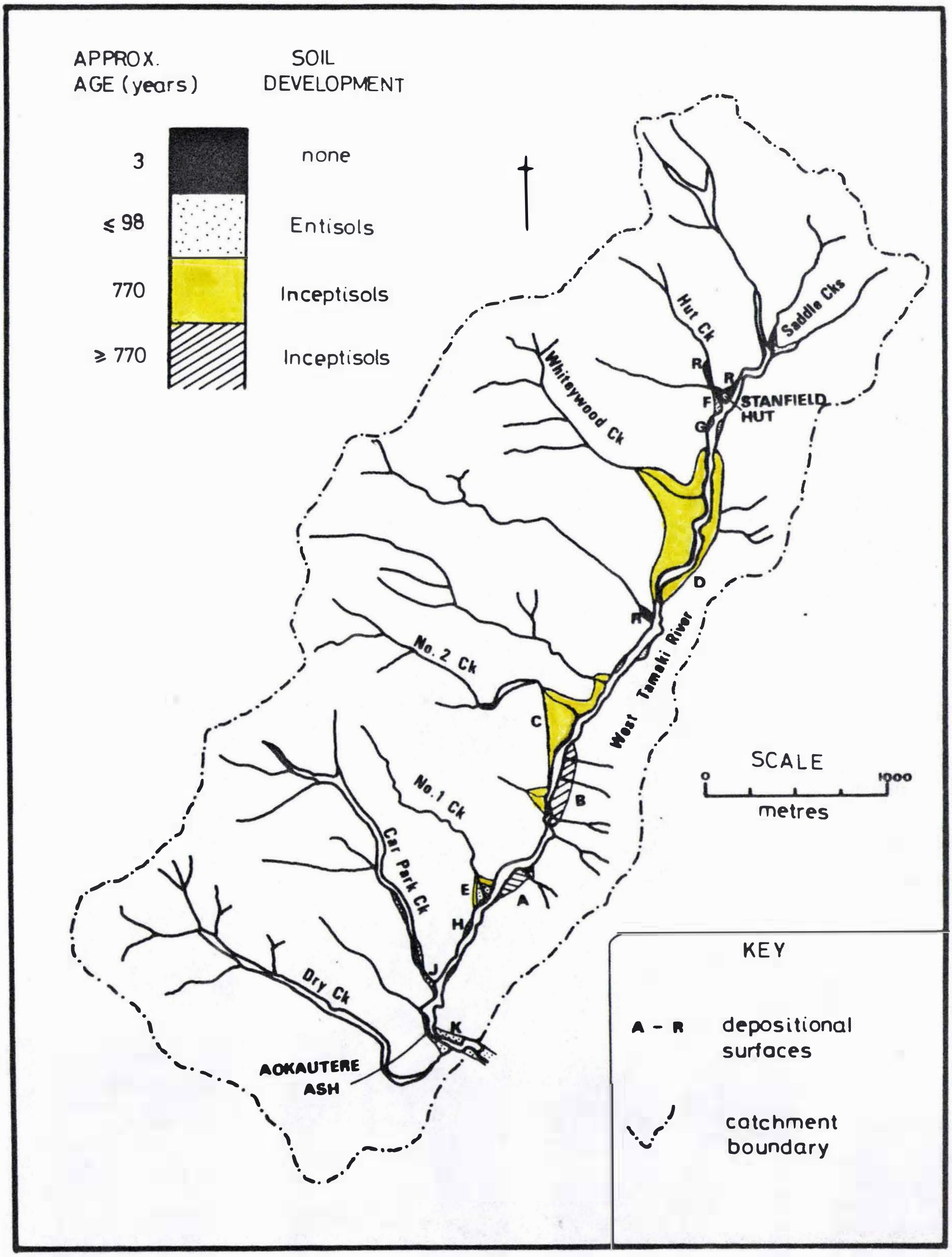
Interpretation

These tephras indicate that the soil above 87cm has accumulated in the last ca. 3440 years, with 27cm accumulating in ca. 1621 years between the two eruptions and 60cm accumulating in the ca. 1810 years since the Taupo eruption. The presence of the Waimihia Lapilli toward the base of the profile indicates that there was little soil development prior to ca. 3440 years ago, or alternatively that if soil development did occur during a relatively stable period since the end of the last stadial, the soil had been stripped by erosion processes prior to this date. Erosion, prior to the current soil formation episode, could be attributed to a) a period of climatic deterioration with increased erosion rates or b) a natural catastrophe, such as fire. However, there is no evidence of burnt vegetation in this area to support the latter hypothesis.

Particle-size and organic matter analyses of the profile (see Fig. 15) indicate that there are two layers of maximum organic matter accumulation, interrupted by a zone of higher silt content between approximately 25cm and 60cm depth. Examination of the sand fraction (0.063-2mm), derived from the zone of higher silt content, reveals a significant volcanic component (rhyolitic glass, augite, hypersthene, hornblende, magnetite), together with quartz and feldspar, derived from a greywacke provenance. This assemblage has the mineralogical characteristics of a tephric loess.

Thus, it is interpreted that the present period of soil formation was initiated by peat accumulation over greywacke bedrock a short time prior to ca. 3440 years ago (ca. 4640 years B.P. if the rate of peat accumulation before the Waimihia eruption was the same as the rate of accumulation between the Waimihia and Taupo eruptions, i.e. about 1cm in 60 years). Then, a period of increased loessial addition occurred, when tephric loess become a dominant component in the accumulating soil profile. Since this time, loess additions have diminished, and today accumulation of organic materials is again the major addition to the profile.

FIGURE 16: DEPOSITIONAL SURFACES IN THE WEST TAMAKI RIVER CATCHMENT.



4.3.3 Depositional Surfaces in the West Tamaki River Catchment

General Description.

A number of discontinuous depositional surfaces are preserved alongside the main channel of the West Tamaki River catchment. One of these has been tree-ring dated (Grant, pers. comm.), and two further aggradational periods have been radiocarbon dated. Further investigations, as part of the present study, indicate several more aggradational surfaces within the catchment (see Fig. 16). Each deposit represents at least one erosion event.

The soils developed on these gravel surfaces may be considered as a chronosequence ("a sequence of related soils that differ, one from the other, in certain properties, primarily as a result of time as a soil-forming factor", Soil Sci. Soc. Am., 1975). The remaining 4 soil-forming factors (Jenny, 1941) may be considered to have been relatively consistent during pedogenesis so far as these surfaces are concerned:

parent material	-	greywacke gravels
vegetation	-	podocarp-hardwood forest (climax vegetation type)
climate	-	approximately constant along the main channel
relief	-	similar surfaces, dipping gently downstream, of similar altitude.

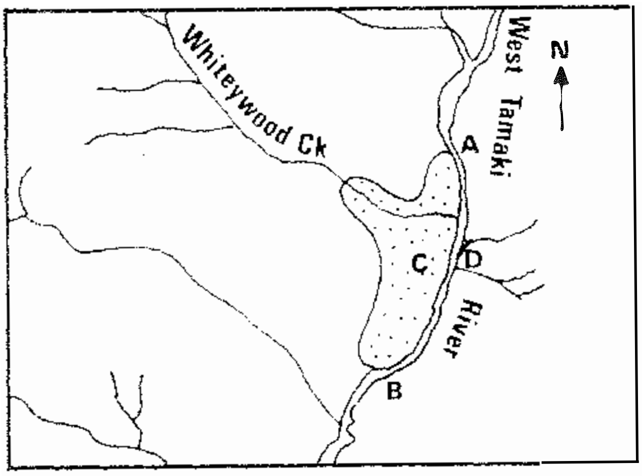
(There is one exception to this, in the case of the terrace system on which soils A and B have developed. These contain a considerable component of tephric loess, i.e. parent material is not constant as a soil-forming factor, in this case).

Profile descriptions, and loss on ignition data (indicating organic matter content) are presented in Appendix II.

Interpretation

The Whiteywood Creek fan deposit (Fig. 18) shows evidence for at least three periods of aggradation. A possible reconstruction of events leading to its present form is given in Fig. 17. At the base is a small buried soil,

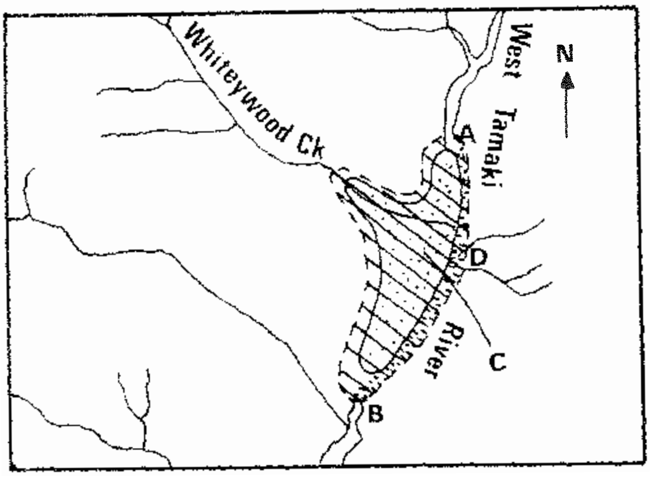
FIG. 17: A Reconstruction of Events Forming the Whiteywood Creek Fan.



(a) 12,500 yrs. B.P. - active aggradation phase

⁘ fan deposit

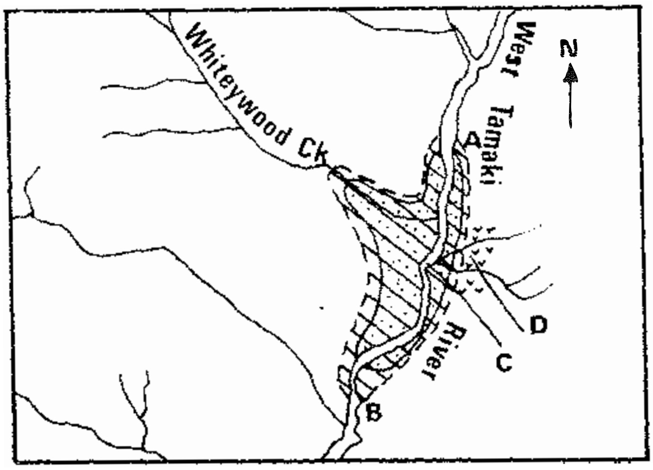
A-D-B river channel



(b) 770 yrs. B.P. - second aggradation phase

▨ second fan deposit

A-D-B blocked river channel (former river channel becomes inundated by gravels, and side creeks are blocked to form a swampy area at fan terminus).



(c) present day - relatively stable period with soil development and vegetation growth

A-C-B present river channel (river has cut a new course through fan deposit, and peat bog has formed in blocked tributary at D).

Fig. 18: Whiteywood Creek fan deposit -
(1) vegetated with a rimu stand,
(2) records at least 3 aggradation periods.

Fig. 19: A Soil Profile developed on the Whiteywood Creek fan deposit.

seldom exposed at river level, which overlies the earliest, as yet undated, gravel deposits of the fan. The bulk of the fan is a middle unit that forms the lower two-third of the cliff face, at T23/695185. A wood speciman of Griselinia littoralis (broadleaf) found within this unit, about 3m above river level, has been radiocarbon dated at 12,150±150 years B.P. (NZ4314B), suggesting that active deposition was occurring on the fan ca. 12,000 years ago (Fig. 17a).

A third period of aggradation is indicated by the upper gravel unit of the fan, on which a mature rimu stand has developed. Tree-ring dating of one old rimu at 450 years old (Grant, cited in Stephens, 1977), gives a minimum age for this last period of aggradation. It is this deposit in which the present-day soil is formed (Fig. 19). At the terminus of the fan, three metres of carbonaceous silts overlie medium to coarse greywacke gravels. A wood sample obtained from the base of these carbonaceous silts has been radiocarbon dated at 770±60 years B.P. (NZ4547C). This provides a more accurate date for the third aggradational period. Field observations suggest that the former river channel ran further to the east of its present course, (Fig. 17a), and that during this third aggradational period, the fan deposit filled this river channel, and formed the swampy area at its terminal margin (Fig. 17b).

Since this time, the river has cut a new course through the fan, so that the sequence of fan deposits are exposed on both sides of the main river channel, (Figs. 17c, 18).

An ancient terrace system (Fig. 20) is preserved downstream of Whiteywood Creek fan at two localities marked A and B, in Fig. 16. The soils developed on these surfaces, contain a significant accumulation of loess, mixed with a large number of boulders (Fig. 21). A dark, well structured Ah horizon overlies friable, weak to moderately structured AB and Bw horizons. The soil profile indicates that a considerable amount of time has elapsed since soil development bagan. By comparing soil

Fig. 20: Old terrace in the West Tamaki River channel-vegetated with a podocarp-hardwood stand.

Fig. 21: A Soil Profile developed on the old terrace system.

profile development, and organic matter contents it is suggested that these surfaces predate the upper surface of the Whiteywood fan (Fig's 18, 19). The vegetation on both surfaces is a mature podocarp-hardwood forest (see Appendix II).

At the mouth of No. 2 Creek, another extensive fan deposit is vegetated with a mature podocarp-hardwood stand (see Appendix II). The soil developed on this surface (soil C) is about 0.5m thick, and is extremely bouldery, with little or no loessial component. Its morphology is similar to soil D on Whiteywood fan (Fig. 19), and it is suggested that these two soils are of a comparative age. A buried soil, at the mouth of No. 1 Creek (soil E) also has a similar appearance, and it is considered that it may also be of a similar age. All three soils are classed as Inceptisols (Soil Survey Staff, USDA, 1975) or clini-fluvic soils (NZ genetic classification). The surfaces on which they have developed may represent lateral downvalley continuations of a single depositional episode.

A weakly developed soil occurs on the fan surface, on which Stanfield Hut is located. The red beech stand (Nothofagus fusca) has been tree-ring dated at 98 years old (Grant, pers. comm.), providing a minimum age for this surface (see Fig. 22, arrowed). The soil, which has developed in the surface gravels of No. 1 Creek fan is at a similar stage of development; and it seems possible that it is of similar age. Both are AC soils, and are thus classified as Entisols (Soil Survey Staff, USDA, 1975), or clinic soils (N.Z. genetic classification).

Younger terraces, vegetated predominantly with mahoe (Melicytus ramiflorus), occur downstream of Stanfield Hut and No. 1 Creek (soils G and H), and at a number of other localities in the stream channel. These are, in general, no more than 0.5m above the present river bed. The soils developed on these terraces have weakly structured Ah horizons overlying unweathered gravels. These soils are also Entisols, (clinic soils, New Zealand genetic classification), and appear to be $\leq$98 years old.

Fig. 22: An extensive Gravel terrace, formed during Cyclone Alison (foreground), and a 98 year old fan deposit at Stanfield Hut (arrowed), vegetated with a Red Beech stand.

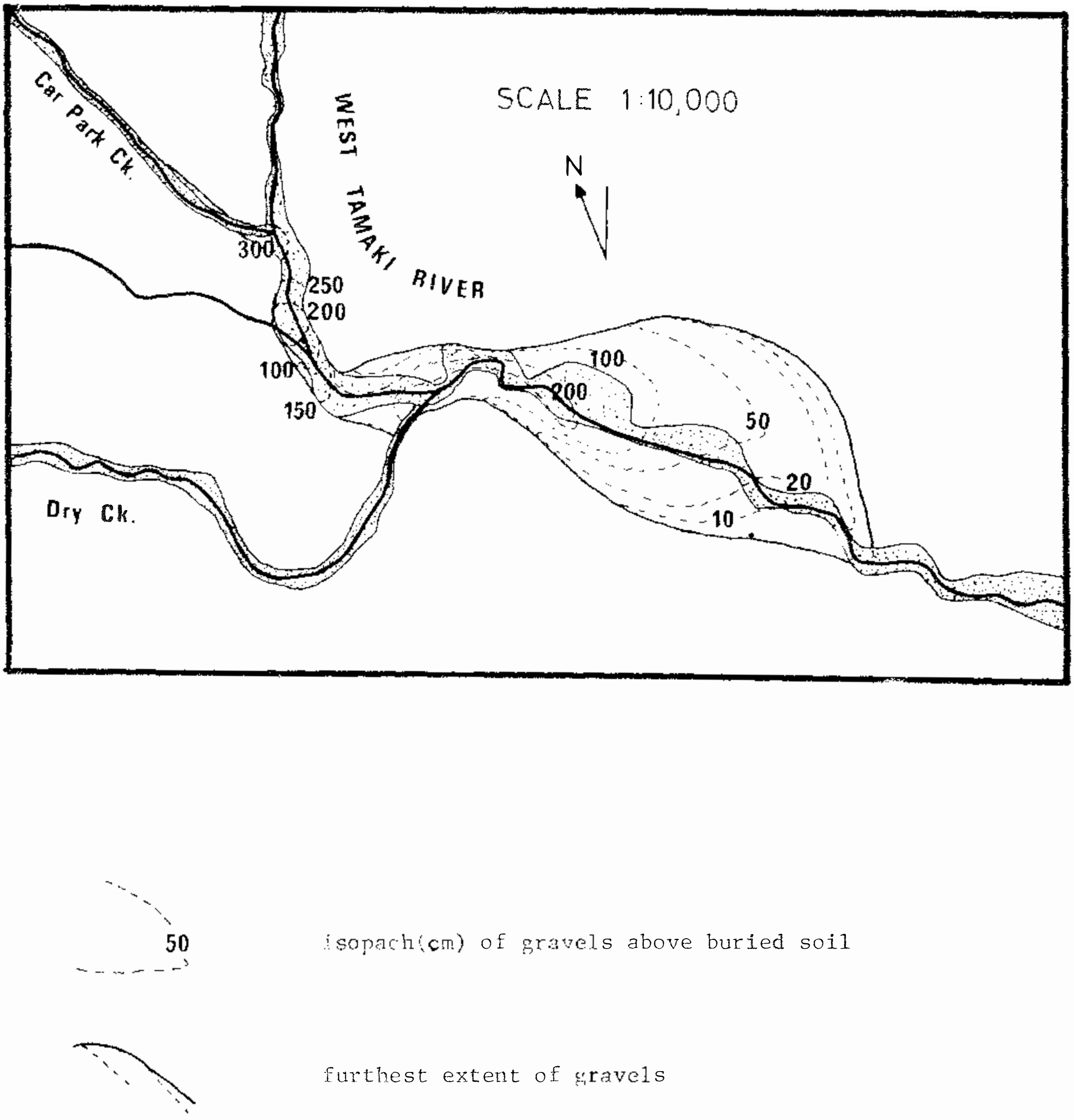
Fig. 23: Recent soil, formed in a gravel deposit, at the mouth of Car Park Creek.

In addition, a further gravel fan and terrace system is preserved from the mouth of Car Park Creek, for about 1.2km downstream. The gravels are angular and very fresh-looking, and there has been little time for soil development, (soil K, Fig. 23). At the mouth of Dry Creek, and in river bank exposures downstream of Dry Creek, these gravels can be seen burying an older well-developed, yellow-brown soil. This soil is stony and occurs on low, flat terraces further downstream. It has been mapped as the Kopua stony silt loam by G.J. Smith (cited in Mosley, 1977), and classified as a yellow-brown loam-yellow-brown earth intergrade (strongly enleached alvi-fulvic soil) by Rijkse (1977).

The thickness of gravel above the buried soil was measured at a number of points from the Car Park Creek fan to its downstream margin on the floodplain of the main West Tamaki River channel. An isopach map (Fig. 24) allows an estimate to be made of the volume of detritus in this fan and terrace deposit. A minimum of 190,000m^3 of gravel (125,000m^3 of bedrock, using the factor used by Mosley, 1977) was eroded and transported during this erosion event. Soil development on this surface indicates that the erosion event occurred at some time during the last 98 years, and may well coincide with the period of scouring with production of wide, braided channels, after the 1920's-1930's, which Brougham (1977) discusses, (Chapter 2.1).

A set of very low terraces, adjoining the West Tamaki main channel, were deposited during the most recent significant erosion event, Cyclone Alison, of March, 1975. These terraces (marked R in Fig. 16) are essentially bare gravel surfaces (Fig. 22 in foreground), particularly well preserved between Head Creek and Hut Creek (Fig. 16) in the main West Tamaki channel, and in Hut Creek (Fig. 8).

FIGURE 24: ISOPACH MAP OF RECENT GRAVEL SURFACE, ASSOCIATED WITH CAR PARK CREEK AND DRY CREEK SUBCATCHMENTS IN THE WEST TAMAKI RIVER CATCHMENT.



isopach(cm) of gravels above buried soil

furthest extent of gravels

4.3.4 Aerial Photographs (1946-1966-1974-1978)

DATE OF PHOTO	% OF SUBCATCHMENT ERODED (i.e. bare ground exposed)
9.10.46	3.4
1.11.66	11.2
28. 3.74	5.6
20.3.78	4.9

TABLE 5: PERCENTAGE ERODED AREA IN CAR PARK CREEK AND No. 1 CREEK FROM 1946-1978

The earliest aerial photographs of the study area taken by the Department of Lands and Survey. date back to 1946. At this time, the catchment appears to have been in a relatively stable situation, with only a few prominent erosion scars evident. The stream beds of the subcatchment, at this time, appeared to be narrower than they are today. However, the vegetation was immature in places, giving a patchy appearance on the aerial photographs. This is particularly evident on the north-east facing steep slopes of the subcatchments, and along the main channel of the West Tamaki River.

By 1966, the subcatchments had developed a large number of erosion scars. Table 5 indicates that the area of bare ground had increased by more than three-fold since 1946. The majority of these eroded areas occurred on north-east facing slopes and in the heads of subcatchments.

During the following 12 years, a certain amount of re-vegetation of these areas, both naturally and by the New Zealand Forest Service, has taken place. A comparison of aerial photographs taken in 1974 and 1978 indicates that although the same eroded areas are evident, both natural and exotic vegetation growth on these scars has occurred in the last 4 years. Today, the Cats Paw Scar is seen to be vegetated over at least 50% of its area, largely by exotic species, planted by the New Zealand Forest Service.

A few other erosion scars in these two subcatchments have been planted with exotic species; and many of these, together with the other eroded areas are slowly being colonised by native species.

CHAPTER FIVE

A PEDOLOGICAL INVESTIGATION OF THE SOILS IN CAR PARK CREEK SUBCATCHMENT

CHAPTER FIVE

A PEDOLOGICAL INVESTIGATION OF THE SOILS IN CAR PARK CREEK SUBCATCHMENT

5.1 INTRODUCTION

A pedological investigation of the soil resources within this subcatchment was carried out primarily to investigate the relationship of soil classes to erosion forms. The method of investigation was:

a) the definition, mapping and naming of soils within the survey area;

and b) noting the relationship of soils distribution to vegetation pattern, slope, geomorphology, parent materials and erosion forms within the survey area, with possible extrapolation of findings to similar areas.

Thus, in the process of this survey some detailed information has been obtained about soils occurring in the area previously mapped as "Ruahine steepland soils", (e.g. Rijkse, 1974; G.J. Smith, cited in Mosley, 1977).

The general characteristics of the survey area, Car Park Creek, are discussed in Chapter 3. It is a subcatchment characterised by steep to very steep slopes, and it has been considerably modified by erosion processes (Fig. 25). The survey area is approximately 180 hectares in size, and in this study it has been mapped at a scale of 1:5,000 (see Soil Map, Appendix III). It was previously mapped at a scale of 1:63,360 by G.J. Smith (cited in Mosley, 1977).

Gibbs (1962) describes steeplands as landforms formed, or forming, under the influence of erosion. He attributes the main effect to stream cutting but also acknowledges the significance of fault movements with subsequent stream erosion, before soils can accumulate. The material found on slopes, both regolith and soil, is not permanently fixed, but moves downslope either imperceptibly by soil creep, or by massive sliding

Fig. 25: Car Park Creek - a subcatchment of the West Tamaki River.
(note very steep valley-sides in a subcatchment which slopes steeply upto its head, due to upthrow by the Mohaka Fault which runs along the main West Tamaki River Channel).
Photo: R. Blakely.

movements. Consequently, a study of soils in such terrain is necessarily related to current erosion processes. A soil mapping unit of common usage in New Zealand to cover the intricacies of the soil pattern in such terrain is that of "steepland soils". This was initially used by Gibbs (1954) to cover a complex and diverse range of soils, formed on steep terrain. He describes these soils as being "formed and maintained by erosion", (1962).

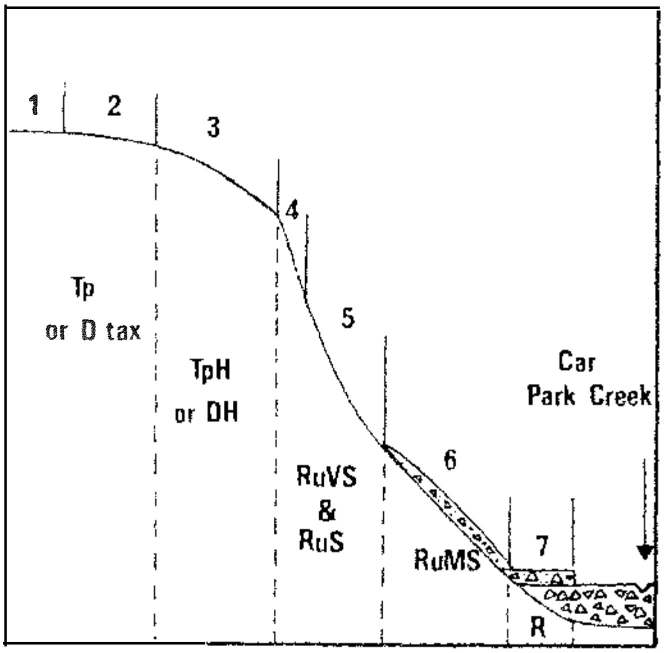
Other workers, such as Campbell (1973), recognise a catena-like pattern of soils on valley-sides. Campbell (1973) describes four distinct soil units occurring on a) a ridge, b) an intermediate steep slope, c) an eroded slope and d) an accumulation slope. He considers that this approach provides a basis for better definition of mapping units, and separation of the taxonomic units within them.

Campbell (1975) and Laffan and Cutler (1977) discuss landscape periodicity on rolling and steep land. They show how the catena-like pattern is further complicated by rejuvenation processes. The resulting slope deposits may represent periods of accumulation, for example of loess, or erosional and depositional events (Laffan and Cutler, 1977). The soils developed on each surface mark a period of landscape stability, (Butler, 1959). The resulting mapping unit is of increased complexity and variation, with its range of properties widened.

A similar situation appears to exist in the south-eastern Ruahine Range. Here, a number of geomorphic units can be recognised on the valley-sides, each characterised by a certain range of soils. Superimposed on these units are deposits resulting from 1) accumulation of loess and volcanic ash, and 2) rejuvenation processes. The resulting soils pattern is very complex, although certain common characteristics will be shown to apply to many of the soils.

The soil mapping units employed in the survey include two soil types and their related hill soils, and steepland soils. Some broad mapping units

Fig. 26: Diagrammatic Cross-section to show the Distribution of Soil Classes, in relation to the landsurface units, within Car Park Creek.



SOIL NAME	SOIL SYMBOL	LANDSURFACE UNIT *	DESCRIPTION OF LANDSURFACE UNIT
Takapari peaty loam, Dannevirke taxadjunct,	Tp D tax	1 & 2	interfluve and seepage slope
Takapari hill soils, Dannevirke hill soils,	TpH DH	3	convex creep slope
Ruahine steepland soils,	no soil	4	fall-face
	RuS, RuVS	5	transportational midslope
	RuMS	6	colluvial footslope
Recent soils	R	7	alluvial toeslope

* (according to Conacher and Dalrymple, 1977)

have been used because, in certain areas, soils are greatly modified by erosion, so that large variations can be found over short distances.

The soils have developed from a number of parent materials. These range from peat with tephric loess to basement greywacke and include loess derived from greywacke, colluvium, alluvium, scree deposits and shattered fault zone materials.

The Takapari and Dannevirke soils occur on flat to easy rolling surfaces (units 1 and 2, Conacher and Dalrymple, 1977). Their related hill soils occur in areas where the landsurface becomes more steeply sloping, that is on more steeply sloping interfluves and on the convex creep slope (unit 3, Conacher and Dalrymple, 1977). Ruahine steepland soils occur on the steep to very steep valley-sides (units 4, 5 and 6 of Conacher and Dalrymple, 1977). A diagrammatic cross-section of a valley-side in Car Park Creek, to show the relationship of soil classes to landsurface units, is given in Fig. 26.

5.2 METHOD OF APPROACH

Ives (1970, 1972) discusses the problem of mapping in the New Zealand high country. Having mapped soils of the Mowbray catchment in South Canterbury, he found difficulty in relating taxonomic and mapping units identified, with those of other surveys. This was attributed to: 1) non-definition of the range of properties within a taxonomic or mapping unit, and 2) insufficient awareness and use of data from other surveys. Thus any soil survey should adequately define, accurately map and uniformly name soils, in order to be able to correlate them and ensure that one soil has the same name wherever it occurs. Most of the soil mapping units adopted in this study have been previously described (e.g. Rijkse, 1977; Pohlen et al. 1947). It was, thus, considered of importance to 1) investigate the differences and overall similarities within and between mapping units, and to 2) establish correlation with taxonomic units used in pre-existing surveys.

This soil survey was carried out in three stages:

1) Reconnaissance trips - enabling the surveyor to become acquainted with a) the erosion problem in the Southern Ruahine Range, and b) the range of soils which exist there. These trips were also used as an opportunity to choose a suitable study area in which a detailed soil survey could be carried out.

2) Aerial photographic studies - Aerial photographs of the catchment were studied to investigate a) the nature of the land surface, b) vegetation patterns, and c) extent and localities of erosion.

Information from stages 1 and 2 was used to plan a suitable approach to stage 3.

3) Field investigation - This stage involved a number of traverses across the catchment, and description of soil profiles encountered on the total range of landforms. Subsequently, a number of soil mapping units were identified, and their extent mapped on a base map of 1:5,00 scale (Appendix III). The range in profile characteristics within each mapping unit was closely studied. Erosion forms within the area were noted and their distribution with respect to the soil units was investigated.

The terminology of Taylor and Pohlen (1970) was used as a basis for soil profile descriptions. Horizons were designated according to the FAO-Unesco system (1974).

Soil colours were recorded moist. Root size and abundance were described according to the Soil Survey of England and Wales (Hodgson, 1974) as Taylor and Pohlen (1970) do not set down a format for root descriptions.

Ives (1970) presents some additional specific terms for profile descriptions, which he developed whilst surveying the Mowbray catchment, in South Island. One of these has been adopted in the present study:

"extremely stony", as an additional class for stoniness
indicating the presence of >60%
stones (or gravel). The very stony
class, of Taylor and Pohlen (1970) is
modified accordingly.

The textural qualifying terms "peaty" and "stoniness" are used in this study. Stoniness is included at the beginning of the horizon descriptions together with the textural class, as it is considered to be of major importance to the soil characteristics in soils which are very - extremely stony. A field assessment of the feel of many of these soils indicated a grittiness. This suggests that colluvial greywacke material present in the soil has had insufficient time for breakdown to finer particles. Thus, a "gritty feel" is added to the horizon descriptions where relevant, as it is considered to be an important factor characterising soils in which rejuvenation is an important process.

Also, some soil profiles had a "greasy feel", which was considered to be indicative of a large allophanic component within the soil clay component.

5.3 SOILS

The soils encountered in the study area are listed below according to topography. They are classified according to:

(1) the New Zealand genetic classification (common and technical names) and

(2) Soil Taxonomy (Soil Survey Staff, USDA, 1975).

SOILS LEGEND (to accompany soil map)

Soils of the Flat to Rolling Land of the Mountain Range

(1) very strongly leached organic soil (very strongly enleached eldelodic soil)

(2) Lithic Borosaprist, with inclusions of Typic Borosaprists

TAKAPARI PEATY LOAM (Tp)

(1) Taxadjunct* to strongly leached intergrade between yellow-brown loams and yellow-brown earths (strongly enleached alvi-fulvic soil)

(2) Typic Dystrandept, (or Typic Hapludand, in G. Smiths provisional classification of Andisols, 1978)

DANNEVIRKE SILT LOAM TAXADJUNCT (D tax)

Soils of the Moderate to Moderate-Steep Slopes

(1) Steepland soils, related to yellow-brown earths (strongly enleached co-fulvic clinic, fulvic-clinic soils)

(2) Typic Dystrochrept

RUAHINE STEEPLAND SOILS, MODERATELY STEEP-STEEP PHASE (RuMS)

(1) Hill soils, related to very strongly leached organic soil (very strongly enleached eldelodic soil)

(2) Typic Placaquept, with inclusions of Histic Placaquepts and Humic Haplaquepts

TAKAPARI HILL SOILS (TpH)

(1) Hill soils, related to strongly leached intergrade between yellow-brown loams and yellow-brown earths (strongly enleached alvifulvic soil)

(2) Entic Dystrandept , with inclusions of Lithic Dystrandepts (or Typic Hapludand , in G. Smiths provisional classification of Andisols)

DANNEVIRKE HILL SOILS (DH)

---

* Taxadjunct - a term used by the U.S.D.A. (USDA, 1967) for the classification of a soil, whose definitive characteristics (at least two) are outside but near the limits of an already defined series. Soils marginal to already defined series may also be handled as taxadjuncts. This concept is similar to the concept of the soil variant as it is used in New Zealand literature (Taylor and Pohlen, 1970).

Soils of the Steep to Very Steep Slopes

(1) Steepland soils, related to yellow-brown earths (strongly enleached co-fulvic clinic, fulvic-clinic soils)

(2) Typic Dystrochrepts with inclusions of Lithic Udorthents (RuS) and vice versa (RuVS)

RUAHINE STEEPLAND SOILS (RuS)

RUAHINE STEEPLAND SOILS, VERY STEEP PHASE (RuVS)

Soils of the Valley Floor

(1) Recent soils, on gravel surfaces (Luvic soils)

(2) Typic Udifluvents

RECENT SOILS (R)

N.B. The mapping symbols written in brackets after the soil names of each mapping unit are used hereafter as an abbreviation for the soil name, for example Tp, where used in the text, refers to the TAKAPARI PEATY LOAM soils.

Most of these mapping units have been previously described (Rijkse, 1977; Pohlen et al. 1947). However, the D tax and DH soils are described for the first time in this survey. Also, the RuMS has been added as an additional phase to the "Ruahine steepland soils". This phase occurs at localities in the catchment where a soil has developed on a colluvial footslope.

TpH is a mapping unit adopted by Rijkse (1977) in Pohangina County. It occurs just below Tp, which exists on the summit plateau. It is described as being about 0.5 metres deep, with a peaty A horizon. It has been mapped by Rijkse from 1070-1370 metres elevation on the western side of the Range. In the present survey, these soils occur on ridge-sites at elevations as low as 750 metres, and in many cases are considerably thicker than 0.5 metres. Their representative profile description shows them to be markedly different to their related counterpart, Tp, which occurs on less steeply sloping terrain.

5.3.1 The Ruahine steepland soils

Description

The Ruahine steepland soils are located on the steep to very steep valley-sides of the subcatchment (units 4, 5 and 6 of Conacher and Dalrymple, see Fig. 26). They may be subdivided into three phases, on the basis of steepness of slope and mean soil depth. Fig. 26 shows shallow RuS and very shallow RuVS soils occurring on the transportational midslopes, whereas the deeper RuMS soils occur on the colluvial footslopes. A wide range of profiles occur within each phase and some show no soil development, (see Table 6). The extent of each phase within the Ruahine steepland soils mapping unit is shown on the soil map, where the delineated areas are dominated by the soil phase to which they are assigned, but may contain inclusions of the other two soil phases. This is particularly relevant in areas mapped as RuS in which a substantial number of RuVS inclusions may occur and vice versa. A few stable sites occur within each phase, where soils are relatively well developed; however, these are considered to be minor inclusions within any of the three soil phases. From the total number of profiles, average soil depths have been calculated as:

Soil phase	total depth of A and B (where present) horizons
RuMS	60 cm
RuS	45 cm
RuVS	35 cm

Root distribution is commonly throughout the full extent of the solum, which undoubtedly plays an important role in soil stabilisation. A representative soil profile description is given below for each soil phase, together with Table 6 which indicates the range of properties within the Ruahine steepland soils.

(a) Ruahine steepland soil (RuS) Fig. 27

slope: 30° - 38° elevation: approx. 500-1000m

topography: steep slopes

drainage: well drained

vegetation: severely damaged podocarp-hardwood forest

(Lack of canopy trees, sub-canopy dominated by kamahi, with various small trees, broadleaf, ferns and scrub. Open understory)

classification: Typic Dystrochrept

profile: cm

O +1-0
org. litter of leaves, twigs; root mat.

Ah 0-9
dk brown (10YR 3/3); v. stony silt loam; friable with gritty feel; wk. dev. f-mdm. nutty structure; many f-cse roots. Indistinct, irreg. boundary.

Bw 9-45
dk greyish brown (10YR 4/2); v. stony silt loam; friable with gritty feel; wk. dev. mdm blocky structure, breaking to f. nuts; many f-cse roots.

C on very shattered weathering greywacke.

(b) Ruahine steepland soil, very steep phase, (RuVS)

slope: ≥40°; elevation: approx. 500-1000m

topography: very steep slopes

drainage: well drained

vegetation: severely damaged podocarp-hardwood forest (mainly scrubby broadleafs, pepperwood, ferns, mahoe and stunted Kamahi, with a few podocarps).

classification: Lithic Udorthent

profile:

Ah 0-20cm dark brown (10YR 3/3); extremely stony silt loam; firm with gritty feel; weakly developed fine to medium nutty structure; many fine-coarse roots; distinct, wavy boundary

C 20-45cm shattered, weathering greywacke

R on solid, greywacke bedrock

(c) Ruahine steepland soil, moderately steep-steep phase, (RuMS)

slope: 18°-30°; elevation: approx. 500-800m

topography: moderately steep to steep slopes

drainage: well drained

vegetation: damaged podocarp-hardwood forest (relatively dense understorey of broadleaves, pepperwood, lianes, ferns with Kamahi and a few podocarps).

classification: Typic Dystrochrept

profile:

O +1-0cm organic litter of leaves and twigs; root mat.

Ah 0-12cm dark brown (10YR 3/3); very stony silt loam; friable, with gritty feel; moderately developed fine to medium nutty structure; abundant fine-coarse roots. Indistinct, wavy boundary.

Bw 12-33cm brown/dark brown (10YR 4/3); extmly stony silt loam; friable with gritty feel; weakly developed med. blocky structure; many fine-coarse roots. Indistinct, wavy boundary.

Bw2 33-52cm brown (10YR 5/3); extremely stony sandy loam; friable; very weakly developed fine to medium blocky structure; common fine to coarse roots.

C 52-100cm greywacke gravels, with greyish brown (10YR 5/2) sandy matrix; structureless

R on greywacke bedrock.

Genesis

Erosion is undoubtedly the overriding process affecting profile development within these soils, with the occurrence of a considerable number of erosion slips and scree deposits. Other processes which occur include a limited amount of accumulation and incorporation of organic matter, with moderate to strong leaching.

Erosion processes within these steepland soils complicate the three phase soil pattern (shown in Fig. 26) by producing within each phase: bare rock and scree deposits, buried, truncated and skeletal soils. As a consequence, each soil phase encompasses a wide range of properties. All three soil phases do not necessarily occur in any one slope unit. RuMS soils occur over a limited area where the slope is sufficiently gentle for colluvium to accumulate and where little undercutting by the stream channel occurs. The distribution of RuS and RuVS soils is controlled primarily by the angle of slope and erosion pattern.

Classification

A considerable variability within each soil phase results in the presence of Dystrochrepts and Udorthents within this mapping unit. RuS soils are characteristically Dystrochrepts, which meet the colour and depth requirements of the typic subgroup, and RuMS soils being slightly deeper also

TABLE 6 VARIATION OF PROPERTIES IN THE RUAHINE STEEPLAND SOILS MAPPING UNIT

HORIZON	COLOUR	TEXTURE	(moist) CONSISTENCY	STRUCTURE	RANGE OF THICKNESS (cm)	STONINESS
Ah	dark brown/brown; dark brown; very dark greyish brown	silt loam; loamy sand; sandy loam	very friable friable firm ($^+/_-$ gritty feel)	week to moderately developed; very fine, fine or medium nuts; fine crumbs	5-44	stony, very stony extremely stony
Bw	dark brown; dark brown/brown; brown; dark greyish brown; dark yellowish brown	silt loam; sandy loam	very friable friable firm ($^+/_-$ gritty feel)	weak to moderately developed; fine, medium, coarse or very coarse blocky (breaking to fine nuts, in many cases)	pocketing (0-7) 0-59	stony, very stony extremely stony

C : greywacke bedrock (often shattered)
: " fault breccia
: " gravels (e.g. scree deposit)
: " " with loess (possibly with some tephric component)
: " colluvium (gravels with finer matrix, with or without loess).

TABLE 6 (contd.)

NOTES:

1) A and B horizons may or may not be present in any soil (due to non-development or removal by erosion processes).

2) Several soils have been described with buried horizons e.g.

O	+1-0cm	leaves, twigs
C	0-35cm	fresh, angular greywacke gravels
Ahb	35-60cm	dark brown (10YR 3/3); very stony silt loam; very friable; weakly developed very fine to fine nutty structure; many fine to coarse roots; native earthworms present.
Bwb	60-115cm	brown/dark brown (10YR 4/3); very stony silt loam; very friable; weakly developed medium blocky structure; common fine to coarse roots.
Cb	115+	weathering greywacke.

fit into this subgroup. Within the RuS soil phase a number of Lithic Udorthents occur as inclusions. The modal RuVS soil is classified as a Lithic Udorthent, with inclusions of Typic Dystrochrepts.

Accordingly to the New Zealand classification the Ruahine steepland soils are strongly leached clini -fulvic, fulvi-clinic or clinic soils, in order of decreasing soil development, (common name: strongly leached steepland soils, related to yellow-brown earths).

5.3.2 The Takapari peaty loam (see also Appendix IV)

Description

The Takapari peaty loam (Tp) is located on the level to gently sloping summit plateau of the crest of the Ruahine Range, (units 1 and 2, of Conacher and Dalrymple, 1977, see Fig. 26). Here, it occurs under a dense leatherwood vegetation, and is commonly about 0.5 metres thick. In local depressions, it may be considerably thicker than 1 metre and in very poorly drained areas the leatherwood succombs to a snowgrass vegetation.

Two profile descriptions given in the text are (a) of a modal profile, made toward the end of a dry summer; and (b) of a deeper version of the soil, made toward the end of the winter season (Fig. 15). It is likely that differences in soil colour and consistency between the two descriptions is due, in part, to a difference in drainage characteristics between the two soils, but also to a difference in soil moisture due to the time of year at which the respective profiles were described. Thus in profile (a): the Ha1 horizon has a less red hue than that of profile (b), and in Ha2 there are signs of mottling. Also, large shrinkage cracks which have formed after a long, dry period, and being characteristic of a peat, occur in profile (a) where the soil profile is exposed, i.e. at a roadside cutting, and on the bare ground surfaces.

(a) Takapari peaty loam (Tp)   Fig. 28

slope: 0 - 6°; elevation: approx. 1100-1300m

topography: summit plateau

drainage: poorly drained

vegetation: dense leatherwood scrub (*Olearia colensoi*), with snow grass (*Chionochloa pallens*) in very poorly drained areas.

classification: Lithic Borosaprist*

profile: (cm)

cm

0 +2-0
fresh to well decomp. org. litter

Ha1 0-12
dk brown (7.5YR 3/2) peaty loam; sl sticky; sl plastic, mod dev mdm - cse nutty structure; no stones; abundant f-cse roots.

Ha2 12-48
dk brown (7.5YR 3/2) peaty loam; sl sticky, sl plastic, mod dev. cse-v cse blocky structure; a few gwk chips (weathering to brownish yellow, 10YR 6/8) toward base; cmn mdm-cse roots; mottling increasing toward profile base, particularly assoc. with roots and worm channels.

(2) C on
weathering, shattered greywacke bedrock.

Genesis

The Takapari peaty loam occurs in a relatively stable area of low erosion potential. Due to a cold, wet climate, soil development on the gentle slopes of the summit plateau is slow with accumulation of organic matter being the dominant process. Thus a peat has developed at this elevation, with the process paludization (accumulation of a thick mass of organic materials in a poorly drained site) being operative. In the wet winter months it is probable that the soil profile is completely waterlogged and reduced. In the drier summer months, some mottling may occur in the profile, particularly associated with cracks and roots channels. A laboratory investigation of nitrogen mineralisation within the soil suggests that nitrification is inhibited, with a large percentage of the inorganic-N produced being present in the ammonium form (see Appendix IV).

Classification

These soils are classified as Borosaprists (Soil Survey Staff, USDA, 1975) on a basis of organic matter determinations, the pyrophosphate colour test and soil temperature regime. Profile (a), a modal profile, is considered to be a Lithic Borosaprist,* (see footnote) whilst profile (b) approaches a

---

* In order to slot profile (a) into the lithic subgroup, this Borosaprist is required by Soil Taxonomy to have a lithic contact within the control section. Clearly the organic soil material rests upon greywacke rock at a depth of about 0.5m, which is however shattered, so that cracks commonly occur at intervals less than 10cm, a condition which does not satisfy the definition of a lithic contact. However, no roots penetrate the cracks. Due to its fractured nature, chunks of greywacke may be dug out with difficulty with a spade - a criteria for the paralithic contact. However, it is improbable that greywacke fragments of U.S. gravel size (2-75cm) would disperse after end-over-end shaking in water or sodium hexametaphosphate solution, for 15-hours. Hence, the best available subgroup category is considered to be lithic. Thus, for the purposes of this survey a lithic contact is considered to occur where: "the shattered greywacke (with many cracks at intervals closer than 10cm, but without or only the barest minimum of root penetration down the cracks, and with gravel fragments (2-75cm) that can be broken out but do not disperse in sodium hexametaphosphate solution) occurs within the prescribed limits established for soil profiles consisting of mineral or organic soil materials".

In profile (b) (Fig. 15) weathering greywacke occurs at 105cm. One criteria for the definition of a Typic Borosaprist is that it does not have a lithic contact within the control section. The depth of the control section for a Histosol of sapric organic soil materials is 130cm. However, if a lithic or paralithic contact occurs at a shallower depth, this contact is taken

footnote (contd.)
as the base of the control section (p.68, Soil Taxonomy). Clearly the definitions for Histosols are confusing, and require better clarification. In this study profile (b) is considered to approximate most closely to the typic subgroup of the Borosaprist great group.

Typic Borosaprist* and represents an inclusion, where a greater depth of peat has accumulated in a depression in the underlying bedrock.

According to the N.Z. classification, the Takapari peaty loam is a very strongly enleached eldelodic soil, (common name: very strongly leached organic soil).

5.3.3 The Takapari hill soils (TpH)

Description

The Takapari hill soils (TpH) have developed below this relatively stable area, and occur on slopes of up to 30°, i.e. sloping interfluves, and on convex creep slopes. They are characterised by a peaty loam Ah horizon or a peaty Ha horizon, overlying a mineral soil.

At highest elevations and in local depressions, a peaty Ha horizon occurs, often with an Ah below it. In other places, a deep Ah horizon may be found. Below this is a grey, gleyed horizon, which is in most cases mottled. This can be as thick as 40cm to 50cm, although at lower elevations this reduces to the order of a few centimeters thick. In the former case a well developed iron pan (or placic horizon) occurs at the base of the poorly drained B horizon. This is cemented by black metallic-looking manganese in the top half, and a brown iron accumulation in the lower half. It is no greater than one to two centimetres thick, and is typically very wavy and discontinuous. With decreasing elevation, the depth of the overlying B horizon decreases, and the thin iron pan is seen to be less well developed, and not as cemented. The two features appear to be genetically related. Below the iron pan is a comparatively freely-draining horizon, derived from colluvial material. This overlies the basement greywacke which in places appears very weathered, and can be dug into with a spade. The total soil profile is commonly between 0.5 and 1.0 metres deep.

Two representative profile descriptions are given below:

(a) Takapari hill soil, (TpH) Fig. 29

slope: 12^{o}-30^{o}; elevation: approx. 1000-1100m

topography: convex creep slope, below summit plateau

drainage: poorly drained

vegetation: leatherwood scrub dominant, with some broadleaves, pepperwood, ferns, coprosmas, pink pine, Dracophyllum spps.

classification: Typic Placaquept.

profile:

cm

0+2-0
litter of leaves, twigs; well decomp. organic mat.

Ah0-18
dk brown (7.5YR 3/2) peaty loam; friable; mod. dev cse nutty structure; abundant f-cse roots (+ assoc incipient mottling); sl stony. Indistinct, wavy boundary.

Bg 18-40/56
dk greyish brown (10YR 4/2); v. stony silt loam; yellowish brown (10YR 5/6) mottles; mod. dev. cse blocky structure; firm; a few mdm-cse roots; mixing by native earthworms of overlying horizon materials. Distinct, wavy boundary.

Bms 40/56-41/57
discontinuous cemented pan, black at top, st. brown at base.

Cw 41/57-110
yellowish brown (10YR 5/6); extmy stony silt loam; gritty feel; no roots; wk. dev. f-mdm blocky structure to structureless

R on greywacke bedrock.

(b) Takapari hill soil (TpH)

slope: $12^{o}-30^{o}$; elevation: approx. 800m

topography: sloping interfluve, between two subcatchments

drainage: poorly drained

vegetation: Kamahi-broadleaf dominant, with some leatherwood scrub

classification: Typic Placaquept

profile:	O	+2-0cm	organic litter and well decomposed humus.
	Ahg	0-12cm	dk brown (7.5YR 3/2) peaty loam; dark yellowish brown (10YR 4/4) mottles; slightly stony; friable; moderately developed coarse nutty structure; abundant fine to coarse roots (with associated oxidation along root channels) Distinct, smooth boundary
	Bg	12-17cm	greyish brown (10YR 5/2) silt loam; slightly stony; friable; weakly developed medium blocky structure; a few roots; Distinct, wavy boundary
	Bs	17-18cm	accumulation of iron and manganese oxides, weakly cemented
	Bwg	18-40cm	yellowish brown (10YR 5/4) silt loam, with dark yellowish brown (10YR 3/4) mottles; stony; weakly developed coarse blocky structure; a few medium to coarse roots, friable.
	Cw	40-68cm	yellowish brown (10YR 5/6); very stony silt loam; friable with gritty feel;

weakly

		developed coarse blocky structure to structureless
2C	68+	greywacke bedrock

Genesis

The morphology of this soil indicates that gleying and/or podzolisation are occurring. Ross and Mew (1975) discuss some gley podzols from Westland, in South Island, New Zealand, which have certain morphological similarities to TpH. However, in the Westland soils, iron pans are more highly developed and are often associated with a zone of humic accumulation above them. These soils have formed on glacial outwash gravel surfaces and show a peaty topsoil, overlying a grey-olive impervious subsoil (sometimes with mottling) overlying an iron pan. They consider that these features of the soil, together with its waterlogged nature are features of gleying, rather than podzolisation. They suggest that podzolisation was once operative, and may still be today to some extent, but gleying is now the dominant process.

Crompton (1952) described the morphological features of some poorly drained soils in Great Britain, New Zealand and Australia. He describes a thin iron-pan soil occurring at altitudes above 305 metres in Scotland, where gleying occurs in a peat-forming climate. The morphology of the thin iron-pan soil is described as:

> "A peat surface, from a few inches to several feet thick, overlies a dull brownish-grey horizon which merges into pale blue-grey gleyed loam or clay loam resting sharply on a thin continuous hard iron-pan rarely more than ¼" thick, which in turn rests upon yellow-brown freely drained, or at the most, slightly imperfectly drained, C horizon".

This description bears a strong resemblance to that of TpH. Crompton (1952) suggests that this soil has developed as a result of reduction of iron in an horizon of gleying immediately beneath the peaty surface due to the peat acting as a sponge and maintaining saturated conditions immediately below it. Subsequently, the reduced iron is oxidised at a lower better drained part of the profile, and an iron pan slowly develops. Crompton suggests that the iron pan may deepen with age. If reduction and oxidation are the main processes involved in the pan genesis then the most intense and prolonged gleying might be expected above the shallow depressions of the incipient pan. With time, the intense gleying at these sites leads to further removal of iron to greater depths in the profile by means of a diffusion mechanism. Thus, the result is greater contortions in the form of the iron pan, as these depressions become enlarged.

Crompton (1952) and Stevens (1968) discuss and review literature concerning the genesis of gleyed versus podzolised soils. Stevens (1968) suggests possible mechanisms of podzolisation and gleying. He considers that the formation of a podzol, or spodosol (Soil Survey Staff, USDA, 1975), most likely involves the mobilisation (by chelation) and translocation of sesquioxides down the profile, with immobilisation, probably by microbiological destruction of the ligand in the spodic horizon.

In TpH a yellow-brown horizon of uncertain origin occurs beneath the placic horizon. To confirm whether this horizon beneath the placic horizon (i.e. below 56cm) is a spodic horizon or not, extractable iron and aluminium were obtained from samples taken at 10cm intervals down the entire profile. Two extraction techniques were used:

1) extraction with 0.1M sodium pyrophosphate, to extract predominantly organically complexed iron and aluminium, the form expected in a spodic horizon, and

2) extraction with sodium dithionite and citrate to extract predominantly inorganic amorphous iron and aluminium compounds, such as may be found in a cambic horizon of an Andept.

One of the criteria laid down by Soil Taxonomy (1975) for a spodic horizon is:

$$\frac{\text{\% of pyrophosphate extractable Fe and Al}}{\text{" " dithionite-citrate extractable Fe and Al}} \geqslant 0.5$$

The results obtained from the above analyses are shown in Fig. 30. They indicate that there has been little removal of iron and aluminium from the Bg horizon into the region below the placic horizon. There is a small amount of iron and aluminium accumulated at depth; but the ratio of pyrophosphate to dithionite-citrate extractable Fe and Al is 0.48, therefore not satisfying the criteria for a spodic horizon. Loss on ignition data indicates a minor accumulation of organic matter in the lower half of the profile.

The ratio of pyrophosphate to dithionite-citrate Fe and Al in the overlying Bg horizon ranges from 0.55 to 0.64. It is thus not strongly depleted of pyrophosphate extractable iron and aluminium, which would be expected for the albic horizon characterising a Spodosol. This can probably be accounted for by the fact that water movement through this soil, which occurs on slopes of up to 30^{o}, is lateral rather than vertical, so that the Bg (or Br) horizon never becomes strongly eluviated; with illuviation in the underlying horizon insufficient to produce a spodic horizon. The colour of this underlying horizon i.e. the one beneath the placic horizon indicates that iron is in its oxidised form, Fe^{3+}; and no mottles are apparent. The more freely-draining nature of this horizon may be explained by impedance of soil water movement at the placic horizon, with gleying occurring above this point. Thus, the horizon beneath the placic horizon remains relatively well aerated and weakly weathered, and is designated a Cw horizon (profile description **a**). At lower elevations in the catchment on the steeply sloping interfluves the iron pan is less well developed, and in places is largely uncemented. In this case, water is not impeded to such an extent and the underlying horizon is more strongly weathered. Some root penetration is possible with a slight increase in structural development and colour change. This horizon is therefore designated a Bw horizon (or Bwg, if mottling occurs), and may or may not be underlain by

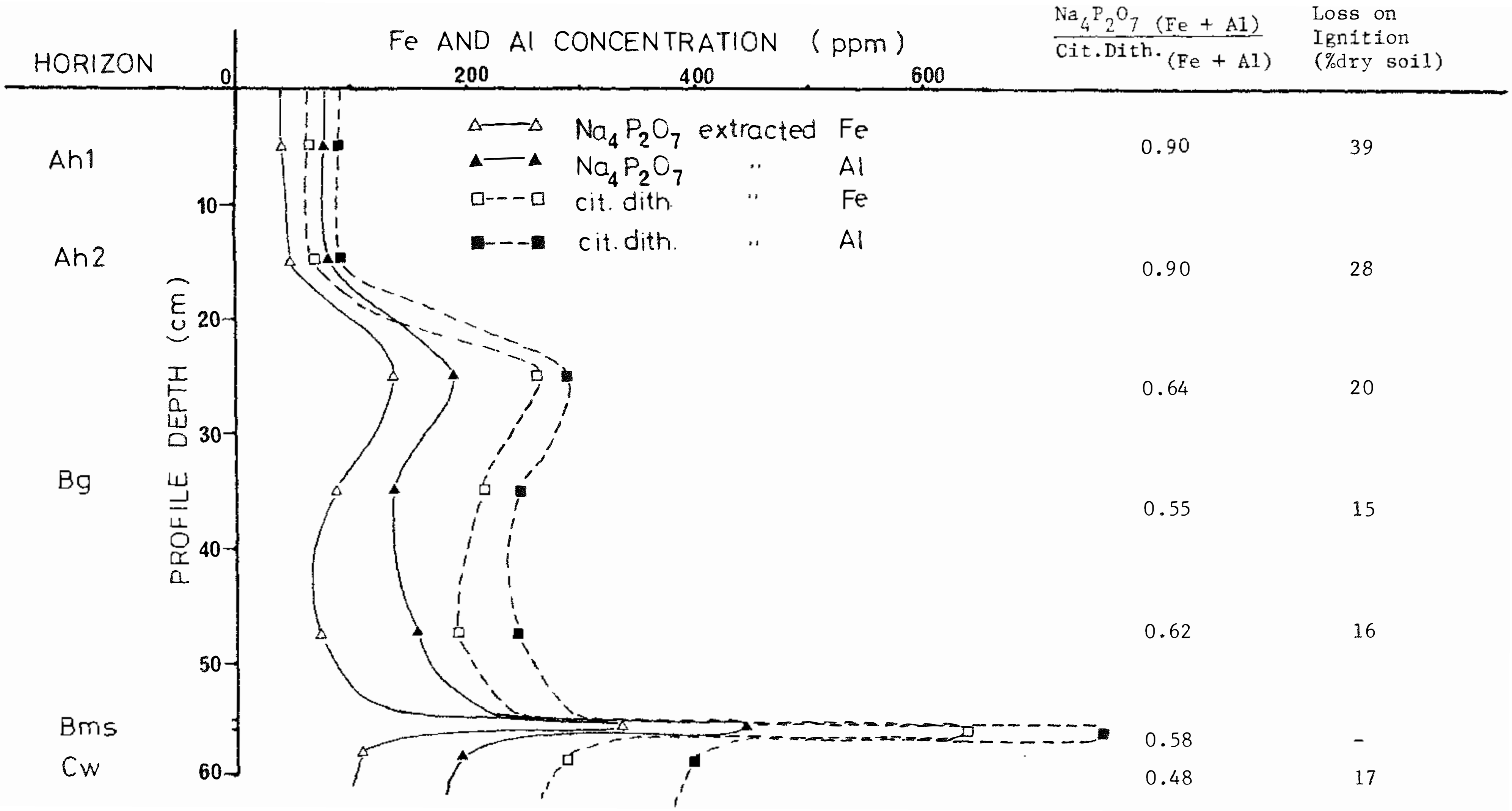


FIG. 30: IRON (Fe) and ALUMINIUM (Al) DISTRIBUTION IN THE SOIL PROFILE OF A TAKAPARI HILL SOIL.

a Cw horizon (profile description b).

Thus, it is considered that gleying is the dominant soil forming process in TpH; and podzolisation, if it does occur, is only a minor soil forming process. Accumulation and incorporation of organic matter take place, with decomposition being relatively slow so that a peaty topsoil develops. Pedoturbation by native earthworms is a significant process, with evidence of active burrowing in the majority of profiles. Leaching also occurs, with eluviation and deposition of iron and aluminium in the profile. Water movement through the profile is considered to be predominantly in a lateral direction, which may explain to some extent why the Bg (or Br) horizon does not fully develop into an eluvial (or albic) horizon.

Classification

The Bg (or Br) horizon satisfies the criteria for a cambic horizon. On a basis of its colour (a chroma of 2 or less, if mottling is present; or 1 or less if there is no mottling) together with the nature of the epipedon and the presence of a thin placic horizon within the modal profile, the soil is classified as a Typic Placaquept (Soil Survey Staff, USDA, 1975). In places on the convex creep slopes, where the epipedon has sufficient thickness and organic matter content to satisfy the criteria for a histic epipedon, inclusions of Histic Placaquepts may be found. At lower elevations, on the sloping interfluves, the iron pan is less well developed and largely uncemented. Here, it is likely that inclusions of Humic Haplaquepts will occur.

The Takapari hill soils have previously been classified as hill soils related to very strongly enleached eldelodic soils (common name: organic soils) in the New Zealand classification. However, on a basis of the present study, the profile development of these soils suggests that they are very strongly enleached madentic soils (gley soils), and as such bear little similarity to the Takapari peaty loam soils.

5.3.4 The Dannevirke soils

Description On the level to gently sloping surfaces, near the valley throats of (1) the subcatchment, and (2) the West Tamaki River catchment, a considerable accumulation of loess (0.5-2.0 metres) with a large contamination of tephric minerals, is found.

The soil developed in this parent material typically has a dark, nutty structured Ah horizon, overlying a friable, yellow-brown Bw horizon. Where the soil has developed on level to rolling topography (units 1 and 2 of Conacher and Dalrymple, see Fig. 26), i.e. on (a) depositional gravel surfaces at the valley throat, and (b) on ridge-crests (unit 1), it is virtually stoneless, (Fig. 31). On the moderately steeply sloping sides of the ridge-crests (unit 3) the soil is stony and admixed with loessial colluvium, especially toward the base of the solum . These are the hill soil equivalents of the more well developed stone-free soils, (Fig. 32). They have little or no O horizons and thinner A horizons.

The soils described in this survey have been compared with soils described in others surveys of adjacent areas. The stone-free soil resembles the Dannevirke silt loam, of the Dannevirke series, described by Rijkse (1977) as occurring on high terraces on the west side of the Range. Pohlen et al. (1947), when initially describing the series, commented on the occurrence of a Dannevirke heavy silt loam, in a few small areas at the foot of the Ruahine Range (about 30km north of the present survey area). It was noted that this soil type was stony in places.

A comparison of profile descriptions of the Dannevirke soils (Rijkse, 1977) with those of soils found within the survey area (not including the hill soils), indicate that texture, consistence, stoniness and horizon depths are similar in all horizons, and colours are identical for the B and C horizons. However, the soils of the present survey have a darker coloured A horizon and a difference in structural development. It appears that they are closely related to the Dannevirke silt loam, described by Rijkse; and have thus been mapped as a taxadjunct (similar to the New Zealand mapping unit, the variant, Taylor and Pohlen, 1970, see 5.3) of the Dannevirke silt loam (D tax), together with their associated hill soils (DH).

The Dannevirke hill soils (DH) are defined in this survey as those soils occurring on the flanks of the ridge-crests (unit 3 of Conacher and Dalrymple, 1977). Unlike the soils formed on the more stable sites, they have little or no O horizon, thinner A horizons, are stony throughout, and are formed in colluvial material, intimately mixed with the tephric loess parent material.

Representative profile descriptions of D tax and DH are given over:

Genesis

The Dannevirke soils exist in a relatively stable zone. Some bank erosion occurs, where these soils extend down to the main channel. However, the friable, freely draining D tax soils are in a zone of low erosion susceptibility. Major soil forming processes are the accumulation and incorporation of organic matter, with a moderate amount of leaching. Pedoturbation by native earthworms is often sufficient to produce an AB horizon; as well as numerous krotovinas of A horizon material in the B horizon, and vice versa (Fig. 33 a, b). The D tax soils maintain a good vegetative cover, with several mature podocarps. The average soil depth is calculated to be 100cm. A few small erosion features are associated with the DH soils. Small terracettes may be seen on the ground surface, and the soil morphology indicates that some soil creep is occurring. However, the friable, freely-draining nature of these soils means that root distribution is extensive, increasing their stability.

(a) Dannevirke taxadjunct (D tax) Fig. 31

slope: 0 - 12°; elevation: approx. 410m

topography: flat depositional surfaces, ridge-crests and footslopes at valley throats

drainage: well drained

vegetation: mature podocarp-hardwood forest

classification: Typic Dystrandept (or Typic Hapludand)

profile: cm

0 +5-0 fresh litter, well decom. humus.

Ah 0-24 v dk. brown (10YR 2/2) silt loam; friable with greasy feel; mod. dev. mdm to cse nutty structure; abundant f-cse roots.
Indistinct, irreg. boundary.

AB 24-34
dk. yellowish brown (10YR 4/4); silt loam; friable with greasy feel, mod. dev cse blocky structure, breaking to mdm nuts; many f-cse roots; a v few small gwk chips; interfingering of A horizon due to mixing by native earthworms.
Distinct, wavy boundary.

Bw 34-90
yellowish brown (10YR 5/6); silt loam; friable with greasy feel; mod dev. cse blocky structure; a v. few small gwk chips; a few cse roots with some dead and burnt tree roots evident. Indistinct, smooth boundary.

C 90-190
Lt. olive brown (2.5Y 5/4); silt loam; firm with sl. gritty greasy feel; massive; no roots.

R 190+
greywacke bedrock

(b) Dannevirke hill soil, (DH) Fig. 32

slope: 12°-30°; elevation: approx. 500m

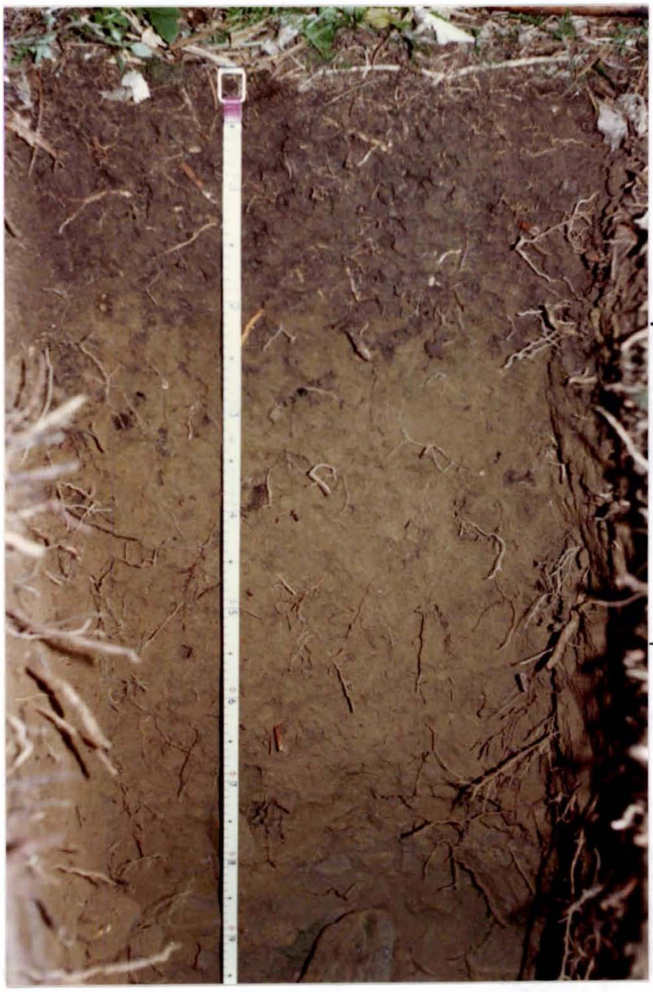
topography: moderately steep-steeply sloping flanks of ridge tops.

drainage: well drained

vegetation: mature podocarp-hardwood forest

classification: Entic Dystrandept (or Typic Hapludand)

profile: cm



0 +1-0
fresh litter of leaves and twigs.

Ah 0-17
v. dk. brown (10YR 2/2); stony silt loam; friable with greasy feel; mod dev. mdm. -cse nutty structure, abundant mdm-cse roots.
Distinct, wavy boundary

Bw1 17-57
dk. yellowish brown (10YR 4/4); v. stony silt loam; friable with greasy feel; mod. dev. cse. blocky structure; many mdm. -cse roots.
Indistinct, wavy boundary

Bw2 57-99
yellowish brown (10YR 5/4); v. stony silt loam; v. friable with greasy feel; wk. - mod. dev. cse.-v. cse. blocky structure; a few roots.

C on shattered greywacke bedrock.

Fig. 33 Native Earthworm and Native Earthworm Burrows

(a) The presence of native earthworms in many soil profiles undoubtedly has an important effect on soil forming processes and soil profile development.

SCALE
10 cm

(b) Native earthworm krotovinas of A horizon material in the underlying B horizon.

APPROXIMATE
SCALE
1 cm

Classification

The D tax soils are classified as Typic Dystrandepts (or Typic Hapludands, using G. Smiths provisional classification of Andisols, 1978); whilst the modal DH soil is classified as an Entic Dystrandept (or Typic Hapludand) on a basis of field and laboratory data. Bulk densities, pH in NaF, 15 bar water retention (of dried and undried samples) values, sand and clay mineralogy studies and P retention values (Appendix V) all suggest that the exchange complex of these Dannevirke soils is dominated by amorphous materials, (see also Chapter 6).

Thus, according to the New Zealand classification these soils are classified as alvic soils (yellow-brown loams). This is in contrast to previous New Zealand classificaitons of the Dannevirke series (e.g. Rijkse, 1977) where it has been classified as an alvi-fulvic soil (common name: intergrade between yellow-brown loam and yellow-brown earth).

5.3.5 Recent Soils (R)

Description These soils occur on recent depositional gravel surfaces i.e. terraces and fans, on the stream channel bed, where alluvium has accumulated (i.e. unit 7, of Conacher and Dalrymple, 1977). The alluvium forming the parent material for these soils is characteristically coarse, angular greywacke gravels, sometimes interbedded with finer silty and/or sandy beds. The soils formed within these alluvial materials, in the Car Park Creek area, have an accumulation of organic litter on their surfaces to a thickness of several centimetres, and a poorly expressed Ah horizon overlying the greywacke gravels. They characteristically contain no B horizon, although many fine roots penetrate down through the C horizon, indicating the initiation of pedogenesis below the Ah horizon. A representative soil profile description is given below (see also Fig. 23).

Recent soil, (R)

slope: level - gently sloping, 0-6°

topography: terrace surface in main channel

drainage: well drained

vegetation: toetoe, grasses, few small shrubs

classification: Typic Udifluvent

profile:	0	+10-0	root mat , litter, humus, fine gravels
	Ah	0-12	very dark greyish brown (10 R 3/2); extremely stony loamy sand; soft consistency; weakly developed fine crumbs around roots; abundant very fine-medium roots.
	C	12-100+	stratified greywacke gravels, with silts and sands.

Genesis

The extent of soil development on depositional gravel surfaces depends on the age of the surface. Thus, an investigation of soil development on a number of depositional surfaces can be used as an aid in the chronological ordering of these surfaces, as discussed in Chapter 4. Soil formation is initiated by accumulation of organic matter on the surface of the gravel deposit, and an Ah horizon develops as roots and their associated soil fauna penetrate the soil. Soil development appears to progress more rapidly in a parent material with a greater proportion of finer-textured materials within the gravels. Fig. 22 indicates the limited extent of colonisation of a terrace surface formed,three years prior to the date when this photo was taken,during Cyclone Alison. Evidence suggests that complete colonisation of the surface of such gravel deposits will take at least 10-20 years. After 40-50 years, the surface is colonised with mahoe trees, grasses, ferns, lianes, thistles and foxgloves, and after 90-100 years there has been sufficient time for a young stand of trees to develop (e.g.

red beech, in the case of the Stanfield Hut terrace surface).

Classification

These soils which have little evidence of pedogenic horizons are classified as Udifluvents, being Entisols which have formed on depositional surfaces on the stream channel bed. They are free-draining, with colour values which satisfy criteria for the typic subgroup of Udifluvents.

In the New Zealand genetic classification they are luvic soils, i.e. recent soils rejuvenating by water-borne accumulation.

5.4 GENERAL DISCUSSION

Within the survey area the distribution of soil classes is associated with specific geomorphic surfaces (classified according to the nine-unit landscape model, of Conacher and Dalrymple, 1977). At highest elevations on level to gently sloping surfaces (landsurface units 1 and 2), the Takapari peaty loam (Tp) occurs. Below this on sloping interfluves, and the convex creep slopes (landsurface unit 3), the Takapari hill soils (TpH) occur. These are a distinct grouping of soils, and unlike the Tp soils, their peaty topsoils are underlain by 0.5 to 1.0 metres of mineral soil. The Ruahine steepland soils (RuMS, RuS, RuVS) occur on moderately steep to very steep valley-sides (units 4,5,6) of the subcatchment. On the interfluves at lower elevations, and their gently sloping footslopes (units 1 and 2), the Dannevirke taxadjunct soils (D tax) have developed, and on the more steeply sloping flanks of the interfluves (unit 3), the Dannevirke hill soils (DH) occur. Soil morphology of DH closely resembles D tax, although it is slightly less well developed, and contains a large number of stones. On the young discontinuous depositional surfaces (unit 7), on the stream channel bed, Recent soils occur. These are extremely stony with little or no B horizons. At many sites these soils bury older soils which have formed during a prior stable period.

Erosion is a particularly important process affecting the development of Ruahine steepland and Takapari hill soils. Virtually all of the erosion in Car Park Creek occurs within the areas mapped as these two soils.

Relatively deep soils form on the crests of the interfluves. At lower elevations the Dannevirke soils occur, but with increasing elevation these soils become more strongly leached, and the A horizons become more peaty. The soils become imperfectly drained, and iron and aluminium becomes reduced and mobilised within the profile. An incipient iron pan is seen at approximately 750 metres elevation. With increasing elevation, the peaty nature of the Ah horizon increases, the mottling of the Bh horizon becomes more intense (ultimately developing into a Br horizon) and cementation and thickness of the iron pan increases. Thus the Dannevirke soils grade upwards into the Takapari hill soils with increasing elevation.

The average soil depth of the TpH soils is equivalent to the DH soils i.e. 70cm. However, root distribution is impeded by the imperfectly drained nature of the B horizon and the underlying iron pan. No roots penetrate below this iron pan, and as the Bg horizon becomes increasingly more developed, conditions for root growth become increasingly adverse. On the convex creep slope at the head of the subcatchment, root abundance decreases markedly between the Ha (or Ah) and underlying B horizons. Vegetation on this soil unit is typically scrubby with only a few large podocarps at lower elevations. Much of the root growth is lateral rather than vertical.

The TpH soils occur in a zone characterised by deep-seated erosion scars. Examples of rock and debris slides, debris avalanches and gully erosion may be seen in Car Park Creek, within this mapping unit. It is likely that soil creep together with creep of underlying colluvial materials is a dominant process in this zone, responsible for large-scale terracette features, seen on the landscape in this area (Fig. 7).

CHAPTER SIX

AN INVESTIGATION OF SOIL PARAMETERS RELATED TO SOIL GENESIS AND ERODIBILITY

CHAPTER SIX

AN INVESTIGATION OF SOIL PARAMETERS RELATED TO SOIL GENESIS AND ERODIBILITY

6.1 INTRODUCTION

Soil-water relationships are an important factor in understanding erosion processes within a catchment (see Chapter 2.5), and a number of measurements have been made to characterise such relationships in the present study.

Saturated hydraulic conductivity measurements were made on cores taken from both surface and subsurface horizons of selected profiles.

Total porosity and macroporosity of the different soil units were measured. In this study, total porosity is defined as the fraction of the total volume of a piece of soil that is occupied by air and water, (Gradwell, 1971). Macroporosity, the amount of large pores (New Zealand Soil Bureau, 1968), is defined as the fraction of soil volume drained by a matric potential * of -49mb (-50cm) of water (Gradwell, 1968).

---

* The term "matric potential" is used throughout the text to describe the soil water energy status. It is defined as "the amount of work that must be done per unit quantity of pure water in order to transport reversibily and isothermally an infinitesimal quantity of water from a pool containing a solution identical in composition to the soil water at the elevation and the external gas pressure of the point under consideration to the soil water" (Commission, 1, I.S.S.S., 1963). The matric potential is commonly measured by applying a suction to the soil, and relating the suction force to moisture content. For an unsaturated soil, the matric potential is a negative quantity, as water from the reference pool would flow readily into the soil, with a release of energy. Below a free water table (i.e. when the soil becomes saturated), the matric potential becomes zero.

The term macroporosity is synonymous with "aeration porosity" as used by, for example, Townsend (1973) and Kohnke (1968), and refers to pores greater than 0.06mm in diameter (Townsend, 1973). Macroporosity is an important factor affecting rainfall acceptance and transient storage of water within a soil, as discussed by Periera, (1955). It is likely to be related to the ultimate infiltration capacity of a soil with the topsoil macroporosity being a particularly variable property at any one site (New Zealand Soil Bureau, 1968).

Loss on ignition (approximate organic matter content) and bulk density data were also obtained. It is considered that these factors are related to structural stability, aeration and water movement within a soil, as discussed by, for example, Meeuwig (1971) and Gradwell and Arlidge (1971). Meeuwig (1971) found organic matter to be the most important soil parameter affecting erodibility in high elevation rangeland in U.S.A.; and Gradwell and Arlidge (1971) found that signs of progressive deterioration of soil structure, where soils had been used for market gardening over a period of twenty or more years, were related to decreases in organic carbon content. The latter workers also discuss the soil dry bulk density, and its indirect relationship with root growth and aeration.

Estimates of available water-holding capacity, (AWC) were made. This is defined as the amount of water held by a soil between Field Capacity and Permanent Wilting Point. Field capacity is approximated by an estimate of soil water content after initial rapid drainage, and lies in the range -49mb to -350mb (Russell, 1973). In this study it was taken to be the water content at -49mb. Permanent Wilting Point is approximated as the soil water content at a matric potential of -15 bars, below which water becomes unavailable for plant use.

The 15-bar water retentions of (i) field moist soils and (ii) soils, air-dried as a pretreatment, were measured and the decrease in value of (ii) compared with (i) was noted. The magnitude of this decrease in

15-bar soil water retention, between soils, previously undried and previously air-dried (hereafter referred to as the "drying effect") is considered to be a measure of amorphous clay content, (G. Smith, 1978).

The importance of soil water retention values to erosion studies has been discussed by workers such as Jackson (1966) and Ward (1975). When soil is saturated, a positive soil-water pressure develops, the shear strength of the soil is reduced, and in turn, the likelihood of soil movement downslope is increased. Consequently a soil, in which the soil-water characteristics promote its tendency to become saturated, under the prevailing environmental conditions (e.g. low macroporosity, low hydraulic conductivity and small A.W.C.) has a greater susceptibility to erosion than one in which saturation is not likely (e.g. high hydraulic conductivity, large macroporosity, large A.W.C.).

The sand and clay mineralogies of selected soils were also investigated. These provide information about the nature and provenance of soil parent materials, and also indicate the amount of weathering that has occurred in the respective soil profiles, (Chapter 2.5).

6.2 SOIL PHYSICAL PROPERTIES

6.2.1 Materials and Methods

Soil samples were collected from: 1) modal profiles of the soil mapping units, and 2) a number of other selected sites for investigation. Undisturbed cores and clods were collected in the field for hydraulic conductivity, bulk density and porosity measurements. Field moist, finely aggregated soil was used to estimate 15-bar water retention values. Bulk soil samples, collected in the field, were used for particle density, pH and loss on ignition analyses.

6.2.1.1 Particle Density, (P.D.)

The method described by Gradwell (1971) was used. It was considered that some of the samples may have an allophanic component. It has been found that P.D's calculated for oven-dried allophanic soils are smaller than those calculated on the moist sample. Thus, moist soils were used in this study, and the dry weight of soil was not obtained until after the other relevant measurements were made.

6.2.1.2 Bulk Density, (B.D.)

Bulk density of samples was measured, using 2 techniques. Triplicate measurements were made for each soil horizon of each modal soil site.

Method 1 The dry B.D. of soils was estimated, using the procedure of Gradwell (1971). Thin-walled metal cylinders, of internal dimensions 50mm long by 48mm wide, were used to collect intact cores from the field. The area ratio* of these cores was 0.14.

The soil cores were dried in a ventilated oven at 105°C, for 24 hours, before being weighed. Then:

$$\text{dry bulk density} = \frac{\text{dry weight of soil (kg)}}{\text{volume of cylinder (m}^3\text{)}}$$

Method 2 In the case of weakly structured, stony soils, difficulties were encountered in taking intact cores, as described above. Invariably, stones were pushed by the corer into or away from the soil cores, causing considerable disturbance of the soil structure. In these cases an alternative method for calculation of B.D. was used.

---

*Loveday, 1974, discusses soil sampling techniques for physical measurements; and considers that an important characteristic of a core sampler is its area ratio:

$$\text{Area ratio} = \frac{\text{area of the annulus of displaced soil}}{\text{" " " sample at the cutting edge.}}$$

It is considered that for minimum, or negligible disturbance of the structure in the sample, the sampler should have as low an area ratio as possible, certainly no greater than 0.15.

Although, this method is generally considered less preferable than Method 1 (Loveday, 1974) it was considered that in the existing situation it would provide more accurate results. This method was also used for comparison with results obtained by Method 1.

Intact clods of soil were collected in the field for porosity measurements as described below. Particle densities were also measured for these soils. Thus, B.D. was estimated for clods using the formula:

$$B.D. = (1- \text{porosity}) \times \text{particle density} \quad (kg.m^{-3}).$$

6.2.1.3 Total Porosity and Macroporosity

Porosity measurements were made, using the procedure detailed in Methods of Soil Analysis, Part 1 (American Society of Agronomy, 1965). The apparatus consists of a burette connected by means of plastic tubing to a Buchner funnel, the burette and funnel forming the two arms of a U-tube. The porous plate of the Buchner funnel consists of sintered glass which can withstand a pressure difference of about 100mb, without air entry.

Samples were undisturbed clods of soil, collected in the field, and sealed in a plastic bag to retain their moisture. The samples were of a large enough size to approximate the field conditions of porosity; but small enough to fit into the Buchner funnel without touching the sides. To ensure good contact between the sintered glass plate and soil clod, loose soil particles were sprinkled onto the plate, before placement of the clod.

A petri dish was placed over the top of the Buchner funnel, and a plug of cotton wool in the top of the burette to minimise loss of water by evaporation.

Total porosity was calculated by measuring the amount of water held by the soil at saturation, i.e. zero pressure potential. In practice the soil was considered to be still saturated at -3mb (-30mm) matric potential, so that there was no free water standing above the sintered glass plate.

All measurements were calculated as the difference in height between the meniscus in the burette, and the centre of the clod.

The amounts of water, which drained out of the sample at matric potentials of -20mb (-200mb) and -49 mb (-500mm) were also noted. In most cases, the soils were left for several hours to equilibrate at a certain water potential. Soil samples were not allowed to dry out before placement on the plate, so that equilibration could be reached relatively quickly.

Total porosity was calculated using the formula:

$$f = \frac{t_f}{t_f + v_s}$$

and macroporosity was calculated using the formula:

$$mf = \frac{v_m}{t_f + v_s}$$

where f = total porosity

mf = macroporosity

t_f = total volume of water in clod, at saturation,

v_s = volume of soil solids

v_m = volume of water held between saturation and -49mb matric potential in clod.

Between 3 and 10 replicates were used for each soil horizon.

6.2.1.4 Saturated Hydraulic Conductivity (Ksat)

A method developed by Corker (1977) was adopted for the measurement of Ksat of three soil profiles in the laboratory. Cores (four replicates) were taken from two depths in two localities for the Takapari hill soils. Cores (four replicates) were taken from three depths at one locality for the Dannevirke taxadjunct soil.

Soil cores, 75mm long and 75mm wide, were obtained using standard soil core sampling equipment (Richards, 1954). The cores were carried back to the laboratory, and processed the next day. This involved gently pushing the core out of its aluminium liner and coating it, by painting on hot, melted paraffin wax. This method prevents any seepage down the sides of the soil core whilst measurements are being made. The liner was attached by wax to the top of the soil core to hold a constant head of water. A funnel was attached to the base of the soil core to direct the effluent into a measuring cylinder. Across the top of the funnel a layer of tissue paper and fine mesh netting was waxed to the base of the soil core to prevent soil aggregates and loose particles from breaking off. The processed core was clamped into position and a constant head of water applied to its surface. Any leaks in the wax coating were detected at this time, and coated over with some additional layers of melted wax.

The rate of movement of water through the core was estimated by collecting the effluent in a measuring cylinder over a certain time period. Hydraulic conductivity was then calculated using Darcy's Law (see e.g. Marshall, 1967):

$$\mathrm{Ksat} = \frac{Q}{A\ \left(\frac{1}{1+h}\right)} \quad \mathrm{mm.day}^{-1}$$

where Q = flow rate ($\mathrm{mm}^3.\mathrm{day}^{-1}$)

A = surface area of soil core (mm^2)

l = length of soil core (mm)

h = head of water above soil core (mm).

Measurements were made as soon as possible after the soil was sampled because it was considered that with time, microbial activity might change the channel system within the core altering the value for Ksat. Also, water was added to the surface of the soil core through a paper tissue, minimising compaction effects at the surface, which might decrease infiltration rates.

6.2.1.5 15 bar Water Retention (Permanent Wilting Point, P.W.P.)

The 15 bar water retention of soils was measured on:

(1) undried samples, in order to estimate the available water-holding capacity (A.W.C.) of soils (in conjunction with estimates of field capacity, F.C.), where

$$\text{A.W.C. (vol. vol.}^{-1}\ \%) = (\text{F.C.} - \text{P.W.P}) \times \text{dry bulk density (km.m}^{-3}).$$

In the present study, it was considered that gravimetric soil water content, at a matric potential of -49mb is an approximate measure of field capacity; and gravimetric soil water content at a matric potential of -15 bars is an approximate measure of permanent wilting point.

(2) undried and air-dried (overnight, at 40°C) samples, in order to estimate the "drying effect"(i.e. the decrease in 15 bar water retention of an air-dried soil, compared with values given by an undried soil, being calculated as a percentage of the original undried values) which is used as a crude measure of amount of amorphous material present. This is necessarily a rough estimate, the amorphous material existing in many different forms and hydration states in the soil. Thus the "drying effect" will depend on the initial hydration state of the amorphous material.

A pressure plate apparatus, as described by Gradwell (1971) was used to determine the water content of soil samples, equilibrated at a pressure of 15 bars, for one week. Soil samples, which consisted of fine aggregates with some loose material, were lightly packed into rubber rings, 10mm long and 52mm wide, and placed on a ceramic plate. These were thoroughly wetted, and left for a few hours (undried samples) or overnight (dried samples) to ensure that the whole soil was saturated before a pressure of 15 bars was applied. The 15 bar water retention is then calculated as the gravimetric water content of soils, which attained an equilibration water content under a pressure of 15 bars, after one week.

$$15 \text{ bar water retention} = \frac{\text{weight of water}}{\text{weight of dry soil}^{*}} \times \frac{100}{1} \%$$

6.2.1.6 Loss of Weight on Ignition

Over-dry soil samples (105^{o}C) were ignited for 0.5 hour at 700^{o}C in a muffle furnace, to give an approximate figure for organic matter content, (Bear, 1969). A number of test runs, in which samples were heated for 0.5 1.0, 2.0, 4.0 and 6.0 hours, indicated that there was no further loss of weight after the first 0.5 hour. This time was thus considered adequate to give complete combustion of the sample at this temperature. This method only gives an approximate estimate of organic matter because during ignition some structural water is also lost from the clay fraction, so that the loss of weight value may be an overestimate for organic matter. However, the accuracy of this method was considered adequate because organic matter data was required primarily for comparative rather than absolute values.

6.2.1.7 Soil pH in (a) Water and (b) Sodium Flouride, (NaF)

(1) The pH of soil samples was measured in a 1:2.5 soil:water suspension. The suspension was left overnight, and the pH was then read with electrodes in the supernatant liquid, (N.Z. Soil Bureau, 1968).

(2) To investigate amorphous material content, the pH of a suspension of 1.0g of soil in 50ml of IN NaF was recorded after two minutes (using the method of Soil Taxonomy, Soil Survey Staff, USDA, 1975). If amorphous materials are present the fluoride ions replace hydroxyl ions from the colloidal surface with a resultant increase in pH value. For the exchange complex to be dominated by amorphous materials (if there is sufficient clay to have a 15 bar water content, of previously dried soil, of ⩾20%), the pH (in NaF) is required to be greater than 9.4 (Soil Taxonomy, 1975).

---

* the soil is dried overnight, at a temperature of 105-110^{o}C.

6.2.2 Results and Discussion

6.2.2.1 Particle Density (P.D.) and Bulk Density (B.D.)

Results for particle density (P.D.) and bulk density (B.D.) are given in Table 7. Fig. 34 displays the results for B.D. graphically. The P.D.'s of soils in the study area are influenced by three factors: amounts of tephric material, amounts of non-tephric material and amounts of organic matter. (The P.D. of dominant soil minerals, such as quartz and feldspar is near 2650kg.m^{-3}, and the density of organic matter is usually between 1300kg.m^{-3} and 1500kg.m^{-3}). Table 7 shows that surface horizons have the lowest values for P.D.; the Takapari peaty loam (Tp) and topsoil of the Takapari hill soils (TpH) having particularly low values due to their peaty nature.

The B.D. of a soil gives some indication of its structural condition. Low B.D.'s usually indicate an open structure and therefore a large capacity for water storage. Heinonen (1954, cited in Marshall, 1967) found that, in clay soils, available water-holding capacity varies inversely with B.D.. He attributed this to more open granular aggregates in soils of lower B.D. (see also Fig. 38). The structural randomness of amorphous clay constituents in the soils helps to create a loosely packed soil structure, with resultant friable consistency.

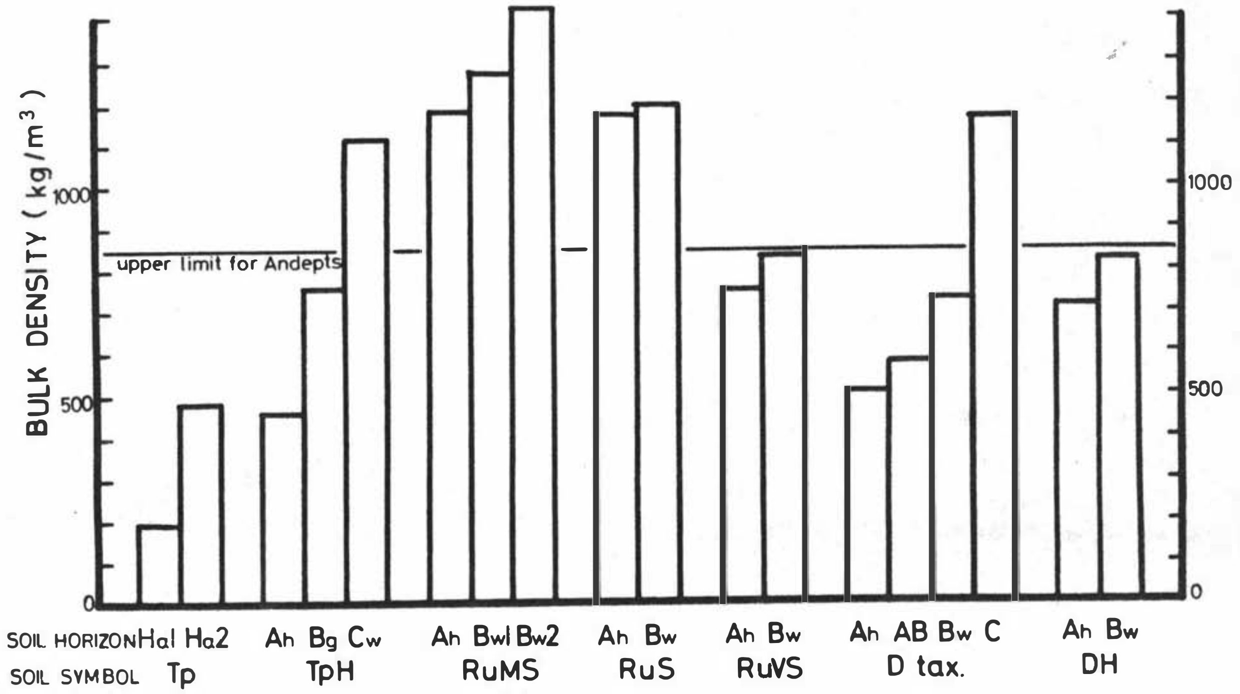
B.D. values are particularly low in the Ha and Ah horizons of Tp and TpH respectively, and are highest in the Ruahine steepland soils (RuMS, RuS, RuVS). TpH shows a large change in B.D. with depth. It is possible that extremely low values for B.D. in Tp reflect the presence of amorphous clays as well as a large amount of organic matter present in the soil.

The Dannevirke soils (D tax., DH) have low B.D.'s, which are attributed to their large amorphous clay component. The Ah horizon within TpH has a slightly lower B.D. value than the Dannevirke soils, due to a greater

TABLE 7: BULK DENSITY AND PARTICLE DENSITY VALUES FOR SELECTED SOIL PROFILES OF THE STUDY AREA

SOIL NAME	SOIL SYMBOL	HORIZON SAMPLED	BULK DENSITY CLODS	BULK DENSITY CORES	PARTICLE DENSITY
			km/m^3		
Takapari peaty loam	Tp	Ha1	190	190	1790
		Ha2	460	480	2240
Takapari hill soils	TpH	Ah	460	-	2030
		Bg	760		2470
		Cw	1110		2540
Ruahine steepland soils mod. steep - steep phase	RuMS	Ah	1180	-	2560
		Bw1	1270		2650
		Bw2	1420		2650
steep phase	RuS	Ah	1170	-	2620
		Bw	1190		2650
very steep phase	RuVS	Ah	750	750	2430
		Bw	830	830	2590
Dannevirke silt loam taxadjunct	D	Ah	500	470	2210
		AB	580	540	2290
		Bw	730	630	2630
		C	1160	-	2650
Dannevirke hill soils	DH	Ah	710	700	2350
		Bw	820	760	2650

FIGURE 34: A HISTOGRAM TO SHOW THE BULK DENSITY VALUES FOR EACH SOIL CLASS



organic matter content. The lower horizons within TpH have markedly increased B.D. values due to lower organic matter contents. Bg is still probably dominated by amorphous clay components having a bulk density of less than 850kg/m^3; however, the underlying C horizon has a B.D. of 1110kg/m^3.

The Ruahine steepland soils have higher B.D. values. Due to their occurrence on unstable sites, accumulation of low B.D. materials e.g. loess (with tephric components, weathering to amorphous clays) or organic matter, is minimal, and these soils are dominated by the accumulation of greywacke materials in a weakly structured soil.

The RuVS soil selected has a relatively well developed profile, with a thin Bw horizon. It is considered that it formed in a relatively stable pocket, on very steep terrain, surrounded by less well developed soils. Its B.D. values indicate that some tephric loess may have accumulated at this point, and this is confirmed by sand mineralogical evidence.

6.2.2.2 Total Porosity and Macroporosity

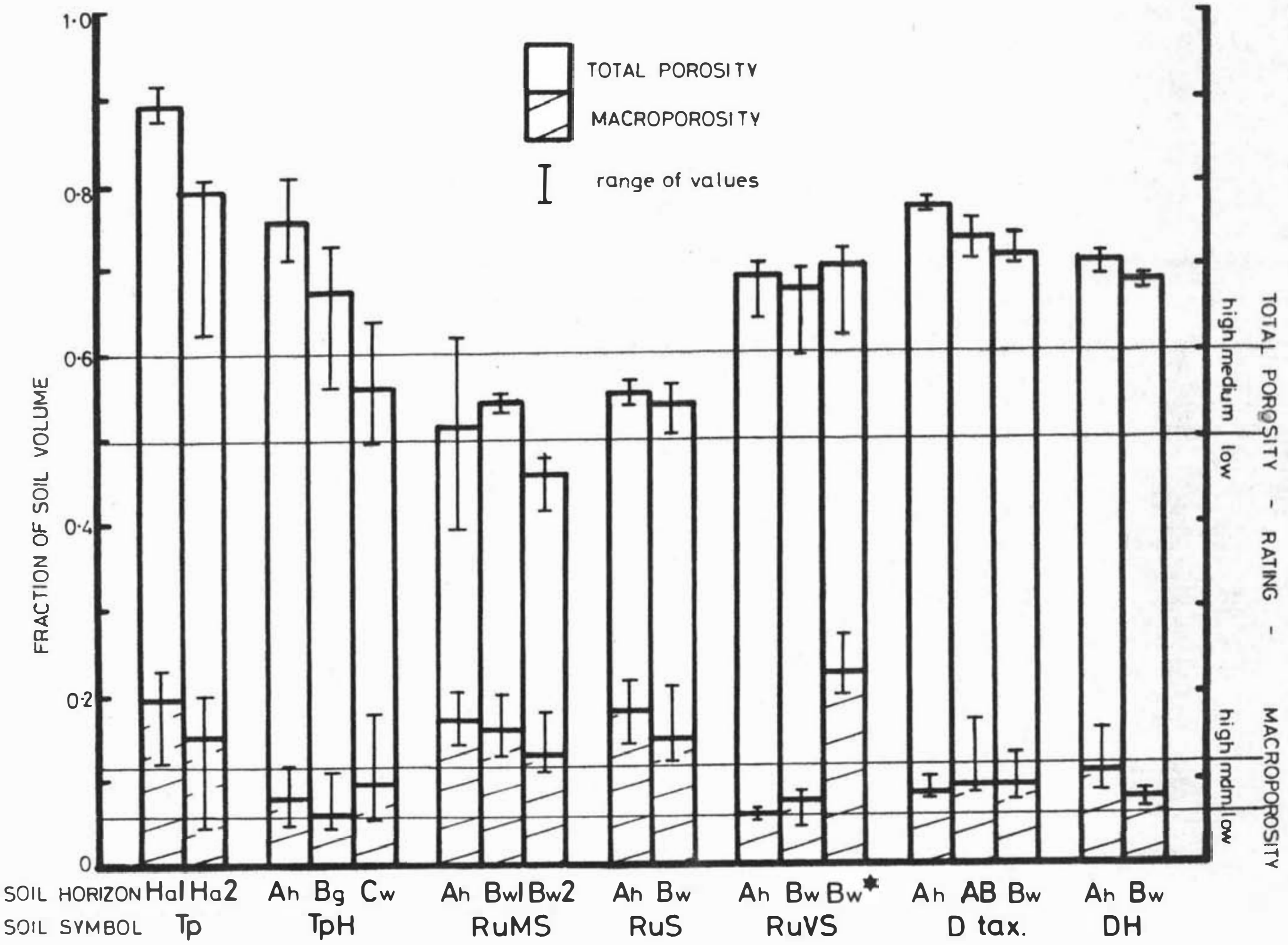
Total porosity and macroporosity data for the selected soil samples is shown in Fig. 35. This indicates that the range of values for many samples was considerable (between ± 0.015 and ± 0.3 for total porosity data, and ±0.1 to ± 0.8 for macroporosity data). Thus, within any soil horizon total porosities (and macroporosities to a greater extent) will vary considerably over short distances. However, a certain number of broad trends in the results are evident, which are discussed below. Also, results are given for a Bw horizon, in which native earthworm activity had produced krotovinas,* approximately 15mm in diameter.

Total porosity values show a general decrease with depth in most soil profiles. Since organic matter tends to improve soil structure, and hence increase total porosity, as mineral grains are less tightly packed, this

---

* Krotovina: an infilled tunnel in a soil horizon generally filled with material from another horizon.

FIGURE 35: TOTAL POROSITY AND MACROPOROSITY OF SELECTED SOIL SAMPLES.



*RuVS Bw horizon with krotovinas.
Total porosity and macroporosity ratings of New Zealand Soil Bureau, 1968.

trend may be related to a decrease in organic matter content with depth. Macroporosity values show this trend to a lesser extent, in the majority of profiles, suggesting that macropores are not as simply related to organic matter values. It is probable that macroporosity is also affected by the presence of roots, stones, earthworm channels and possibly inorganic amorphous materials. Macroporosity is seen to remain relatively constant with depth in the Dannevirke taxadjunct soil, probably due to the exchange complex being dominated by amorphous material.

The presence of Ah horizon material, as a krotovina, in the selected Bw horizon sample, gave a "high" porosity value (using the rating system of N.Z. Soil Bureau, 1968). It also gave a particularly large value for macroporosity at 22.6%. It is highly probably that preferential movement of air and water would occur in krotovinas. Such krotovinas were of common occurrence in the study area.

The Takapari hill soil (TpH) profile is of particular interest. The percentage of macropores decreases in the Bg (or Br) horizon, and then increases in the Cw(or Bw) horizon. The value for the Bg horizon is infact the lowest value for macroporosity in all soils tested. This suggests that drainage in the Bg horizon is poor, and that the Cw horizon is relatively well drained. This is substantiated by the soil morphology which shows considerable gleying in the Bg horizon, occurring above a freely-drained lower horizon.

RuMS and RuS, two soil phases of the Ruahine steepland soils, have the lowest values of total porosity, having "low-medium" ratings. However, they have "high" values for macroporosity. This suggests that such soils will drain relatively rapidly and have a relatively low storage capacity. This effect was also noticed by McDonald (1961) when discussing some physical properties of New Zealand soils from greywacke parent material. The soil profile from the third phase, RuVS, has a larger total porosity, suggesting a greater content of organic matter and improved structural development, compared with RuS and RuMS soils. This evidence further substantiates the suggestion that the atypical nature of the selected RuVS soil is due to its formation in a relatively stable pocket.

6.2.2.3 Saturated Hydraulic Conductivity (Ksat)

The hydraulic conductivity values for three soil profiles are shown in Table 8 and Fig. 36. Ksat values for the Takapari hill soils (TpH) are of particular interest in the present study, since they occur in a zone susceptible to soil creep and mass movement. The Dannevirke taxadjunct soil profile (D tax) was sampled for comparison. The D tax soils occur on ridge-sites at lower elevations in the catchment, and are well-drained. The TpH soils occur at higher elevations on ridge-sites and convex creep slopes and are poorly to very poorly drained.

Ruahine steepland soils were not tested. It was considered that sampling of these stony to extremely stony soils on steep to very steep terrain was impracticable for the purposes of the present study. Their morphology indicates that they are rapidly draining, as does the macroporosity data.

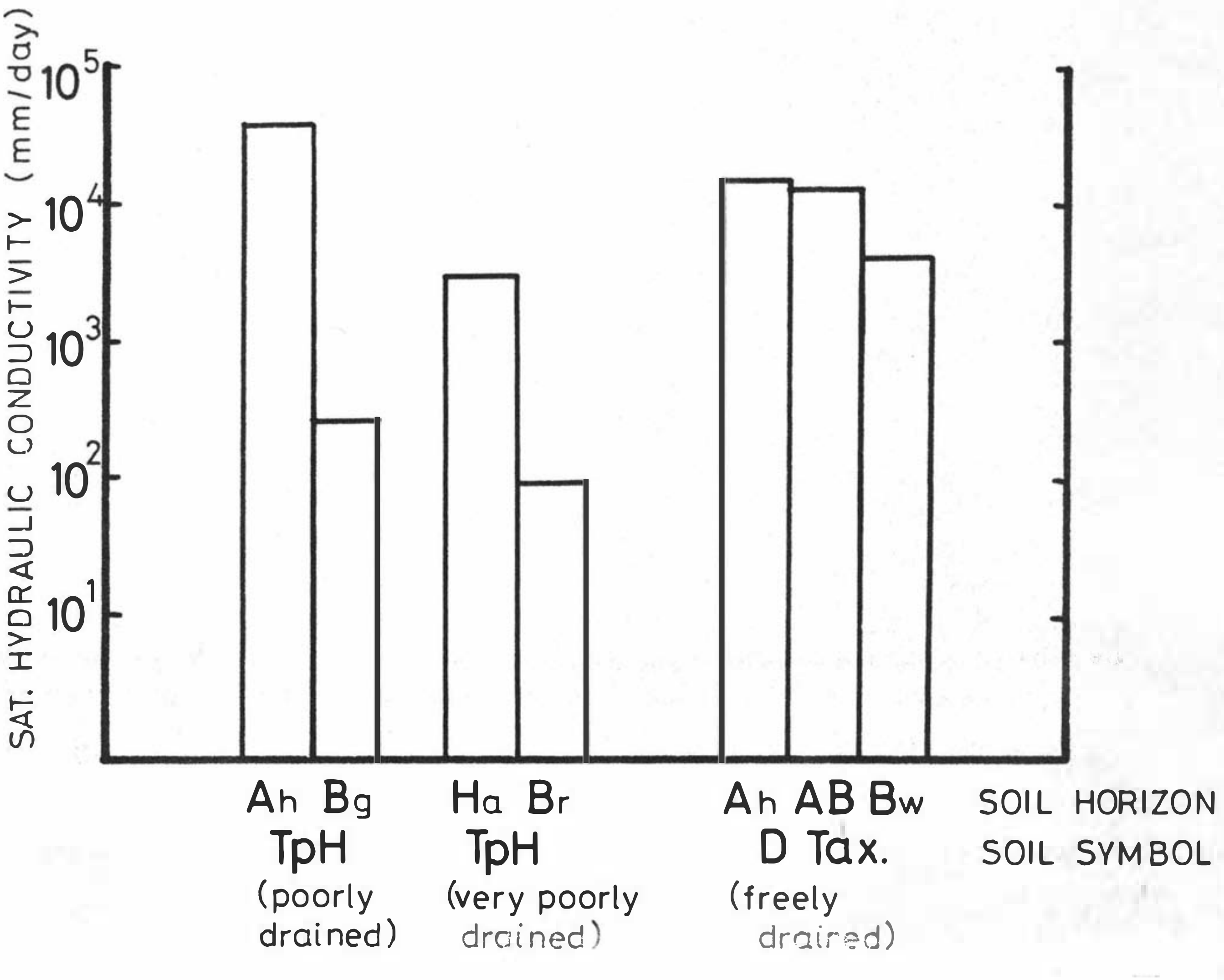
Ksat values for the surface horizons of TpH and D tax soils (sampled at a depth of 0-75mm) were very rapid in the majority of cores tested, and of the order of 10^3-10^4mm.day^{-1}. This data gives an indication of the infiltration rate into the surface soil. The Ksat values for the surface horizons far exceed the 24-hour one-year event rainstorm intensity of 60mm.day^{-1}, calculated for the West Tamaki River catchment, (Martin, pers. comm). Thus, it is probable that the infiltration capacity of the surface soil would seldom be a limiting factor to water intake, and the likelihood of surface runoff is small.

In comparison with the D tax soil (see Fig.36), the TpH soils show a marked decrease in Ksat in the Bg (or Br) horizon compared with the upper horizons, some of the cores having extremely low values (0.1mm. day^{-1}).

TABLE 8: SATURATED HYDRAULIC CONDUCTIVITY DATA FOR SELECTED SOILS

SOIL NAME	SOIL SYMBOL	DRAINAGE CHARACTERISTICS	HORIZON SAMPLED	Ksat (mm day^{-1})		PERMEABILITY RATING (Smith & Browning, 1946)
				RANGE OF VALUES	AVERAGE	
Takapari hill soil	TpH	poorly drained	Ah	7,139-92,534	39,654	v. rapid
			Bg	10- 738	286	slow-rapid
Takapari hill soil	TpH	very poorly drained	Ha	170-11,669	3,191	mod.-v. rapid
			Br	0.1- 408	102	extrmly slow-moderate
Dannevirke taxadjunct	D tax	freely drained	Ah	9,677-26,470	15,356	v. rapid
			AB	10,368-18,851	13,671	v. rapid
			Bw	1,152-7,416	4,594	rapid-v rapid

FIGURE 36: K sat VALUES FOR THREE SELECTED SOIL PROFILES.



This suggests that water movement through this B horizon is considerably impeded and a perched water-table may develop at its upper boundary. Thus, water infiltrating rapidly through the surface horizon will be impeded to a large extent on encountering the underlying Bg (or Br) horizon. This, together with the steepness of slope, suggests that interflow is likely to occur within the TpH soils and may be an important soil process governing the likelihood of slope failure in these soils.

The very poorly drained TpH soil has lower Ksat values than the poorly drained TpH soil. The Br horizon of the former soil has extremely slow to moderate permeability, compared with slow to rapid permeability of the Bg horizon of the poorly drained soil (using the rating system of Smith and Browning, 1946). Thus, Ksat appears to be one factor explaining the slightly different morphologies of these two soils.

Within several of the subsurface cores of the D tax soils, krotovinas were present. In all cases these gave the highest Ksat values measured in the survey indicating that water movement through these porous infilled tunnels imparts more freely draining characteristics to the soil. The Ksat values for the AB and Bw horizons of the D tax soil are considerably larger than for the B horizons of the TpH profiles. It is concluded that the different soil morphologies of the D tax and TpH soils is a reflection of different drainage characteristics between the soils, expressed by the Ksat values measured.

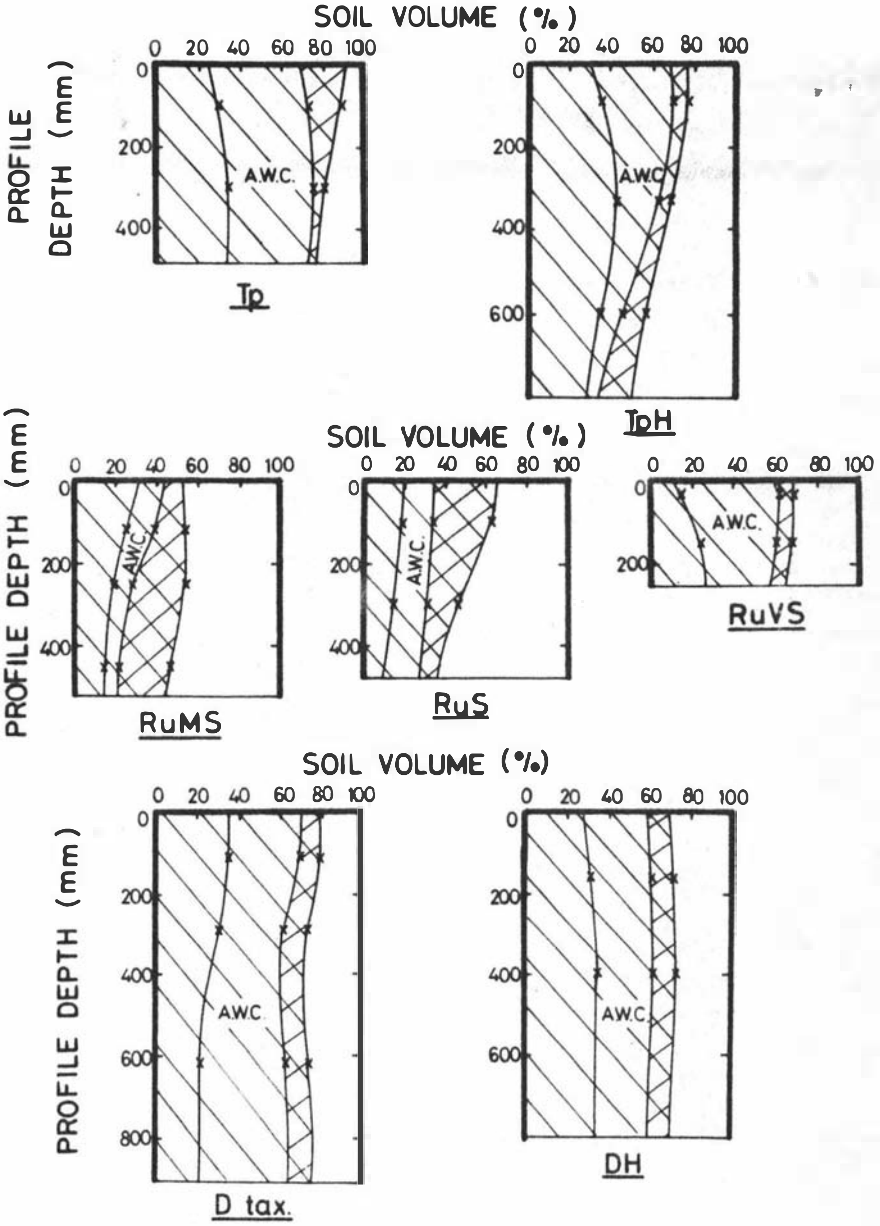
6.2.2.4 Soil Water Retention and Available Water-holding Capacity (A.W.C.)

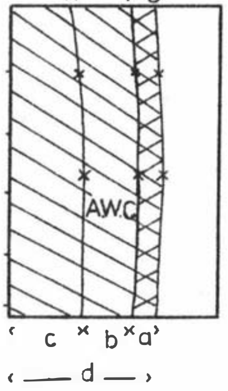
Water retention values for selected soils are given in Table 9, and illustrated in Fig. 37. The A.W.C. has been calculated as the difference between the volumetric water content, at a matric potential of -49mb (≃ Field Capacity, F.C.) and -15 bars (≃ Permanent Wilting Point, P.W.P.).

TABLE 9: SOIL WATER RETENTION VALUES AND AVAILABLE-WATER CAPACITY (A.W.C.) OF SELECTED SOIL SAMPLES

SOIL NAME		SOIL SYMBOL	HORIZON	VOLUMETRIC WATER CONTENT (% soil volume) at			A.W.C.	TOPSOIL RATINGS FOR A.W.C. (McDonald, 1961)
				SATURATION (Omb) (total porosity)	FIELD CAPACITY (-49mb) (macro-porosity)	WILTING POINT (-15 bars)	(FIELD CAPACITY - WILTING POINT) (% soil volume)	
Takapari peaty loam		Tp	Ha1	89	71	28	43	high
			Ha2	80	76	35	41	
Takapari hill soils		TpH	Ah (Ha)	76	68	34	34	high
			Bg (Br)	67	58	42	16	
			Cw (Bw)	56	45	38	7	
Ruahine steepland soils	mod. steep-steep phase	RuMS	Ah	51	39	24	15	medium
			Bw1	54	27	19	8	
			Bw2	45	20	14	6	
	steep phase	RuS	Ah	61	32	17	15	medium
			Bw	44	28	17	11	
	very steep phase	RuVS	Ah	69	63	17	46	high
			Bw	67	54	25	29	
Dannevirke silt loam taxadjunct		D	Ah	77	68	35	33	high
			AB	73	63	-	-	
			Bw	72	61	39	22	
			C	58	51	32	19	
Dannevirke hill soils		DH	Ah	71	60	33	27	high
			Bw	69	59	35	24	

FIGURE 37: WATER RETENTION CHARACTERISTICS OF SELECTED SOIL PROFILES.





KEY

a = freely draining porosity (0 to-50mb)

b = A.W.C. (-50mb to -15bars)

c = water unavailable to plants (>-15bars)

d = total porosity

Water Content at:
W = Wilting Point (-15bars)

F = Field Capacity (-50mb)

S = Saturation (0mb)

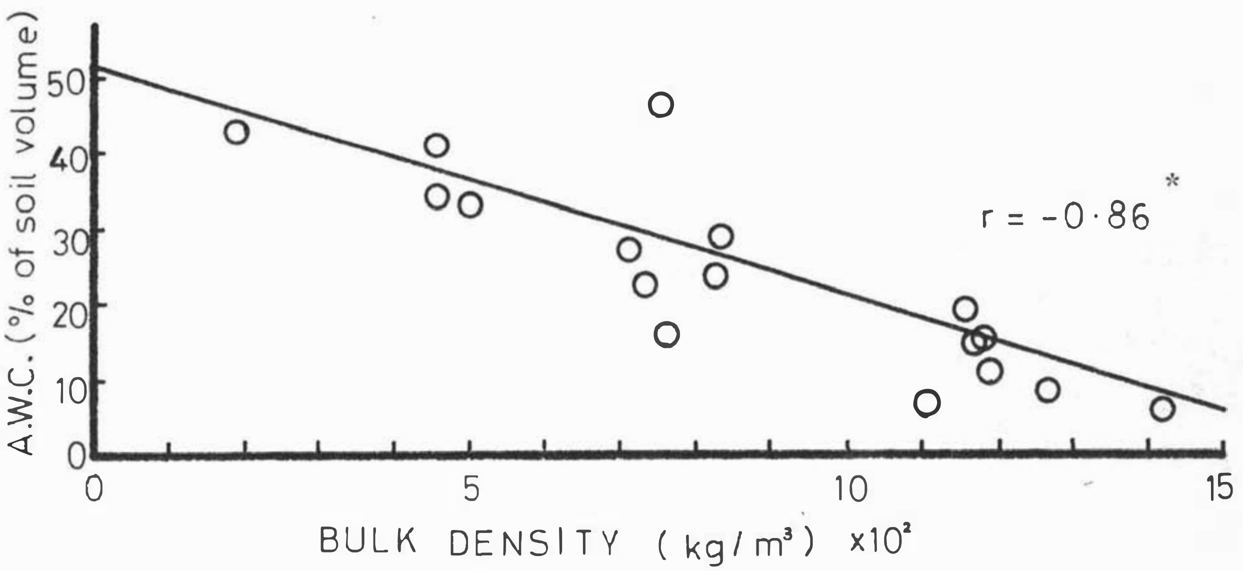
Table 9 shows that all topsoils, except those of RuMS and RuS, have a high A.W.C., being greater than 22% (using the rating system of McDonald, 1961; N.Z. Soil Bureau, 1968). Values for the organic soil, Tp, are particularly high due to a very large organic matter content and low bulk density. The Ruahine steepland soil, moderately steep phase, RuMS, has the lowest value for A.W.C. This soil also has lowest values for organic matter and highest values for bulk density. There is an obvious relationship between A.W.C., bulk density and organic matter. Regression lines between these parameters are shown in Fig. 38 and 39. They show a negative correlation between A.W.C. and bulk density (Fig. 38), and a positive correlation between A.W.C. and organic matter (Fig. 39), significant at the 1% level.

The A.W.C. is the maximum amount of water that is available to plants. In most cases, the soil is below F.C., and less water will be available. Thus, it appears that RuS and RuMS (see Fig. 37) are the soils most likely to induce droughtiness during a dry spell, their ability to store water being considerably smaller than the other soils. This will in turn adversely affect plant growth, and thus decrease the stability contributed by the root system to the solum.

Fig. 37 illustrates the amount of water that is unavailable to plants held at matric potentials greater than -15 bars. It constitutes more than twenty percent of the total soil volume in all horizons of the TpH and DH soils. The same holds for the D tax soil except for the Bw horizon. It seems likely that this water is largely associated with the organic matter and amorphous clay fraction.

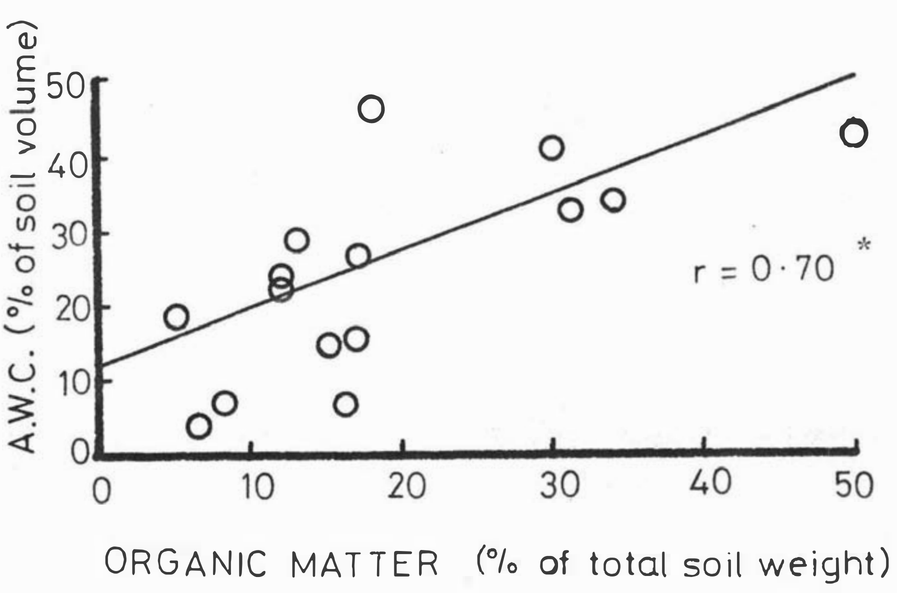
A.W.C., together with Ksat rates, indicate the rate with which a soil will approach saturation, a soil property previously discussed as an important factor in soil erosion studies. Thus, a soil with a small A.W.C. and low Ksat is slowly drained and most likely to become saturated. The RuMS and RuS soils have the smallest values for A.W.C. However, macroporosity

FIGURE 38: THE RELATIONSHIP BETWEEN AVAILABLE WATER-HOLDING CAPACITY AND BULK DENSITY IN SOIL SAMPLES FROM CAR PARK CREEK.



* significant at 1%

FIGURE 39: THE RELATIONSHIP BETWEEN AVAILABLE WATER-HOLDING CAPACITY AND ORGANIC MATTER IN SOIL SAMPLES FROM CAR PARK CREEK.



* significant at 1%

values indicate that they are rapidly drained, so that saturation of these soils may not occur. However, their small storage capacity suggests that they will wet up to field capacity relatively quickly in the autumn months.

In the case of TpH, the surface horizon has a large A.W.C. with a markedly decreased value in the Bg horizon. This information together with macroporosity and Ksat values substantiate the argument that 1) drainage is impeded in the B horizon, relative to the A horizon, and 2) a perched water table may develop at the junction of these two horizons, and in sufficiently wet conditions at the base of the B horizon (where water movement is impeded) at the iron pan. This perched water table will develop upwards during a wet period, thus creating a zone of saturation within the soil, which in turn may result in greater susceptibility to soil creep or mass movement on a slope.

6.2.2.5 15 bar Soil Water Retention, and the Effect of Drying

The effect of air drying (40^{o}C, for 24 hours) as a pretreatment on the ability of soils to retain water at a matric potential of -15 bars, i.e. the "drying effect", was investigated. A provisional suggestion has been made by G. Smith (1978) that the percentage decrease in 15 bar water retention between undried and dried soil samples is a crude estimate of the amount of amorphous clay present.

Results obtained are summarised in Table 10. They indicate a relatively large "drying effect" in Tp, TpH and D tax soils, with the smallest effect noted in the RuS soil. These values for percentage decrease of undried 15 bar water retention, ranging between 13% and 65%, may be compared with values obtained for some yellow-brown loam soils from Taranaki, which gave values between 66% and 83%, (G. Smith, 1978).

The relationship of soil water retention values, and thus A.W.C., to organic matter has been previously shown (Fig. 39). The relatively

TABLE 10: THE EFFECT OF DRYING ON 15 BAR WATER RETENTION VALUES OF SELECTED SOIL SAMPLES

SOIL NAME		SOIL SYMBOL	HORIZON	15 BAR WATER RETENTION (gravimetric water content, minus stones)		Δ	"DRYING EFFECT" (see p.7)
				undried	dried		
Takapari peaty loam		Tp	Ha1	148.58	70.48	78.1	52
			Ha2	75.52	39.71	35.81	47
Takapari hill soils		TpH	Ah	72.72	48.10	24.62	34
			Bg	55.77	34.39	21.38	38
			Cw	73.96	28.98	44.98	61
Ruahine steepland soils	mod. steep-steep phase	RuMS	Ah	35.15	28.04	7.11	20
			Bw1	25.89	18.37	7.52	29
			Bw2	22.33	13.74	8.59	38
	steep phase	RuS	Ah	28.16	22.71	5.45	19
			Bw	16.42	14.33	2.09	13
	very steep phase	RuVS	Ah	44.01	28.00	16.60	37
			Bw	39.34	25.59	13.90	35
Dannevirke taxadjunct soil		D tax	Ah	72.34	39.76	32.58	45
			Bw	58.28	20.10	38.18	65
			C	27.84	15.96	11.88	43
Dannevirke hill soil		DH	Ah	55.08	34.85	20.23	37
			Bw	47.98	24.25	23.73	49

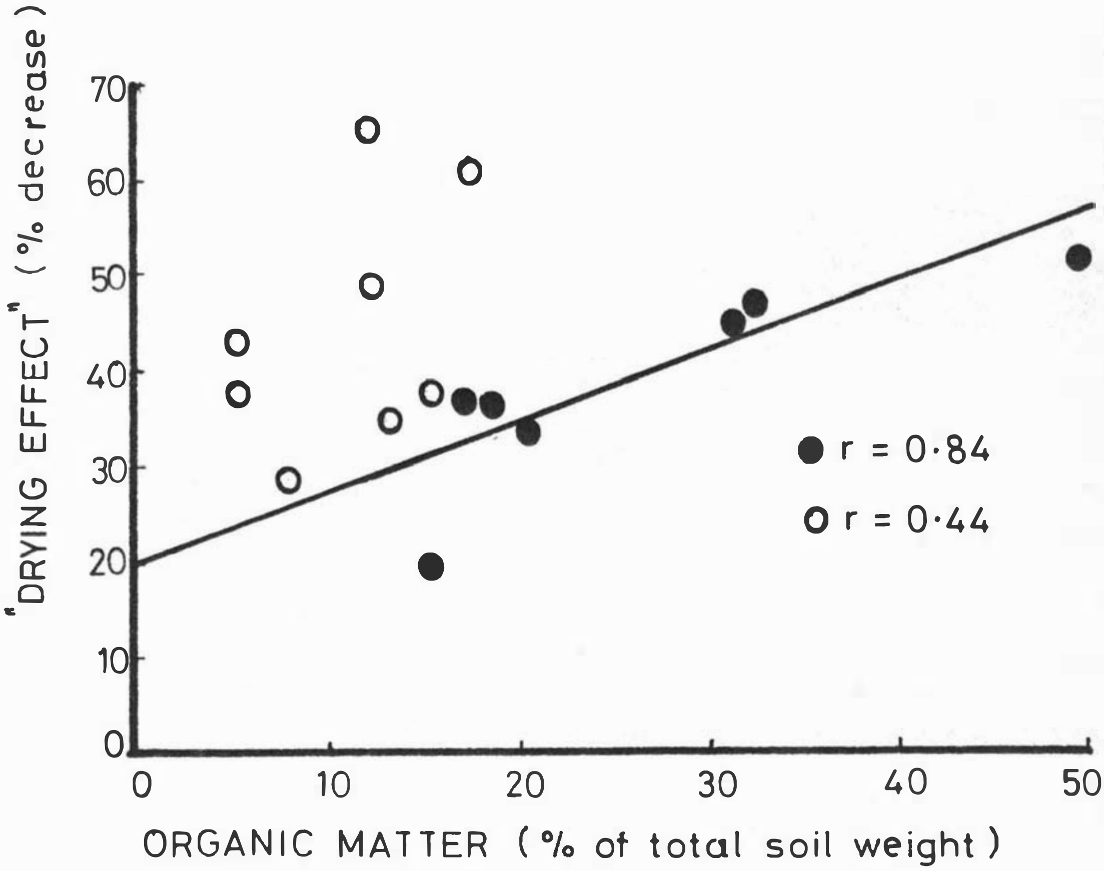
high "drying effect" values for Tp (Table 10) indicate that:

1) organic matter may have some part to play together with amorphous clays in the "drying effect", or
2) these soils contain the greatest amounts of inorganic amorphous constituents.

Fig. 40 shows the relationship between the "drying effect" and organic matter values for all the selected soil samples. Correlation between these two factors, for Ah and Ha horizons, is 0.84, which is significant at the 2% level. The regression line for this set of data is shown in Fig. 40. The correlation between the "drying effect" and organic matter in the B and C horizons is not significant. The data therefore indicate that organic matter has a significant influence on the "drying effect" in Ah and Ha horizons. However, in the underlying B and C horizons, where organic matter levels are lower, the amorphous clays seem to have an overriding influence on the "drying effect", suggesting that this measure for amorphous material is best suited to subsurface horizons which have relatively low organic matter contents. It is also possible that these two factors are interrelated, so that the "drying effect" of the amorphous clays is influenced by the amount of organic matter in the soil.

The particularly large effect of drying in the Cw horizon of TpH, and the Bw horizon of D tax indicate that these subsurface horizons contain a significant amount of amorphous clays. The "drying effect" values for Ruahine steepland soils are seen to be minor in the RuS soil, and greatest (on average) in the RuVS soil. In the RuMS soil, the values are seen to increase with depth, which may be partially explained by a difference in the initial hydration status of the clays. Thus, it is possible that the degree of hydration of the soil clays is comparatively low in the surface horizon, due to air-drying effects after a long dry summer, together with a possible desiccating effect of winds. The "drying effect" is expected to be less for soil clays with an initial low hydration status, compared with those

FIGURE 40: THE RELATIONSHIP OF ORGANIC MATTER TO THE EFFECT OF DRYING ON 15bar WATER RETENTION VALUES FOR SELECTED SOIL SAMPLES.



O B and C horizons, r = 0·44, not significant.

● A and H horizons, r = 0·84, significant at 2%.

"DRYING EFFECT" - for definition see 6.1.

having a higher hydration status.

6.2.2.6 Loss of Weight on Ignition

Organic matter levels are closely related to physical characteristics of the selected soil samples, and are approximated by loss of ignition data, shown in Table 11. The Ruahine steepland soils, which are characteristically weakly structured, are seen to have the lowest loss on ignition values.

Soils on stable sites contain the greatest amounts of organic matter, as accumulation is greatest there. Thus the Tp soil of the summit plateau has developed into a peat under adverse conditions for rapid decomposition. Accumulation of up to approximately 50% organic matter has occurred in the upperpart of the profile. TpH and DH contain less organic matter than their counterparts Tp and D tax (which occur on more stable sites) as reflected in the loss on ignition values.

6.2.2.7 pH Values in (1) Water and (2) Sodium Fluoride

(1) The pH (in water) values indicate that relatively acidic conditions occur in soils, at higher elevations (i.e. Tp, TpH), in which the pH is seen to vary between 4.1 and 4.9, with a slight increase with depth. These low values are adverse to active microbial activity, and together with relatively low mean annual soil temperatures ($<8^{o}C$), help to explain slow decomposition rates in these soils. The D tax and DH soils have slightly higher pH's, between 5.2 and 5.7. In these soils there is less accumulation of organic materials on the surface, and it seems probable that they maintain an active microbial population, aiding the breakdown and admixing of organic materials. The Ruahine steepland soils show a comparatively wide range of pH values. A general trend exists for the pH of all the soils in the study area to decrease with increasing age and weathering, (Table 12).

(2) the pH (in NaF) of soils has been used as a measure of amorphous material content (Soil Survey Staff, USDA, 1975), with the requirement that the water retention of the previously dried soil is greater than twenty percent at

TABLE 11: LOSS OF WEIGHT ON IGNITION DATA FOR SELECTED SOIL SAMPLES

SOIL NAME		SOIL SYMBOL	HORIZON	LOSS OF WEIGHT ON IGNITION (% of dry soil)
Takapari peaty loam		Tp	Ha1 Ha2	49% 32%
Takapari hill soils		TpH	Ah (Ha) Bg (Br) Cw	20% (51%) 15% (15%) 17%
Ruahine steepland soils	mod. steep - steep phase	RuMS	Ah Bw1 Bw2	15% 8% 5%
	very steep phase	RuVS	Ah Bw	18% 13%
Dannevirke taxadjunct		D tax	Ah Bw C	31% 12% 5%
Dannevirke hill soils		DH	Ah Bw	17% 12%

TABLE 12 pH VALUES IN (1) WATER, and (2) SODIUM FLUORIDE

SOIL NAME		SOIL SYMBOL	HORIZON	pH in water (1:2.5)	pH in Sodium Fluoride (NaF) (1:50)
Takapari peaty loam		Tp	Ha1	4.5	7.4
			Ha2	4.6	8.3
Takapari hill soil		TpH	Ah	4.1	7.4
			Bg	4.6	7.7
			Cw	4.9	9.3
Ruahine steepland soils	mod. steep-steep phase	RuMS	Ah	6.2	7.5 *
			Bw1	5.7	7.5 *
			Bw2	6.0	7.5 *
	steep phase	RuS	Ah	5.5	7.5 *
			Bw	5.7	7.5 *
	very steep phase	RuVS	Ah	5.4	7.5 *
			Bw	4.8	8.3
Dannevirke taxadjunct		D tax	Ah	5.2	7.5 *
			Bw	5.5	10.7 **
			C	5.4	10.4 **
Dannevirke hill soil		DH	Ah	5.7	7.7
			Bw	5.7	10.4

* water retention at -15 bars, for previously dried soil is <20%, thus precluding these results from use for Soil Taxonomy classification uses.

** pH in NaF is >9.4, and therefore amorphous material dominates the exchange complex (Soil Survey Staff, USDA, 1975).

-15 bars tension. Thus it excludes certain horizons of the Ruahine steepland soils. The results show that the D tax and DH soils have B and C, and B horizons respectively in which the exchange complex is largely composed of amorphous materials. The presence of amorphous materials in the Bw horizon of RuVS, which is suggested by pH (in NaF) values, is supported by "drying effect" and bulk density data. Relatively high pH (in NaF) values are also noted in subsurface horizons of Tp and TpH. The high organic matter contents of the surface horizons may be obscuring the presence of amorphous materials to this test, an observation also made by G. Smith (1978) in West Indian and South American soils, (Table 12).

SECTION THREE : SOIL MINERALOGY

6.3.1 Sand Mineralogy

6.3.1.1 Materials and Methods

A small portion of the sand fraction (63-125μm) was extracted from selected soil samples (which had been previously air-dried, and passed through a 2mm sieve) in the following manner. Approximately 20g of this <2mm soil fraction was placed in a beaker, to which hydrogen peroxide (6% H_20_2) was added. A more concentrated solution of hydrogen peroxide ($\leq$ 30%) was required for soils with a high organic content. The beaker was slowly heated on a water bath, with further additions of H_20_2, until quiescence. The reaction was taken to completion on the water bath at 100°C for a few hours, and left overnight to cool slowly. The remaining <2mm mineral fractions were placed in centrifuge tubes, with distilled water. A few drops of 1:1 NH_4 solution was added to disperse the clays, and these fractions were ultra-sonically vibrated for three to four minutes to improve dispersion.

The <1.0μm clay fraction was then removed, by decantation of a suspension obtained by centrifuging the soil suspension at 1000rpm for 8.5 minutes. The decantates were kept for clay mineralogical studies.

The remaining coarse clay, silt and sand was dried in an evaporating dish, at 105°C. The 63-125μm sand fraction was obtained by dry sieving. A subsample of this fraction was mounted on a microscope slide in Lakeside Cement, for investigation, using a petrological microscope. Point count analysis of each slide was used as a method to estimate percentages of minerals present; with a minimum of 300 grains being counted on each slide.

6.3.1.2 Results and Discussion

Results of point count analyses are indicated in Table 13. They show that quartz, greywacke rock fragments and rhyolitic glass are the most frequently occurring grains.

The presence of cummingtonite was also noted in the An horizon of the Dannevirke taxadjunct (D tax) soil, which indicates one source of the tephric components to be the Haraharo Rhyolite Complex in the Okataina Volcanic Centre (Ewart, 1968). The presence of andesitic ash in the form of microlites of feldspars and mafics held together in a glassy mesostasis was carefully examined. A few grains were seen to have this appearance in the Takapari peaty loam (Tp) and D tax soils, and it seems likely that some andesitic ash is present in these soils. If greater amounts of andesitic ash were originally present in the soil, they have been largely converted to other minerals, such as allophane, or possibly weathered to a smaller size fraction. Contamination of these soils by andesitic tephras is also suggested by the presence of hornblende (which is common in intermediate igneous rocks, such as andesite, but rare in greywacke and rhyolite), and also hypersthene (common in andesitic rocks).

The composition of plagioclase feldspars was investigated, where possible, using the Michel-Lévy Method (see e.g. Kerr, 1959). Oligoclase (An 25%) and albite (An 10%) were identified in the Takapari hill soils

TABLE 13: SAND MINERALOGY OF SELECTED SAND FRACTIONS OF SAMPLES FROM THE STUDY AREA

SOIL	HORIZON	QUARTZ	FELDSPAR	MICA	GREYWACKE ROCK FRAGMENTS	RHYOLITIC GLASS	HYPERSTHENE	AUGITE	HORNBLENDE	MAGNETITE	ZIRCON
		% of sand fraction									
Dannevirke taxadjunct (Dtax)	Ah	C	c	-	a	a	S	S	R	R	R
	Bw	a	c	-	C	C	c	S	R	S	-
	C	a	c	-	a	c	S	R	R	R	-
Dannevirke hill soil (DH)	Ah	C	C	R	a	C	S	S	S	R	R
	Bw	a	c	R	a	C	S	S	R	S	-
Takapari peaty loam (Tp)	Ha1	C	C	R	S	a	c	c	S	S	-
	Ha2	C	C	S	S	a	c	c	S	S	R
Takapari hill soil (TpH)	Ah	a	C	R	c	a	S	S	S	R	-
	Bg	a	c	-	C	C	c	S	R	S	-
	Cw	a	C	-	C	C	S	R	-	S	-
Ruahine steepland soil (RuVS)	Ah	a	C	-	C	C	S	S	R	-	-
	Bw	a	C	R	C	C	S	S	R	S	-
Ruahine steepland soil (RuMS)	Ah	C	C	S	a	C	S	R	-	R	-
	Bw	a	c	S	a	S	S	R	-	-	-
colluvial pocket beneath (Tp)	C	S	C	S	A	S	S	R	-	S	-

FREQUENCY LEVELS OF MINERALS IN SAND FRACTIONS

A = >50% very abundant

a = 30-50% abundant

C = 10-29% very common

c = 5-9% common

S = 1-4% scarce

R = <1% rare

(after: Fieldes & Weatherhead (1966)

(TpH) and Dannevirke hill scils (DH) soils, respectively. These plagioclase feldspars, rich in potassium, are considered to be abundant in acid-intermediate rocks such as greywacke and rhyolitic ash, (Fieldes and Weatherhead, 1966). Sanadine, an alkali feldspar considered to be characteristic of volcanic rocks such as rhyolites (Kerr, 1959) was noted in a Ruahine steepland soil sample by its characteristic low relief and birefringence.

Rhyolitic glass was observed in all samples investigated. It was abundant (30%-50% of sand fraction) in the Tp soil, in which hypersthene and augite were also common (5%-9%). This soil has the largest proportion of tephric components, probably because there is relatively little addition of greywacke-derived loess and colluvium. At lower elevations, on relatively gentle slopes, greywacke-derived loess is the main constituent with a smaller tephra component in the sand fraction. On less stable sites, where soil creep and mass movement occur, greywacke colluvium is also added to the soil, "diluting" both the greywacke-derived loess and tephra components. It may be that the tephra component at all elevations is of similar volcanic origin, but whereas at high altitudes little "dilution" has occurred due to little greywacke-derived loess deposition; at lower altitudes, the tephra component has been inundated by greywacke loess and colluvium.

The Ruahine steepland soil samples contained 70% quartz and feldspar (derived predominantly from the underlying greywacke bedrock) and greywacke rock fragments. These soils have the smallest proportions of tephra minerals.

The D tax soils contain common to abundant amounts of rhyolitic glass, together with between 4% and 11% mafic grains (augite, hypersthene and hornblende). Fieldes and Weatherhead (1966) described the sand mineralogy of a Dannevirke silt loam, from Eketahuna, which contains more quartz and less glass. It seems likely that during Post-glacial times (Aranuian Stage) less greywacke loess has been deposited in the mountainland, compared with the terraced floodplains of the rivers, traversing the lowlands, which are the major source of Post-glacial loess.

A small pocket of colluvial material exposed in a recent cutting on the summit plateau was also investigated for principle sand mineral fractions. The colluvial pocket occurs between the greywacke bedrock and the base of Tp. It was found to contain predominantly greywacke rock fragments. However 2% to 3% of the sand fraction is hypersthene and augite suggesting that andesitic ash may once have been present, but has subsequently been weathered away. The presence of 2% magnetite, which is very resistant to weathering and remains in the soil when other components have been physically and chemically altered also suggests the former presence of a greater tephra component. Rhyclitic glass is scarce in this deposit, in contrast to the overlying soil, where it is abundant. Thus, this colluvial deposit which predates the overlying soil (about 4600 years old) and contains markedly less rhyolitic tephra, suggests that: (a) there was less rhyolitic volcanic activity when this colluvial material was deposited, or (b) it was deposited, and buried by an overlying deposit, before it could receive a significant quantity of rhyolitic tephra grains, or (c) the original tephras have been largely weathered to amorphous materials.

6.3.2 Clay Mineralogy

6.3.2.1 Introduction

The clay mineralogy of soils, from selected sites within Car Park Creek subcatchment was investigated using 4 techniques:

X-ray diffraction (XRD)

Differential Thermal Analysis (DTA)

Infrared Spectroscopy (IRS)

and Transmission Electron Microscopy (TEM)

XRD techniques are used to identify crystalline phyllosilicate minerals present in soils, as well as other crystalline minerals such as quartz and feldspar. Amorphous materials, undetected by XRD, may be investigated using DTA and IRS. These techniques combine to give a detailed picture of the constituents of the soil clay fraction, for comparison of horizons within a soil profile, and between different soil profiles.

TEM provides additional information about minor constituents, which may be present in amounts too small to be detected positively by the other techniques. It also provides positive evidence for the presence of amorphous materials; and allows a visual assessment of the proportions of easily identified constituents of the clay fractions.

6.3.2.2 Materials and Methods

The soil clay fraction ($\leqslant 1\mu m$) was separated from the selected soil samples, as described in 4.2.1. Pretreatment of the clays was kept to a minimum to ensure minimum alteration of the inorganic components.

(a) X-ray Diffraction, (XRD)

X-ray diffraction patterns were obtained for NH_4^+ saturated clay samples by drying a small aliquot of the clay suspension on a glass slide, and rotating between 4^o and 40^o of 2θ in a Philips X-ray diffraction apparatus.

The normal procedure for the detection of montmorillonite:Mg^{2+} saturation of the clay, and introduction of a drop of 5% glycerol in ethanol which expands the basal spacing of the clay to about 17.7Å, was followed.

To investigate the proportions and structure of vermiculite and pedogenic chlorite, the clays were then K^+ saturated, and sequentially heated through 300°C, 450°C to 550°C, obtaining an XRD pattern for each sample, at each stage. This procedure also enabled investigation for the presence of kaolinite, which is characterised by a basal reflection at 7.18Å. With K^+ saturation, the vermiculite structure collapses to a mica-like structure; with a basal reflection at about 10Å. An aluminous vermiculite, however, will not collapse completely with K^+ saturation; but does collapse when heated to 550°C, for 30 minutes. The amount of collapse of structure from 14Å to 10Å at 300°C and 450°C indicates the amount of substitution of the exchangeable cations between lattice layers by the hydroxy aluminous groups. If interlayering of the vermiculite by hydroxy aluminium polymers is complete, the mineral is pedogenic chlorite. This does not collapse when heated to 550°C, and infact the 14Å peak is normally intensified.

Investigation of the 14Å and 7Å peaks after the three stages of sequential heating also showed the relative contribution, if any, of kaolinite to the 7Å peak.

(b) Differential Thermal Analysis, (DTA)

The D.T.A. method depends on the detection of heat given out or absorbed by a substance due to thermal changes such as dehydration and dehydroxylation, as its temperature is raised uniformly. Pretreatment of the soil samples with hydrogen peroxide is not necessary for D.T.A. as oxidation reactions of the organic matter are suppressed by using a nitrogen atmosphere. A clay sample, in fine powder form,is placed in a specimen holder, in contact with a set of thermocouples. An inert substance is placed in an adjacent speciman holder, also with a set of thermocouples. Whilst no reactions occur within the unknown clay sample as the temperature is raised, the temperature of both the clay sample and inert substance will be the same. When a reaction involving a heat change occurs, the temperature of the clay sample will deviate from that of the inert substance. The temperature difference between the two sets of thermocouples is recorded automatically, as a series of peaks on graph paper. The direction of the peaks indicates whether a heat change is exothermic or endothermic, while the approximate temperature at which a heat change commences, reaches a maximum, and declines can be read off the graph, and the magnitude of the reaction noted. The patterns obtained can be interpreted to identify the presence of certain clay minerals or amorphous constituents. However, Mackenzie (1972) stresses that D.T.A. on its own solves few problems in

Soil Science, and only by integrating the results obtained with those from other investigational methods can detailed information be obtained.

The clay sample for analysis was in an air-dried, crushed, NH_4^+ saturated form, of which 15mg was required. To ensure comparable hygroscopic moisture contents at analysis, the samples were equilibrated for at least 3 days at 56% relative humidity, using a saturated solution of $Mg(NO_3)_2.6H_2O$. A heating rate of 10°C per minute and a nitrogen atmosphere were used for all samples. 10mg of Al_2O_3 were used as the standard inert substance.

(c) Infra-Red Spectroscopy, (IRS)

Clay mineralogical studies using IRS depend on IR absorption, the wavelength of which is equal to the wavelengths of the bonds between or within molecules. Absorption typically occurs in the 4000-400cm^{-1} wavenumber region, (wavelength 2.5-25µm). Thus bonding between and within molecules, and between ions of crystals, can be characterised. In this study the sample for investigation was prepared by weighing accurately 2mg of dried, crushed, NH_4^+ saturated clay, which was then mixed with 170mg of potassium bromide (K Br) and ground to a homogeneous mass in a ball mill. The powder was then inserted into a sample holder, evacuated, and pressed into a nearly transparent 13mm disc for analysis in the IR beam. The prepared disc was left in an oven overnight, at 50°C. A double-beam spectrophotometer was used for analysis, one beam passing through the prepared KBr disc, while the reference beam passes through air. This makes possible differential analysis, thus eliminating errors due to variation in radiation source and to absorption by atmospheric water vapour and carbon dioxide.

In some cases it was necessary to dilute the sample in the KBr disc sixfold, to resolve peaks at lower wavenumbers. In this case, the disc was removed from its holder and crushed. Approximately one-sixth (30mg) was mixed with a further 140mg of KBr, and a second disc prepared.

(d) Transmission Electron Microscopy (T.E.M.)

T.E.M. employs a beam of electrons, focused magnetically onto the specimen. The electrons are scattered by solid objects, such as clay particles, casting a "shadow" on to a screen or photographic plate. The electron micrographs produced reveal the approximate size and shape of the clay particles. They can also be used for positive identification of certain substances such as amorphous materials. However, unlike the 3 previous techniques no structural detail is detectable, unless electron diffraction procedures are used.

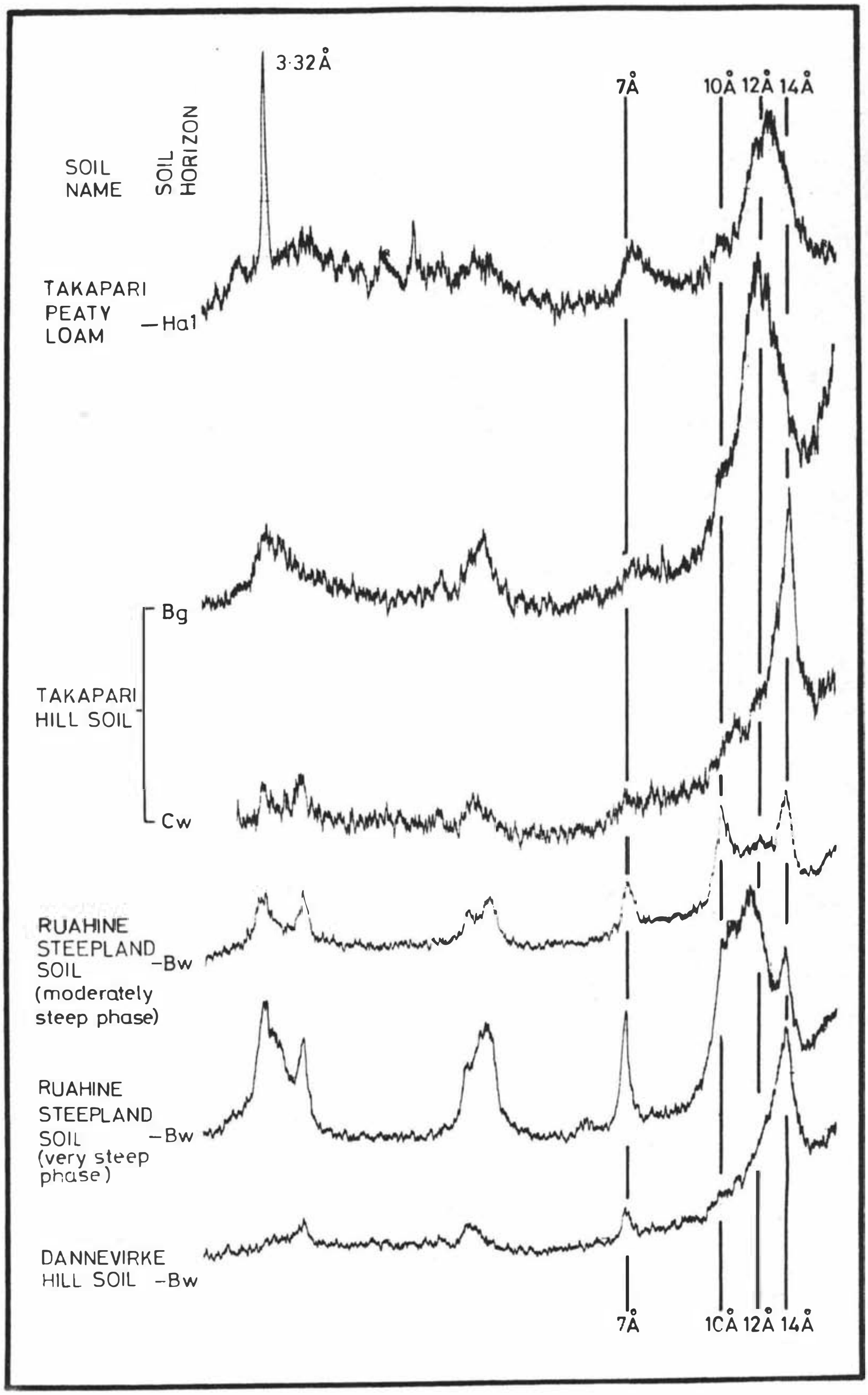
The sample required for investigation needs to be in a dry state, when introduced into the transmission electron microscope, as it is viewed in an evacuated lens column and specimen chamber. It must also be no greater than 0.2μm thick, this being the limit of penetration of the electron beam. In this investigation a very dilute suspension of the NH_4^+ saturated clay fraction was prepared, which looked slightly opaque when held to the light. One drop of this suspension, after being fully dispersed both chemically and ultrasonically was taken, using a clean pipette, and mounted on a carbon film supported by a 3mm copper grid. The specimen was allowed to dry in an oven at 50°C prior to investigation with the electron microscope.

6.3.2.3 Results and Discussion

(a) X-ray Diffraction (XRD)

Initial diffraction patterns obtained for the NH_4^+ saturated clays, indicated that the crystalline components were in all cases dominated by 14Å vermiculite and/or pedogenic chlorite, with varying degrees of interstratification, (see Fig. 41). Fig. 41 indicates that the 14Å peak is particularly well defined in the samples of TpH (Cw horizon) and DH (Bw horizon). It is also clearly evident in the samples of the RuMS and RuVS soils (Bw horizons); which also have well defined 10Å peaks produced by mica. The absence of clearly defined 10Å peaks in the other patterns in Fig 41 is noted. This suggests that mica if present originally (which

FIGURE 41: X-RAY DIFFRACTION PATTERNS OF NH_4^+ SATURATED CLAY SAMPLES FROM SELECTED SOIL PROFILES, SHOWING THE PREDOMINANCE OF 14Å VERMICULITE AND 12Å INTERSTRATIFIED MATERIALS.



is likely due to the nature of parent materials) has been altered to some extent, so that a clearly defined 10Å is not obtained. The shifting of the 14Å peak toward 12Å, in the case of Tp (Hal) and TpH (Bg), in Fig. 41, indicates a considerable amount of interstratification of the vermiculitic material.

Chlorite characteristically gives a small 14Å peak and large 7Å peak in XRD patterns of NH_4^+ saturated clays. Figs. 41 and 42 show the 14Å peak to be larger, indicating that it is due to vermiculite rather than chlorite.

The more weakly weathered Ruahine steepland soils also show quartz and feldspar to be minor constituents in all samples investigated (see Figs. 41, 43) although Tp (Hal) gives a particularly large quartz peak at 3.32Å (Fig. 41). This latter peak may be due, in part, to an aeolian contribution, as well as a contribution of clay-sized quartz weathering from coarser fractions, in this wet, acidic environment.

To characterise material contributing to the 14Å peak, XRD patterns of K^+ saturated clays were obtained, sequentially heated through 3 stages additional to the no heat treatment. Examples of patterns thus obtained are shown in Figs. 42 and 43. In no sample did the 14Å peak collapse to 10Å on K^+ saturation alone, without heat treatment, which would be the case if vermiculite were present. Thus, an intergrading aluminous vermiculite, or pedogenic chlorite, was considered to be present in the clay samples.

Pedogenic chlorite retains its structure even when heated to 550°C and then usually gives an enhanced first order spacing, at about 14Å. The clay fraction of the Bw horizon of the D tax soil gave a pattern indicating a small amount of pedogenic chlorite, (see Fig. 42, arrowed). Clay fractions from the Ah horizon of D tax and from the Bw horizon of RuVS, when sequentially heated to 550°C, produced patterns in which the 14Å peak collapsed to about 10Å, indicating the presence of aluminous vermiculite, (examples are shown in Fig. 42, 43).

In the case of the more weakly weathered Ruahine steepland soils, the

FIGURE 42: X-RAY DIFFRACTION PATTERNS OF A DANNEVIRKE TAXADJUNCT SOIL PROFILE INDICATING THE PRESENCE OF A SMALL AMOUNT OF PEDOGENIC CHLORITE, (arrowed).

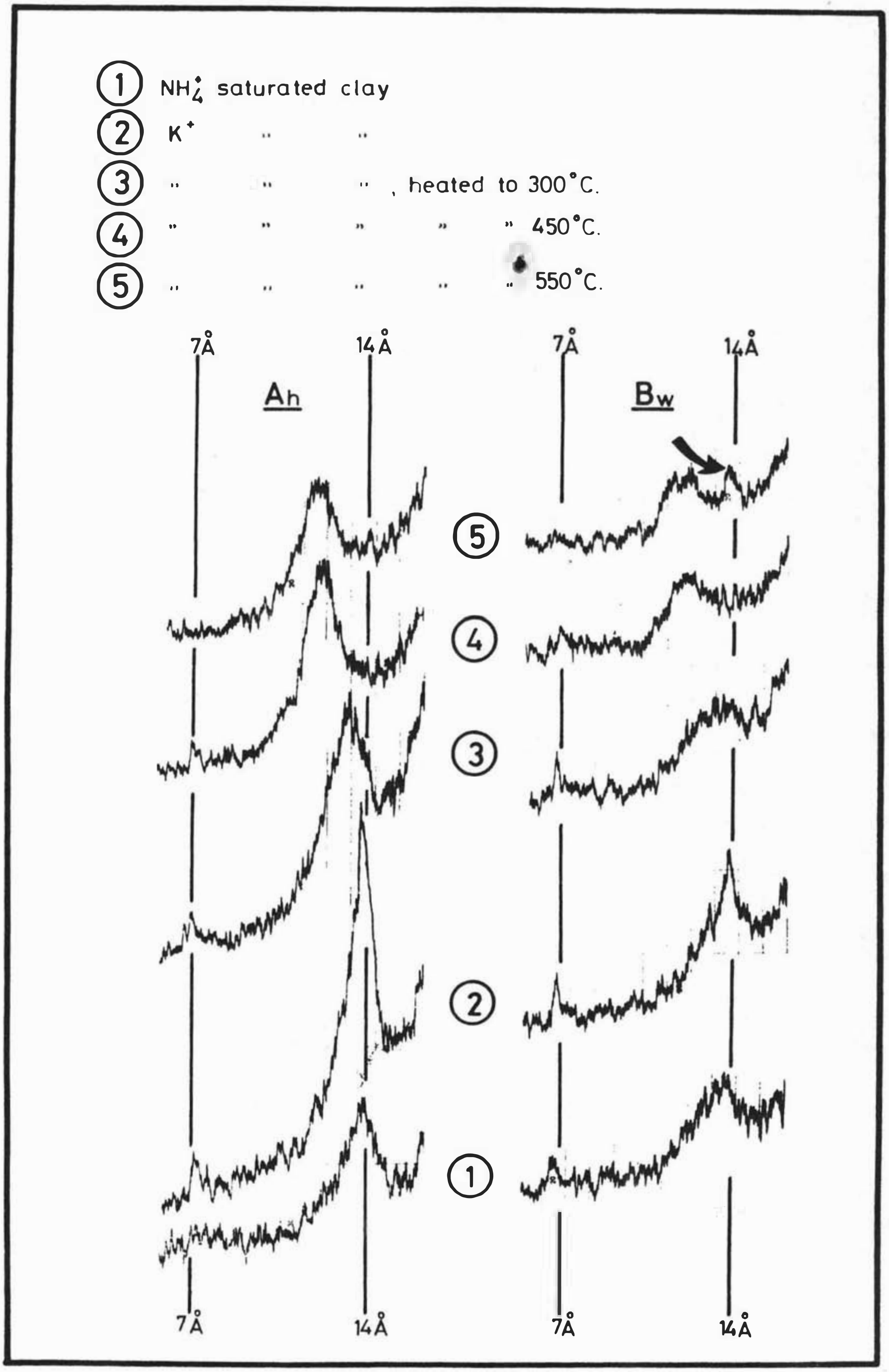
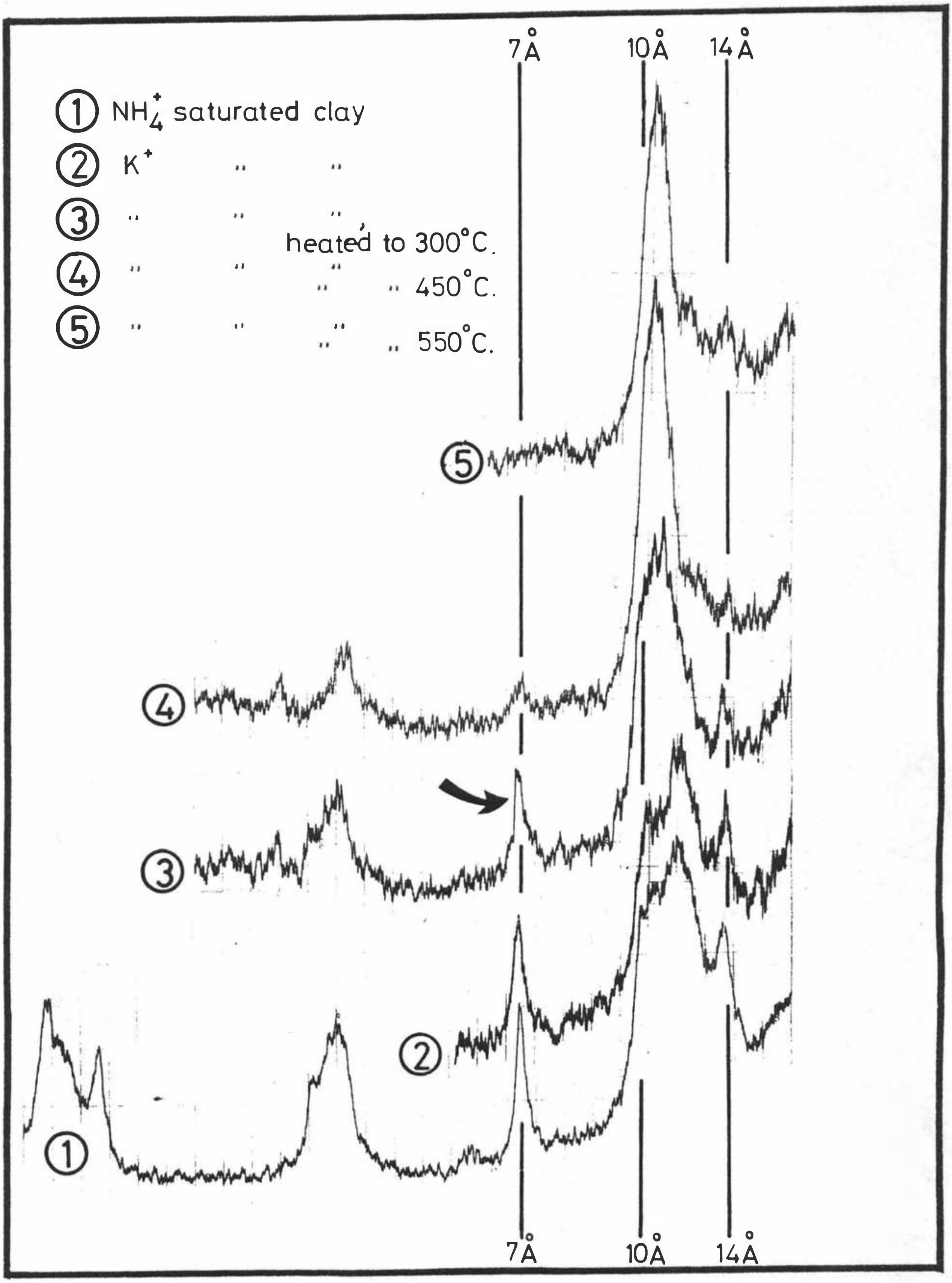


FIGURE 43: X-RAY DIFFRACTION PATTERNS OF NH_4^+ AND K^+ SATURATED CLAY SAMPLES FROM A Bw HORIZON OF A RUAHINE STEEPLAND SOIL (RuVS) FOR THE INVESTIGATION OF VERMICULITE COMPOSITION AND THE PRESENCE OF KAOLINITE.



14Å peak had largely collapsed at 300°C, indicating less replacement of the interlayer cations in the vermiculite by hydroxy alumina polymers, than in the other soils. One example is shown in Fig. 43.

In two Ruahine steepland soil profiles studied the 7Å peak appears to retain much of its intensity at 300°C (arrowed in Fig. 43), although the 14Å peak has begun to collapse. From this evidence, it was considered that a small amount of kaolinite may have been contributing to the 7Å peak.

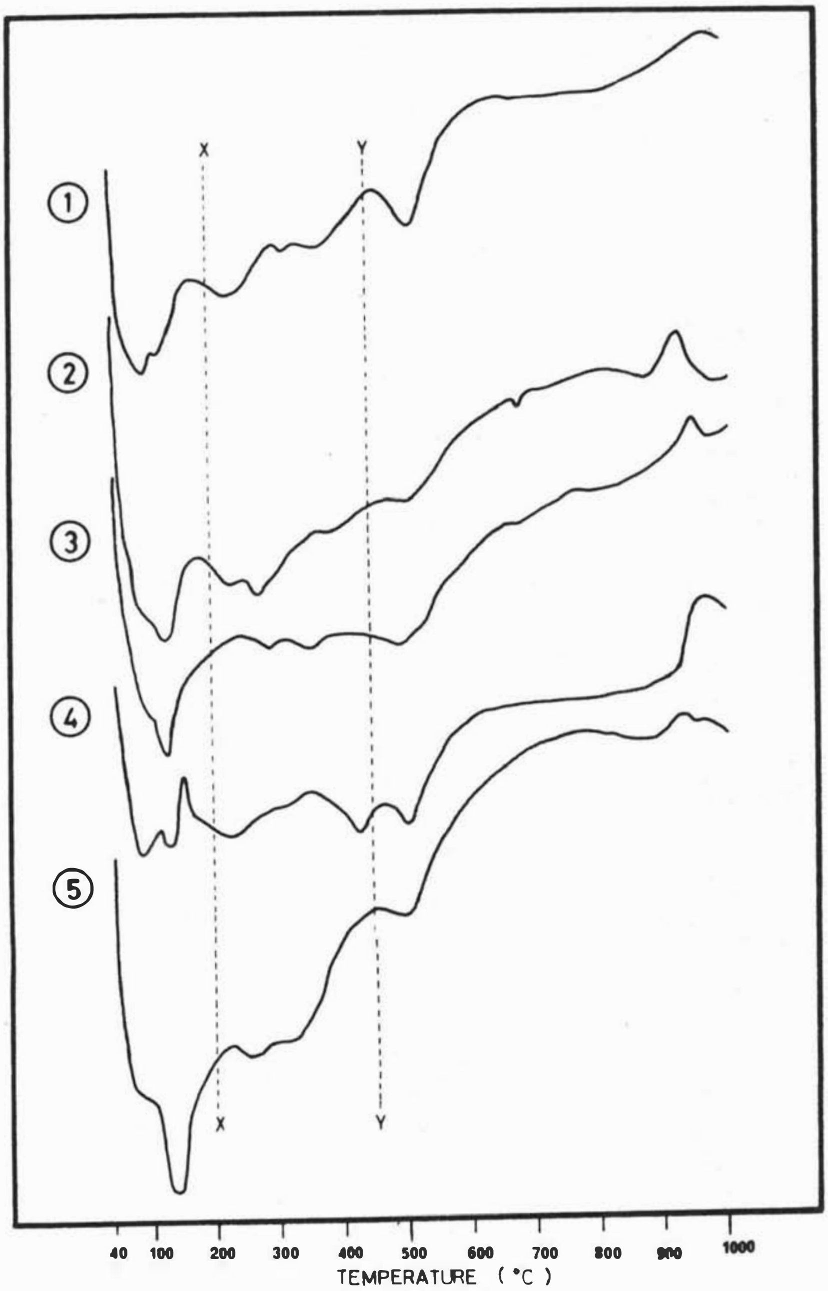
The possible occurrence of allophane being concentrated on slippage planes at the soil-rock interface was investigated at the head of Cats Paw Scar, a rockslide in Car Park Creek. Workers in North Westland, New Zealand (O'Loughlin and Pearce, 1976) have reported one of the principle causes of instability on slopes to be an allophane-rich organic clay layer at a regolith-sandstone interface. Thus, a clay sample was taken from the soil-rock interface, at the head of the rockslide, and its XRD patterns were compared with those of clay samples taken from the Ha and Br horizons of the same soil, a TpH. The clay sample was found to contain a significant amount of crystalline material, identified as aluminous vermiculite. The XRD patterns indicated that its clay mineralogy was similar to the other 2 samples studied, i.e. the Br and Ha horizons of the same soil.

In summary, the XRD patterns show that the crystalline fraction of the soil clays in the study area is dominated by aluminous vermiculite, with small amounts of pedogenic chlorite, mica, quartz, feldspar, and possibly kaolinite in some of the horizons. The relative proportions of these constituents, and the composition of the vermiculites characterise the extent of weathering within these soils.

(b) Differential Thermal Analysis, (D.T.A.)

Further characterisation of the soil clays was carried out by D.T.A. This method of investigation was used on clays suspected of containing a significant inorganic amorphous component. Fig. 44 shows some of the D.T.A. curves obtained. Curves produced by TpH samples, from the Bg and

FIGURE 44: D.T.A. CURVES OF SELECTED SOIL CLAY SAMPLES FROM CAR PARK CREEK.



1 Takapari peaty loam, Tp, Ha2 horizon

2 Dannevirke taxadjunct, D tax., Ah horizon
3 " " " C horizon
4 Takapari hill soil, TpH, Bg horizon
5 " " " " Cw horizon

X = 200 C, Y = 450 C.

Cw horizons, show a doublet on the initial low temperature endotherm, indicating the presence of two phases, whilst the Ah and C horizons of the D tax soil, and the Ha2 horizon of Tp, show this doublet to a lesser extent. This endotherm is due to dehydration of non-crystalline materials with some contribution from dehydration of the vermiculite group. By cross reference with the other techniques it is likely that the low temperature component of the doublet (70-96°C) is due to loss of water, weakly bonded to vermiculite, whereas that at 118-128°C is due to loss of water from allophane. The comparatively large low temperature endotherm at 128°C, produced by clay in the Cw horizon of TpH suggests a greater amount of amorphous material in this horizon than the overlying Bg horizon.

Interstratified phyllosilicates may give an endotherm at 600°C and a sigmoid peak system between 800°C and 900°C (Mackenzie, 1972), but there is no evidence of such curves on the thermal patterns presented here. Indeed, the lack of clearly defined large peaks in all the curves indicates that crystalline minerals do not dominate the clay fractions. D.T.A. is not suited to identification of the chlorite group, as chlorite gives various thermal responses depending on its structure.

The small endotherms, between 200°C and 450°C (between X and Y in Fig. 44) may indicate dehydroxylation of aluminous polymers, in the interlayer space of aluminous vermiculite, although a possible contribution by iron oxides cannot be ignored. Non-crystalline and crystalline materials also contribute to an exotherm, between 935°C and 979°C, in all 5 curves in Fig. 44. This exotherm is attributed to the formation of mullite, a spinel phase, from amorphous materials, which are transformed at lower temperatures, possibly from phyllosilicate clays.

The D.T.A. curves give only a limited amount of information about the soil clay fraction, which must be used in conjunction with information obtained from the other investigational procedures. However, it clearly indicates that although there is a well defined crystalline fraction, amorphous materials are also present in appreciable amounts and are moderately hydrated.

(c) Infra-Red Spectroscopy (IRS)

Fig. 45 indicates the results obtained from IRS studies. Diagnostic vibration patterns of layer silicate minerals, due to constituent units include:

constituent unit	vibration waveno (cm^{-1})
hydroxyl group	3400 - 3750
silicate anion	700 - 1200
octahedral cations	150 - 600 (coupled with Si-O bending vibrations)

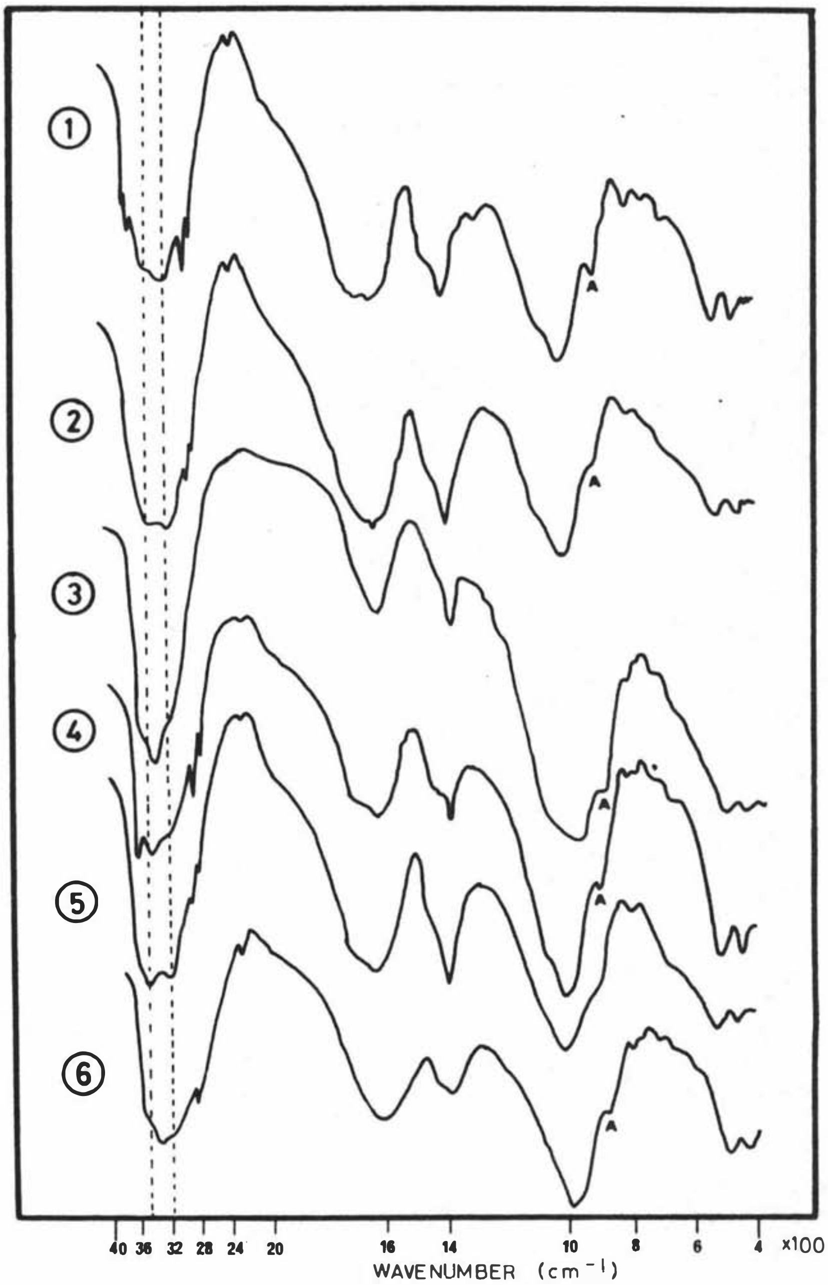
(Farmer, 1974)

The patterns obtained from the selected soil samples, contain these characteristic peaks, thus indicating the presence of layer silicates.

Two broad absorption bands at 3400 and 3200 cm^{-1} (indicated by dashed lines in Fig. 45), due to OH^- stretching vibrations, are most clearly defined in the curves produced by Tp (Ha2), D tax (Ah) and TpH (Cw). That at $3400cm^{-1}$ is due to allophane, whereas that at 3200 cm^{-1} is probably due to interlayer water in the vermiculite component of the clay. The sharp bands at $3700cm^{-1}$ and $3625cm^{-1}$ of Tp (Ha2), are due to bonded OH^- in the octahedral planes of the clay crystalline components.

The strong absorption bands in the $3400cm^{-1}$ to $3200cm^{-1}$ region, together with strong absorption in the $1700cm^{-1}$ to $1600cm^{-1}$ region due to OH^- bending vibrations, indicates a dominance of highly hydrated materials, such as allophane, together with contributions from the interlayer water of vermiculitic materials, in Tp (Ha2) TpH (Cw) and D tax (Ah) soils. A shoulder at $1100cm^{-1}$ indicates a considerable siliceous component in the allophane, and is present in all selected samples, except the Bw horizon of the Ruahine steepland soil, being most pronounced in the Tp and D tax soil samples. Absorption in the $800cm^{-1}$ region is indicative of the presence of silica.

FIGURE 45: INFRARED SPECTRA OF SELECTED SOIL CLAY SAMPLES FROM CAR PARK CREEK.



1 Takapari peaty loam, Tp, Ha2 horizon,

2 Dannevirke taxadjunct, D tax., Ah horizon

3 " " " C horizon

4 Takapari hill soil, TpH, Bg horizon

5 " " " " Cw horizon

6 Ruahine steepland soil, very steep phase,
RuVS, Bw horizon.

A peak at $915cm^{-1}$ ("A" in Fig. 45) due to Al-OH vibrations within the octahedral part of the crystalline structure is not strongly in evidence in any of the patterns. This indicates Al-OH bonds in crystalline minerals are not a major constituent of the sample, and Al-OH is probably in the form of amorphous gels or Al-OH polymers.

Peaks occurring at $1400cm^{-1}$ are due to the vibrations of cations which occupy exchange positions. These cations include NH_4^+ introduced by pre-treatment, together with K^+ and Al^{3+} and possibly small amounts of other cations which are thought to occupy interlayer positions of the vermiculitic materials. The broadness of the peak is indicative of the variety of cations which are present; and its strength is indicative of the cation-exchange capacities (C.E.C.) of the clays. Clay from the Ha2 horizon of the Tp soil produces a comparatively large peak, indicating that the C.E.C. of its clays is quite appreciable. The Ah horizon of the D tax soil also has a large peak at $1400 cm^{-1}$ which is larger than that for the C horizon, and it therefore has a larger C.E.C. In the TpH soil, the clay of the Cw horizon appears to have a larger C.E.C. than that of the Bg horizon, which may be due to a larger amount of amorphous material in the Cw horizon.

The peaks at $2850cm^{-1}$ and $2900cm^{-1}$ indicate OH^- bands, contributed by humus, with a possible contribution also from allophane-organic complexes. These are particularly noticeable in Tp, TpH (Bg) and D tax (Ah).

The spectra indicate a significant amount of hydrated amorphous material in the soils, especially in Tp, TpH (Cw) and D tax (Cw), together with a layer silicate component. The presence of a highly siliceous gel is indicated particularly in Tp, TpH and D tax. RuVS contains some amorphous constituents, being less highly hydrated than in the other soils.

(d) Transmission Electron Microscopy (TEM)

Table 14 summarises the findings of TEM studies of the clays. These studies enabled identification of some phyllosilicates and amorphous materials, and a visual assessment of their relative proportions in the samples.

SOIL NAME	SOIL SYMBOL	SOIL HORIZON	PRESENCE OF AMORPHOUS MATERIAL		HALLOYSITE	KAOLINITE	IMOGOLITE	UNIDENTIFIED LATHS	PHYLLO-SILICATES	OTHER MINOR CONSTITUENTS
			PRESENT	ABUNDANT						
Takapari peaty loam	Tp	Ha1		+	+	+	+		+	volcanic glass diatoms
		Ha2		+	+	+	+		+	volcanic glass diatoms
Takapari hill soils	TpH	Ah		+	+	+			+	
		Bg		+					+	
		Cw		+			+	+	+	
Ruahine steepland soils mod. steep -steep phase	RuMS	Ah	+						+	
		Bw	+						+	
steep phase	RuS	Ah	+		+		+	+	+	
		Bw	+				+	+	+	
very steep phase	RuVS	Ah	+			+	+	+	+	
		Bw	+					+	+	volcanic glass
Dannevirke taxadjunct	Dtax	Ah		+	+		+		+	
		Bw		+	+				+	
		C		+				+	+	
Dannevirke hill soils	DH	Ah		+					+	
		Bw		+			+	+	+	volcanic glass

TABLE 14: RESULTS OF TRANSMISSION ELECTRON MICROSCOPY: VISUAL IDENTIFICATION OF MINERAL AND AMORPHOUS MATERIALS.

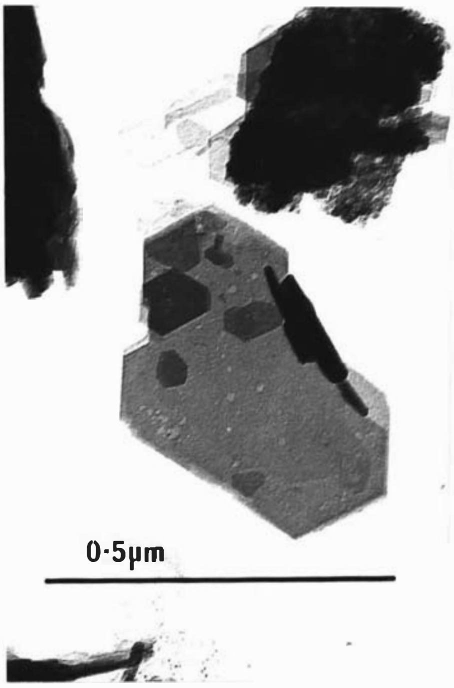


Fig. 46: Kaolinite and tube-like halloysite (Tp, Hal).

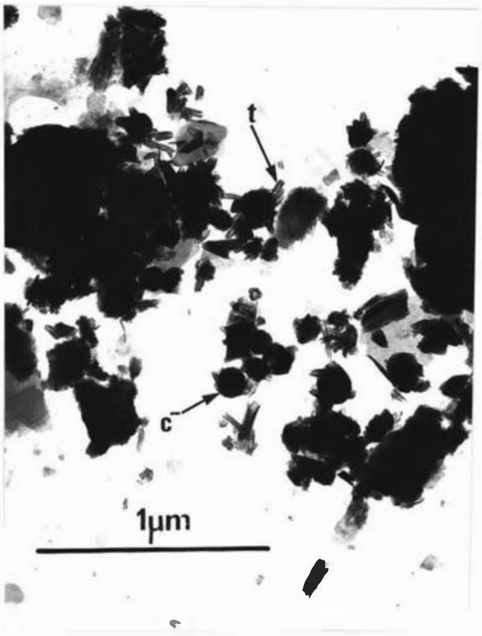


Fig. 47: Chunky cylindrical (c) and tube-like (t) halloysite forms, (Tp, Hal).

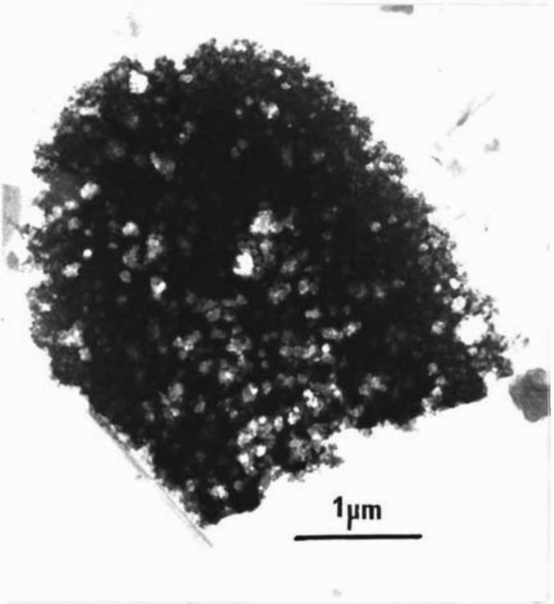


Fig. 48: Weathering Volcanic Glass (Tp, Hal).

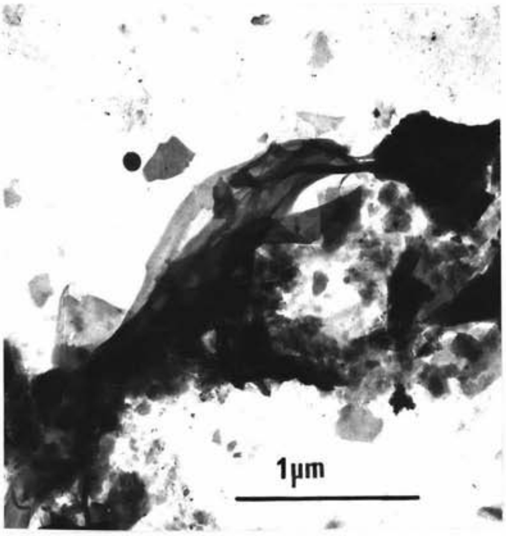


Fig. 49: Amorphous gel (Tp, Ha2).

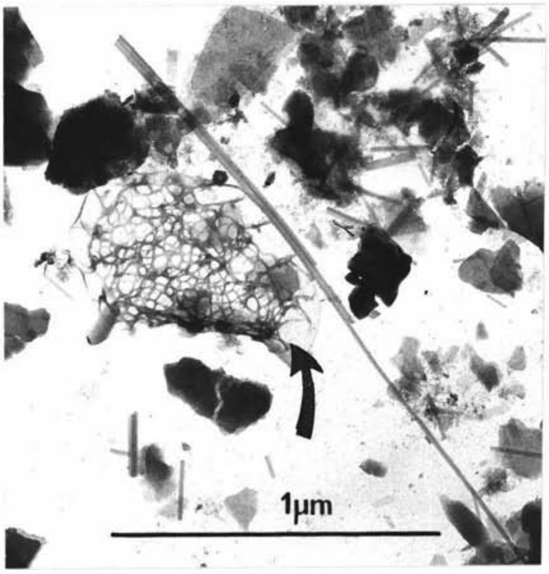


Fig. 50: Amorphous (arrowed) and crystalline material, and unidentified laths, (RuVS, Ah).

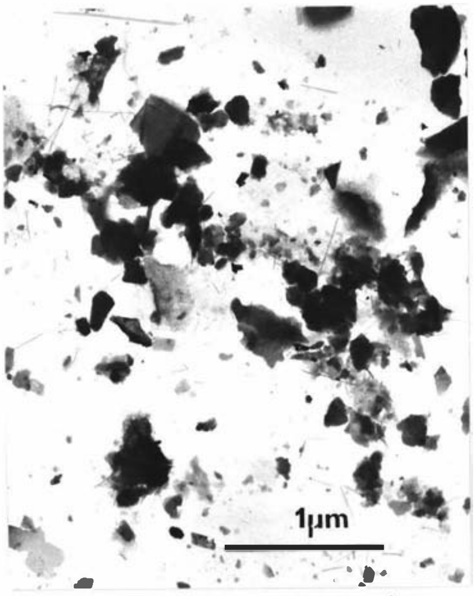


Fig. 51: Representative micrograph of a RuS soil (Ah) showing crystalline flakes, with minor amounts of amorphous material.

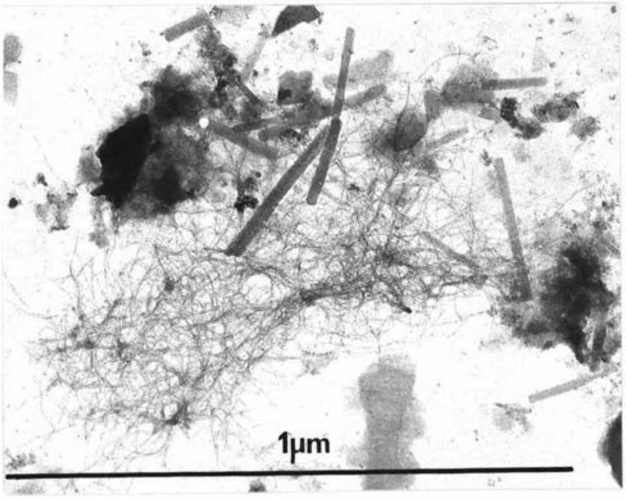


Fig. 52: Imogolite, and unidentified laths (RuVS, Ah).

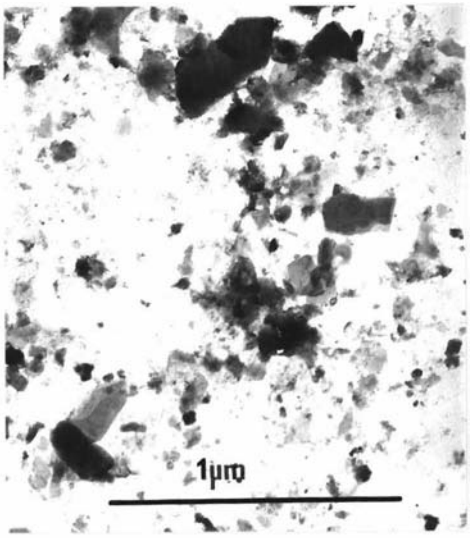


Fig. 53: Representative micrograph of Dtax (Ah) showing finely comminuted amorphous-dominated clay materials.

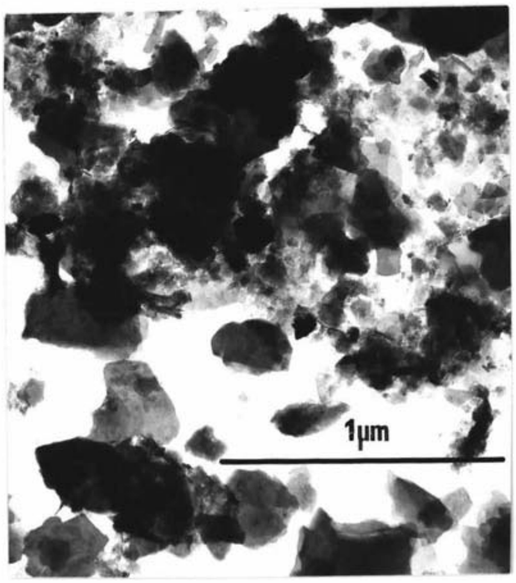


Fig. 54: Representative micrograph of Dtax (C) showing coarser amorphous-dominated clay materials.

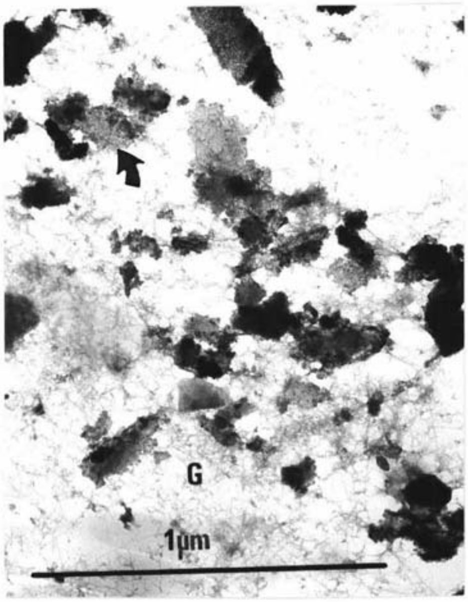


Fig. 55: Aokautere Ash showing amorphous materials (arrowed) in a fibrous gel ground mass (G).

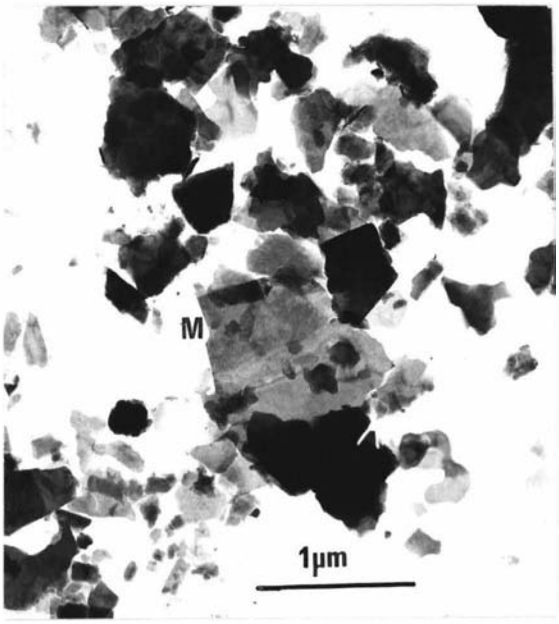


Fig. 56: Greywacke sample showing moirė pattern (M).

Volcanic glass, halloysite, kaolinite, imogolite and diatoms were recognised in several of the grids as listed in Table 14. Several electron micrographs are presented, to illustrate selected examples.

Inorganic amorphous materials are abundant in all horizons of the D tax, DH, Tp and TpH soils, commonly occurring as a filmy gel. This filmy gel form was particularly abundant in Tp (Fig. 49). Amorphous material was also observed in RuVS (arrowed, Fig. 50) together with the other Ruahine steepland soils. Crystalline minerals predominate in all the Ruahine steepland soils, as might be expected (see e.g. Fig. 51).

Kaolinite (Fig. 46), halloysite (Figs 46, 47) and imogolite (Fig. 52), which were not revealed by the other instrumental techniques, were noted in several soil samples, particularly in Tp indicating that they are present in minor amounts. Halloysite occurred in the well-documented tube-like form (Bates et al. 1950), and also in the chunky cylindrical form (Kirkman, 1977b), as shown in Fig. 47. Kaolinite was recognised as clearly defined hexagonal crystals (Bates, 1959), and imogolite as smooth, interweaving threads, (Gard, 1971; Parfitt and McHardy, 1974). Weathering volcanic glass was noted in a number of clay samples, an example being shown in Fig. 48.

The presence of platy micaceous and feldspathic material in the Ruahine steepland soils, which contained large amounts of crystalline flakes, seems probable, although they could not be positively identified. However, X.R.D. patterns indicate that these minerals are present.

Long lath-like crystals, up to 5-6μm in length, occurred in the majority of soil clay samples, generally in small amounts. In two samples of the Ah horizons of Ruahine steepland soils they were observed in appreciable amounts, (Fig. 50, 51, 52). These lath-like crystals are at present unidentified but exhibit a similar appearance to the zeolite mordenite, which occurs sporadically in rhyolitic materials (Gard, 1971). It seems probable that they are a type of zeolite.

Electron micrographs, shown in Figs. 53 and 54 indicate the relative abundance of crystalline and amorphous materials, within the Ah and C horizons of the D tax soil. The Ah horizon is shown to contain more finely comminuted material, presumably due to greater physical, chemical and biological breakdown of soil particles in the upper horizons. These micrographs may be compared with those shown in Figs. 55 and 56, which illustrate the form of the clay fraction of a sample of Aokautere Ash and greywacke, respectively. The clay fraction of the Aokautere Ash, is seen to be largely amorphous with a grain-like appearance (arrowed in Fig. 55), together with a ground mass which is largely a fibrous gel (labelled G). Fig. 56 is an electron micrograph of a greywacke pebble, ground to clay size. It is seen to be largely crystalline, with some of the flakes exhibiting a moirè pattern * (labelled M).

T.E.M. studies were thus particularly useful for a visual assessment of the relative proportions of constituents of the clay-sized fraction. It was also possible to positively identify kaolinite, halloysite (tube-like and cylindrical forms), imogolite and weathering volcanic glass.

6.4 CONCLUSIONS

Soil-water characteristics, and the mineralogy of a number of selected soil samples has been investigated. The results obtained enable a detailed comparison of the properties and genesis of the soils mapped, together with an understanding of the processes occurring within these soils, such as soil water movement, soil water retention and the extent of weathering.

In the case of the Ruahine steepland soils, three profiles were investigated. The RuMS and RuS samples were taken from representative profiles of a moderately steep-steep and steep phase, respectively; whilst RuVs samples were taken from a profile with better horizon development than the modal profile of the very steep phase.

---

* A moirè pattern is that produced on an electron micrograph due to overlapping of platy crystals, producing sets of parallel fringes (Gard, 1971)

Data obtained for the RuMS and RuS soils showed them to be characteristically different from the other soil mapping units. The results show that they have the largest bulk densities, smallest total porosities, and largest macroporosities (together with the samples of the Takapari peaty loam, Tp). They are also characterised by very small A.W.C.'s and the least accumulation of organic matter. These soils, therefore, are freely draining with a low water storage capacity; and during a heavy rainstorm, water will move rapidly through the solum.

Cohesion in soils is a bonding together of particles due to attractive forces; mainly contributed by clays, organic matter and the surface tension effect of air-water interfaces. Since the Ruahine steepland soils have low clay contents (being weakly weathered), low organic matter contents and weak structures, they will tend to become cohesionless on drying, which in turn will decrease their shear strength. Due to their low A.W.C.'s and rapid drainage, the soil water status of these soils will change relatively rapidly compared with the other soils studied in the survey. Thus, at the beginning of a wet period, for example during the autumn months, these soils with low cohesion will become wet rapidly (i.e. attain a low soil water matric potential), and at this stage may be particularly susceptible to erosion. At the end of a wet period, they will drain rapidly to attain a relatively high soil water matric potential. This effect will be enhanced by a lack of organic matter to retain moisture at the surface and in the solum ; so that these soils, in particular, are susceptible to droughtiness which in turn limits plant growth.

Mineralogical studies of RuMS and RuS, and the "drying effect" indicate that they contain the smallest amount of amorphous clays with respect to the other soils in the subcatchment. Sand mineralogy studies indicate 1-3% mafics (hornblende, hypersthene and augite) and 3-13% rhyolitic glass, a smaller percent than in the other soils. The presence of mica, feldspar and quartz shown by X-ray diffraction studies, together with aluminous vermiculites with only a moderate amount of interstratification, indicate that the soils are weakly weathered.

The properties of the RuVS soil differ markedly from those of the RuMS and RuS soils, in a consistent fashion. In this soil, a marked decrease in bulk density is noted together with an increase in the following: total porosity, A.W.C., the "drying effect", pH (in NaF) of Bw horizon, organic matter levels and proportions of mafics (3-4%) and rhyolitic glass (18-24%). Transmission electron microscopy studies of the clay fraction showed the presence of some imogolite, halloysite and amorphous material, as well as aluminous vermiculites and mica. This data suggests that this soil has developed on a more stable site than the RuMS and RuS soils; so that there has been sufficient time for greater amounts of tephric loess and organic matter to accumulate and for a Bw horizon to develop. Thus on the steep to very steep slopes of the subcatchment where many erosion scars occur, there are also sites which have remained stable for some considerable period of time. Because the soil-water characteristics and mineralogy of the soils in the Ruahine steepland soil mapping unit are rather varied, it seems probable that their susceptibility to erosion also varies considerably between sites.

In comparison with the Ruahine steepland soils, the Dannevirke taxadjunct (D tax) and related Dannevirke hill soils (DH) display features indicative of a large amorphous clay component. The D tax soils have (1) pH (in NaF) values >9.4 in all subsoils analysed, and (2) a large "drying effect". The DH soils show these effects to a lesser extent. Both soils have large A.W.C.'s. The saturated hydraulic conductivity values for the D tax soil indicates that infiltration rates are seldom, if ever, limiting so that the soil is freely draining with little or no surface runoff.

The sand mineralogy of the Dannevirke soils indicate 4-11% mafics and 5-36% rhyolitic glass, together with quartz, feldspar, greywacke fragments and other minor constituents. Thus, the parent material may be assumed to be derived from a mixed source provenance of greywacke material and aerial volcaniclastic ejecta from the rhyolitic and andesitic volcanoes of Central

North Island. The sand mineralogy, the "drying effect" values, bulk densities and pH (in NaF) values for respective horizons all suggest that the proportion of tephra components and thus amorphous clays in the Bw horizon is greater than in the C horizon of the D tax soil.

The Dannevirke soils are more strongly weathered than the Ruahine steepland soils. X-ray diffraction patterns indicate that the crystalline clay fraction of both soils are dominated by interstratified vermiculite, however, those of the Dannevirke soils are more highly aluminous. D tax soils contain a small amount of pedogenic chlorite. Visual assessment of the electron micrographs indicates that amorphous material contributes to at least 50% of the clay fractions in the Dannevirke soils. Mica and feldspar have been largely destroyed by weathering in these soils. Thus, due to large water storage capacities, considerable amounts of amorphous clays and organic matter, the Dannevirke soils show properties that render them less susceptible to erosion than the Ruahine steepland soils. This is expressed in their profile development where the freely draining, friable, well developed profiles have a low bulk density and a high porosity.

The Takapari peaty loam (Tp) and Takapari hill soils (TpH) are distinguished by their peaty nature, together with an amorphous clay content largely in the form of highly siliceous gel (as shown by infra-red spectroscopy). The peaty topsoil of TpH, and the Ha horizons of Tp have very low bulk densities, and large A.W.C.'s meaning that the soil is able to store large amounts of water. The porosity and macroporosity values of Tp are large, and the "drying effect" on its water retention properties is also large (probably a combined effect of amorphous clays and organic matter). Tp has the greatest proportion of mafic and rhyolitic sand grains of all the soils examined in the subcatchment, constituting up to 60% of the total sand fraction. Quartz and feldspar are also common. Thus the parent materials for this soil include, in order of abundance: peat, tephric loess, rhyolitic tephras and weathering greywacke.

The position of Tp on the summit plateau of the Ruahine Range abrogates the effects of erosion processes, such as soil creep and mass movement, which dominate soil formation on the steeper slopes to the east.

The TpH soil occurs on slopes, just below the summit plateau. The topsoil (Ah, Ahg or Ha horizon) has low bulk densities and relatively large porosity and A.W.C. values. In the Bg horizon a marked increase in bulk density and decrease in porosity and A.W.C. occurs. This horizon has the smallest macroporosity values of all samples studied. Saturated hydraulic conductivity studies show that infiltration into the surface horizon is typically rapid, and of the order of several thousand $mm.day^{-1}$. However, a very marked decrease in rate of vertical water movement is noted in the underlying Bg horizon. It seems that interflow is likely to occur in this situation. The contrasting properties of the Bg horizon compared with the Ah horizon also suggest that as water movement through the Bg horizon is impeded it will accumulate at the junction of these horizons, so that with time in a sufficiently wet environment, a perched water table will develop. This saturated zone, with its subsequent decreased shear strength, will act as a plane of weakness in the soil and is likely to become the shear plane for mass movement to occur.

Below the Bg (or Br) horizon is a thin placic horizon, overlying a Cw horizon. The Cw horizon shows a marked increase in (i) macroporosity, (ii) the "drying effect" and (iii) pH (in NaF) values, compared with the Bg horizon. This information together with clay mineralogy studies, indicates that the Cw horizon is more freely draining and contains a larger proportion of amorphous materials. Thus, the investigations show that the gleyed or completely reduced B horizon of the TpH soils has different soil-water characteristics to (1) the overlying Ah or Ha horizons and to (2) the underlying Cw horizon. Thus, each horizon has diagnostic soil-water movement and soil-water retention properties, producing a soil with a high susceptibility to erosion processes.

A secondary observation in this study was the large native earthworm activity in most soil profiles (with the exception of Tp) indicated by the presence of large burrows, infilled with material often from another horizon. The investigations indicate that these burrows aid good drainage and aeration of the soil profiles, as well as assisting the breakdown and incorporation of organic matter within these soils, improving structual stability.

In conclusion, the extent of weathering and amounts of amorphous constituents within the clay fractions of the soils, tends to increase in the order: Ruahine steepland soils; Dannevirke hill soils; Dannevirke taxadjunct soils and Takapari hill soils; Takapari peaty loam. The Ruahine steepland soils are characteristically rapidly draining soils, with low water storage capacities. The Dannevirke soils, in contrast have much greater water storage capacities, but are also free-draining, and have a large amorphous clay component. The Takapari hill soils are characterised by drainage impedance in the B horizon with soil-water properties markedly different to those of the horizons above and below it. The Takapari peaty loam exists on stable sites of the summit plateau, where interflow does not occur. Instead, in this area of highest amounts of rainfall, waterlogging of the soil occurs as it becomes saturated upwards from its contact with the underlying greywacke bedrock. This results in (i) low decomposition rates of the organic matter, producing a peat, and (ii) a moderately acid, wet environment for mineral weathering to occur.

CHAPTER SEVEN

FINAL DISCUSSION OF RESULTS AND EROSION PROCESSES, WITH CONCLUSIONS

CHAPTER SEVEN

FINAL DISCUSSION OF RESULTS AND EROSION PROCESSES, WITH CONCLUSIONS

The fluctuation and magnitude of erosion rates in the Southern Ruahine Range through geological time, and in recent decades, has been discussed in the Literature Review. This indicates that:

(1) erosion rates have been highly variable since the Range began to be uplifted, and;

(2) in recent decades, the erosion rates are increasing.

Mosley (1977) provides the following estimates of erosion rates (which he states are based on some very restrictive assumptions) for the southeastern Ruahine Range, thus substantiating (2) above:

(a) a minimum erosion rate of $10m^3\ ha^{-1}\ yr^{-1}$ on a long-term basis, (estimated from the volume of rock removed during valley incision, assuming the Range to be 1.5 million years old).

(b) an erosion rate of $28m^3\ ha^{-1}\ yr^{-1}$, between 1946 and 1974 (estimated by the change in area of erosion scars during this period).

Introduced wildlife, a climatic change, earthquakes, the clearing of natural deposition areas, steepness of slope and the nature of the bedrock have been suggested as factors involved in the recent increases in erosion. However, the argument as to whether increased erosion rates observed today are part of a natural cycle, or whether they are accelerated by one or more of these factors, mentioned above, is disputed. Hence, the aim of this study has been to investigate the extent and types of erosion and the related soil resources with a view to establishing likely mechanisms and reasons for the erosion.

Erosion types which are related to the soil resources are considered to be (a) mass movements, which involve soil materials together with rock fragments and organic matter, and (b) soil creep, which is generally a slower form of erosion.

A detailed soil survey of Car Park Creek showed that the distribution of the soils is associated with different geomorphic surfaces, which have been classified according to the nine-unit landscape model (NULM) of Conacher and Dalrymple (1977). It is likely that the soils of Car Park Creek are representative of soils along the eastern side of the Range, and that a similar pattern of soils will exist in other catchments, their distribution being related to the landsurface unit and altitude.

This study has shown that the mineral soil parent materials are: in situ greywacke-derived materials, with additions of greywacke loess and volcanic ash. The Dannevirke and Takapari series, on more stable sites than the Ruahine soils, contain the greatest amounts of loess together with a large tephra component, producing a deep soil. Field observations and sand mineralogy studies of the Takapari peaty loam indicate that tephra additions include lapilli from the Waimihia and Taupo Pumice eruptions. These tephras indicate a minimum age of soil development for the Takapari peaty loam of ca. 3440 years (extrapolated to ca. 4600 years assuming a constant rate of peat accumulation in the lower part of the profile). This suggests that the summit plateau of the Southern Ruahine Range was stripped bare prior to this date, during an erosive period. The presence of a third tephra, the Aokautere Ash (erupted ca. 20,000 yrs. B.P.) in a gravel deposit, underlying the Dannevirke taxadjunct soil, indicates that active erosion and deposition was occurring alongside the main West Tamaki River channel at this time.

The primary mineral assemblage and extent of weathering indicated by the sand and clay mineralogy studies suggest that the Takapari hill soils are of a comparable age to the Dannevirke soils, although the former are subject to more intense chemical weathering. The Takapari peaty loam contains highly aluminous vermiculites and minor amounts of kaolinite and halloysite, which have formed in the profile under very wet, acidic conditions.

This indicates that this soil is also subject to relatively intense chemical weathering. The primary mineral assemblage of the Ruahine steepland soils indicates that they contain the least amounts of tephra components of the soils studied, whilst their clay mineralogy shows that there has been insufficient time for all of the mica and feldspar in these soils to have been removed or altered. This is to be expected as the Ruahine steepland soils occur on the most unstable slopes in the subcatchment, and their profile development is modified by rejuvenation processes. However, the occurrence of stable pockets within this steepland soil mapping unit has been noted, indicating that the erosion susceptibilities of sites within the mapping unit are varied.

Virtually all of the erosion within Car Park Creek occurs in the areas mapped as Takapari hill soils (TpH) and Ruahine steepland soils (RuMS, RuS, RuVS). A number of soil parameters were measured in the subcatchment to investigate:

(a) why these soils, in particular, are susceptible to erosion, and

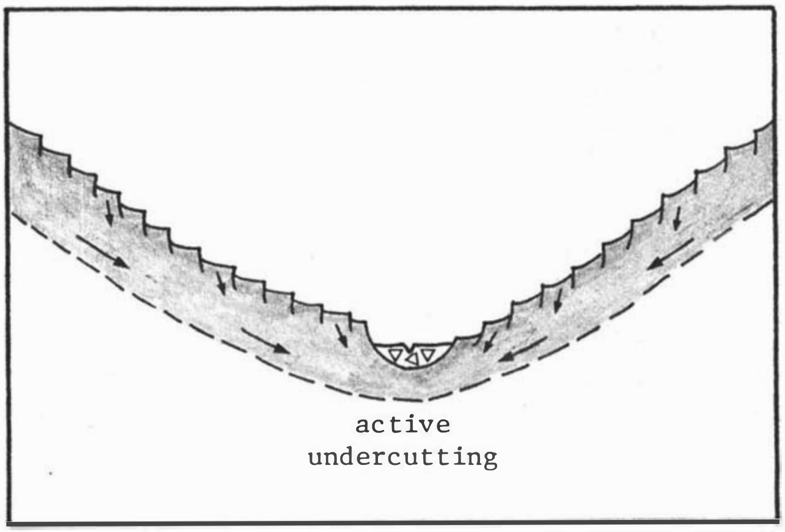
(b) which soil parameters are most closely related to erosion processes.

The Takapari hill soils occur in an area in which most of the deep-seated erosion occurs. Their soil morphology is a peaty top, underlain by a grey, gleyed Bg (or in local depressions a completely reduced Br) horizon, which can be of thicknesses up to 0.5 metre. Below this a discontinuous, thin iron pan occurs, underlain by a more freely-draining horizon. This soil has been described in Chapters 5 and 6, and in the latter the likelihood of interflow through the permeable surface horizon~~s~~ is proposed. It is also suggested that a perched water table may form at the upper surface of the Bg (or Br) horizon in wet periods, thus creating a saturated zone. A decrease in shear strength of this saturated zone occurs on wetting, due to loss of many cohesive bonds (contributed by air-water menisci) and a decrease in frictional forces between particles. Thus, a zone of weakness will develop forming a probable shear plane for mass movement resulting in, for example, debris avalanches and slides. Also, a slower, possibly imperceptible, soil creep may be occurring not only at this plane but also in the underlying structurally weak, gleyed B horizon. Other factors which favour soil creep in this zone include: (a) the slope gradient, of between 12^o and 30^o, (b) a high mean annual precipitation of approximately 2400mm, (c) a vegetational stand, unhealthy in places, and with a limited root distribution, and (d) any factor causing a disturbance of the soil particles, such as earthquakes.

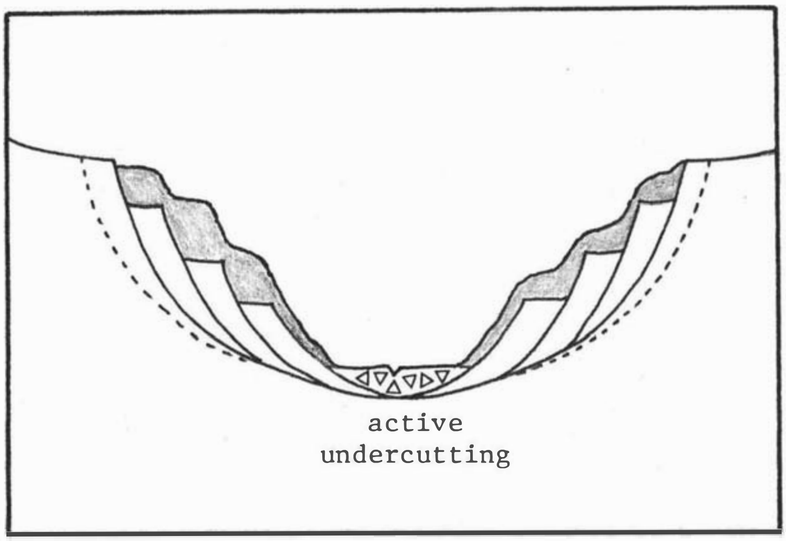
Creep, not only of surficial soil layers, but also of underlying colluvial and shattered bedrock materials may be also occurring. This is favoured by the factors (a) (b) and (c) listed above together with: (e) the structure and lithology of the greywacke bedrock, which is jointed, faulted and shattered, and consists of alternating beds of sandstone and argillite which have differing resistances to weathering. Evidence for a more deep-seated creep movement is the presence of large scale (approximately 100 metres in length), deep terracettes on the convex creep slope, within Car Park Creek, orientated parallel to the ridge-top (see Fig. 7). These appear to be similar in nature, although on a smaller scale, to the small discontinuous scarps occurring in indurated greywacke and argillite, in the Southern Alps of the South Island, New Zealand, (Beck, 1968). The latter are formed by gravity adjustment, often triggered by earthquakes, in a terrain oversteepened by glaciation. In the Southern Ruahine Range, where slopes are oversteepened by fault movement, and earthquakes are common, it is likely that a similar gravity adjustment occurs, which would thus explain these deep terracette features.

Indeed, the presence of terracettes within the zone in which Takapari hill soils occur is an indication of slow valleyward movement of the entire area, which is enhanced by undercuttingat the stream bed. Thus, terracettes may form either as in (a) or (b) (Fig. 57). However, it is possible that

Fig. 57: An Illustration of the Possible Origin of Terracettes, Observed at the Head of Car Park Creek.



(a) terracette formation due to creep of surficial soil materials, over the bedrock.



(b) terracette formation due to deep-seated slumping within the bedrock.

the terracettes of (b) form simultaneously with a more superficial soil creep (forming smaller terracettes, as in (a)) superimposed on its surface. Similar terracette features are also found at the head of the Rokaiwhana Stream, to the south of Car Park Creek.

The Ruahine steepland soils also have a high erosion susceptibility. Soil factors which enhance this susceptibility include weak structural development and low organic matter levels. The RuS and RuVS phases exist on transportational midslopes, with angles of slope characteristically greater than 30°. This steepness of slope is a major factor contributing to their erosion susceptibility. The RuMS phase exists on a more stable slope unit, the colluvial footslope. However, some mass movement undoubtedly occurs in this unit, which is also affected by fluvial erosion processes. The alluvial toeslope, where Recent soils occur, has similar susceptibilities to erosion as the colluvial footslope. The soils on this surface are also commonly weakly structured with low organic matter levels, and occur in a zone susceptible to fluvial erosion processes.

The Takapari peaty loam and Dannevirke taxadjunct soils occur on level to gently sloping topography where mass movement seldom occurs. The Dannevirke hill soils occur on the flanks of the interfluves, below the 750 metre contour, in an area where slight erosion occurs. These latter soils are less well developed than their more stable counterparts, the Dannevirke taxadjunct soils.

The present study suggests that a number of soil parameters are related to the erodibility of a soil which, together with other factors such as slope and aspect, determine its erosion susceptibility. These soil parameters are:

(a) Structural Development - During pedogenesis, the individual soil particles become clustered into aggregates by bonding together by clay particles and humus, with cracks and pores developing as roots and soil fauna penetrate the soil. Thus, a well structured soil contains stable soil aggregates and sufficient cracks and channels to provide good aeration and drainage. Soil structure can be destroyed or seriously reduced by:

(1) wetting a soil when it is dry, or

(2) compression and shearing when it is wet.

The stability of the structure depends on the amount of structural bonds within the soil, provided by the clay fraction, sesquioxide cements, humus and microbial gums.

Thus, in the case of the Ruahine steepland soils and Recent soils which are relatively young and weakly weathered (in the majority of cases), clay and organic matter levels are low with resulting weak structures. The Dannevirke and Takapari soils have better developed structures, although the hill soils associated with each of these series have structures that are less strongly developed.

Destruction or reduction of soil structure will increase soil susceptibility to erosion on a slope. The Ruahine steepland soils, which have weakly developed structures, also dry out considerably during the summer months (having a rapid drainage rate, inferred from a large percent of macropores, and a small A.W.C.). Thus, when the dry soil becomes wetted the soil is liable to lose much of its structural stability. This is enhanced by the position of these soils on steep slopes, where they are subjected to large shearing forces.

Inthe Dannevirke hill soils, the soil-water characteristics do not favour such rapid drainage of the soil, and it is likely that these soils do not dry out to such an extent as the Ruahine steepland soils. Thus, these weakly to moderately structured soils are less susceptible to loss of structural stability. The Takapari hill soils, having poorly to very poorly drained profiles, seldom dry out, even during a long dry summer. The weakly structured B horizon, which in places is completely reduced, is liable to lose its structural stability when subjected to shearing forces. In contrast, the Takapari peaty loam, which occurs on level to gently sloping surfaces, is not subjected to these shearing forces. Likewise, it seldom dries out to any great extent, so that factors within this soil do not favour the loss of structural stability.

(b) Organic Matter - The amount of organic matter in soil is intimately associated with a number of soil physical properties. Its effect on structural development has been mentioned in the preceding pages. It is also related to bulk density and available water-holding capacity, as discussed in Chapter 6.2.2. The presence of an organic litter on the soil surface aids rainfall acceptance and decreases the likelihood of soil splash and surface compaction - factors of major importance to the likelihood of erosion of the surface soil layers. In this study, horizons with high organic matter content are found to have large macroporosities.

The Takapari hill soils, which have peaty surface horizons with large macroporosities, are a case in point. Saturated hydraulic conductivity measurements on the surface horizon of this soil together with macroporosity data suggest that infiltration and drainage are not limited by the drainage characteristics of the surface horizons. Thus, the change of surface soil losses due to runoff, or the ponding of water on the surface where infiltration is limiting, is small.

The Takapari peaty loam soils also have a high organic matter content, but in these soils where vertical water movement occurs and soil depths are generally about 0.5m, the soil becomes saturated upwards from its contact with the basement greywacke, which enhances its waterlogged nature.

The Ruahine steepland soils, in contrast, have relatively low organic matter levels, with little or no accumulation on the surface. Macroporosity data indicate that they are rapidly draining soils, which is due to their textural coarseness and stoniness. However their relatively cohesionless surface horizons are liable to soilsplash and dispersion during intense rainstorms, in an area where there is little or no organic litter protecting the soil surface.

The Dannevirke taxadjunct, and Dannevirke hill soils to a lesser extent, have high organic matter levels and an appreciable accumulation of organic litter on the surface. The large amorphous clay component in these soils contributes to their friable consistence and low bulk density, while at the same time facilitating the formation of amorphous clay-organic complexes. Thus, these soils are freely-draining, and their surfaces are protected by organic matter against soil splash and dispersion.

(c) Rooting Depth - A soil on a slope is strengthened by the presence of tree roots and maximum strength is gained when these roots extend throughout the solum. This is the case in all of the soil mapping units which occur on slopes within Car Park Creek, with the exception of TpH, as shown in the table below:

TABLE 15 AVERAGE SOIL AND TREE ROOTING DEPTHS OF EACH SOIL MAPPING UNIT, WHICH OCCURS ON A SLOPE

SOIL	SOIL SYMBOL	AVERAGE SOIL* DEPTH (cm)	AVERAGE TREE* ROOTING DEPTH (cm)	TREE ROOTING DEPTH AS PERCENT OF SOIL DEPTH (%)
Takapari hill soil	TpH	70	50	approx. 70
Dannevirke hill soil	DH	70	70	100
Ruahine	RuMS	60	60	100
steepland:	RuS	45	45	100
soils	RuVS	35	35	100

* average soil and tree rooting depths are estimated as an average depth of the total numberof soil profiles described in the study.

The Bg (or Br) horizon of TpH being waterlogged provides adverse conditions for root growth, with a marked decrease in root abundance and therefore a marked decrease in shear strength in this horizon, compared with the overlying horizon. This may subsequently increase the likelihood of soil creep within this soil.

(d) Presence of an Impermeable Horizon - In the Takapari hill soils, at the base of the Bg (or Br) horizon, a thin iron pan has developed, below which no roots penetrate. This pan increases in thickness and cementation with an increase in altitude and a resultant increase in mean annual rainfall. Thus, iron pan development is more pronounced on the convex creep slope at the top of the catchment than on the sloping interfluves which extend to lower elevations. As well as impeding root penetration, the iron pan will also impede vertical water movement, thus enhancing the waterlogged nature of the slowly permeable Bg (or Br) horizon.

Where the bedrock occurs close to the soil surface, which is the case in a number of Ruahine steepland soils and Takapari peaty loam soils, it will offer resistance to root penetration and water movement. Thus, on a level surface, for example in the case of the Takapari peaty loam soils, a perched water-table may form above the bedrock and develop upwards. Where the surface of the bedrock is sloping and close to the surface, for example in certain soils of the RuS and RuVS soil phases of the Ruahine steepland soils, water may move along this plane and have a lubricating effect at this point, i.e. where the base of the soil is in contact with the underlying bedrock.

(e) Soil Water Permeability - The ease with which water passes through the soil has been measured directly as saturated hydraulic conductivity (ksat) and indirectly as macropososity. A soil becomes saturated and loses shear strength (increasing its liability to movement downslope) if sufficient water drains through it at a slower rate than it is being received. It is observed that Ksat will decrease with time during a rainstorm, due to factors such as clogging of pores by the inwashing of finer particles. Also, the rate of movement of water through the soil is limited by the horizon of slowest Ksat values, so that even if the surface horizon is freely draining the presence of a slowly draining subsoil may result in waterlogging, and possible saturation.

Ksat and macroporosity measurements indicate that the Ruahine steepland and Dannevirke soils are freely draining, so that saturation of the soil profile is unlikely. The extremely stony Recent soils, which frequently occur on several metres of gravels will thus also be freely draining.

However, in the case of the TpH soils, a rapidly draining topsoil is underlain by a B horizon having a marked decrease in permeability. This is indicated by Ksat measurements and substantiated by macroporosity data. Thus, as a considerable amount of precipitation falls at this altitude (approximately 2800mm annually), the Bg (or Br) horizon, which has vertical Ksat values ranging between 0.1 and 400mm per day, will limit soil drainage. This, together with the presence of a thin iron pan makes the B horizon of TpH particularly susceptible to saturation, and may lead to the formation of a perched water table at its upper boundary, thus increasing the erosion susceptibility of this soil.

In the present study, these 5 soil parameters are of particular relevance in the assessment of soil erodibility. The erosion susceptibility of a soil on a slope depends not only on its inherent erodibility (governed by its internal properties) but also on external factors such as slope and aspect. The likelihood of the shear stress of a soil overcoming its shear strength increases as the angle of slope increases. This is illustrated by the equation:

$$T = \gamma_d \, z \sin \alpha \cos \alpha$$

where T = tangential stress (in Pa)

α = slope angle

γ_d = dry unit weight of soil ($kN.m^{-3}$)

z = soil depth.

Thus, a comparative assessment of erosion susceptibilities may be made by comparing the five soil parameters and angle of slope for each soil class. These are summarised in Table 16. The notation "E" in the bottom right-hand corner of a box indicates that this factor is likely to be a major cause of decreasing a soil's stability on a slope, due to the reasons previously discussed. The summation of "E" factors is used as an index for comparison of soil erosion susceptibilities, (see Table 16). The data suggests that the erosion susceptibilities of the soils in the study area, decreases in the order:

TpH > RuS and RuVS > RuMS, DH and R > Dtax and Tp.

Indirect factors, which may modify this order, based on a comparison of soil and slope parameters include:

(a) weaknesses in the bedrock, which may result in deep-seated mass movements,

(b) fluvial erosion processes, affecting in particular RuMS and R,

(c) climatic factors - Erosion likelihood is increased in the upper reaches of the catchments where the mean annual precipitation is greater than at lower altitudes, (mean annual rainfall/altitude gradient is approximately 151mm/100m, Martin, 1978), and where increased rainfall intensities are expected, although little reliable data is available to substantiate this.

Thus, the Southern Ruahine Range is an area inherently susceptible to very high natural erosion rates, due to:

TABLE 16 FACTORS AFFECTING THE EROSION SUSCEPTIBILITY OF THE SOILS IN CAR PARK CREEK SUBCATCHMENT

PARAMETER		Takapari peaty loam (Tp)	Takapari hill soils (TpH)	Dannevirke taxadjunct (D tax)	Dannevirke hill soils (DH)	Ruahine steepland soils			Recent soils (R)
						RuMS	RuS	RuVS	
STRUCTURAL DEVELOPMENT (of total soil)		moderate	weak - moderate E	moderate	weak - moderate E	weak - moderate E	weak E	weak E	weak E
ORGANIC MATTER LEVEL * (of surface horizon)		v. high	v. high	high	medium	medium	low - medium E	low - medium E	low - medium E
ROOTING DEPTH (% of soil depth)		-	approx 70 E	-	100	100	100	100	-
PRESENCE OF IMPERMEABLE HORIZON (+/_)		-	+ E	-	-	-	+ E	+ E	-
SLOPE		< mod steep	mod steep - steep E	<mod steep	mod steep - steep E	mod steep- steep E	steep E	v steep E	<mod steep
RATINGS FOR PERMEABILITY OF LIMITING HORIZON	MACRO-POROSITY **	high	medium - low	medium	medium	high	high	medium	high
	K sat VALUES ***	-	slow E	rapid- v rapid	-	-	-	-	-
SOIL EROSION SUSCEPTIBILITY INDEX (summation of E's)		0	5	0	2	2	4	4	2

* using the rating system of Metson (1956)
** " " " " " New Zealand Soil Bureau (1968)
*** " " " " " Smith & Browning (1946)

(1) geological factors, such as the type and shattered nature of the lithology, together with active faulting and uplifting of the Range,

(2) steepness of topography, largely controlled by (1), and enhancing mass movement due to gravity adjustment.

(3) climatic stresses, such as intense rainstorms and winds, which affect in particular the south-eastern part of the Ruahine Range. This is illustrated by: (i) the distribution of soils. The Takapari hill soilsextend down to the 750m contour on the east side of the Range, and to the 1070m contour on the west side, (Rijkse, 1977). This suggests that adverse conditions producing a gleyed soil, together with slow organic matter decomposition rates are more prevalent at lower altitudes on the east flank of the Southern Ruahine Range, compared with the west flank, (Rijkse, 1977).

(ii) certain vegetation zones,in the Southern Ruahine Range which show a definite drop in their upper limit, in comparison to vegetation further north in the Range, (see Fig.9).

(4) certain soil parameters, which render the Takapari hill soils and Ruahine steepland soils particularly susceptible to erosion.

Thus within any catchment of the Southern Ruahine Range very high natural erosion rates are to be expected. However, the present study of the West Tamaki River catchment has indicated that within a single catchment there are areas of contrasting erosion potential. Fig. 58 illustrates the extent and distribution of erosion surfaces within this catchment, and delineates areas which are considered to have high, medium and low risk of erosion , based on the evidence presented in this study.

The soil mapping units are delineated in Fig. 58 by extrapolation of information obtained from (1) the detailed soil survey of Car Park Creek and (2) observations and profile descriptions from the main channel of the West Tamaki River. It is considered that soil mapping units are associated with particular geomorphic surfaces and altitudinal zones within the Southern Ruahine Range. Thus, with the aid of a 1:5840 scale aerial mosaic of the West Tamaki River catchment area, soil mapping units have been extrapolated throughout the catchment. Thus, it may be seen that areas of equal erosion risk correspond to soil mapping units on a basis of their erosion susceptibility indices, with the following modifications:

(1) The "high risk" area includes the Takapari hill soils (erosion susceptibility index 5) only where they occur on the convex creep slopes just below the summit plateau. The lower extent of these soils is excluded because:

(a) the peaty nature of the A horizon, the thickness and gleyed nature of the B horizon, and the cementation of the iron pan are all poorly expressed, thus decreasing adverse soil-water propertes; (b) the sloping interfluve areas, where these soils occur at lowest elevations are considered to be relatively stable landsurface units compared with the convex creep slopes and steep valley-sides.

(2) The "high risk" area includes the RuMS soil phase (erosion susceptibility index 2) of the Ruahine steepland soils, and the Recent soils (R) (erosion susceptibility index 2) as well as the RuS and RuVS soil phases (erosion susceptibilities 4) because:

(a) RuMS and R are particularly liable to fluvial erosion processes, such as bank erosion, and (b) RuMS and R receive erosion products from the two phases, RuS and RuVS, which occur above them, often producing buried horizons.

Thus the "high risk" area, delineated in Fig. 58 contains the Ruahine

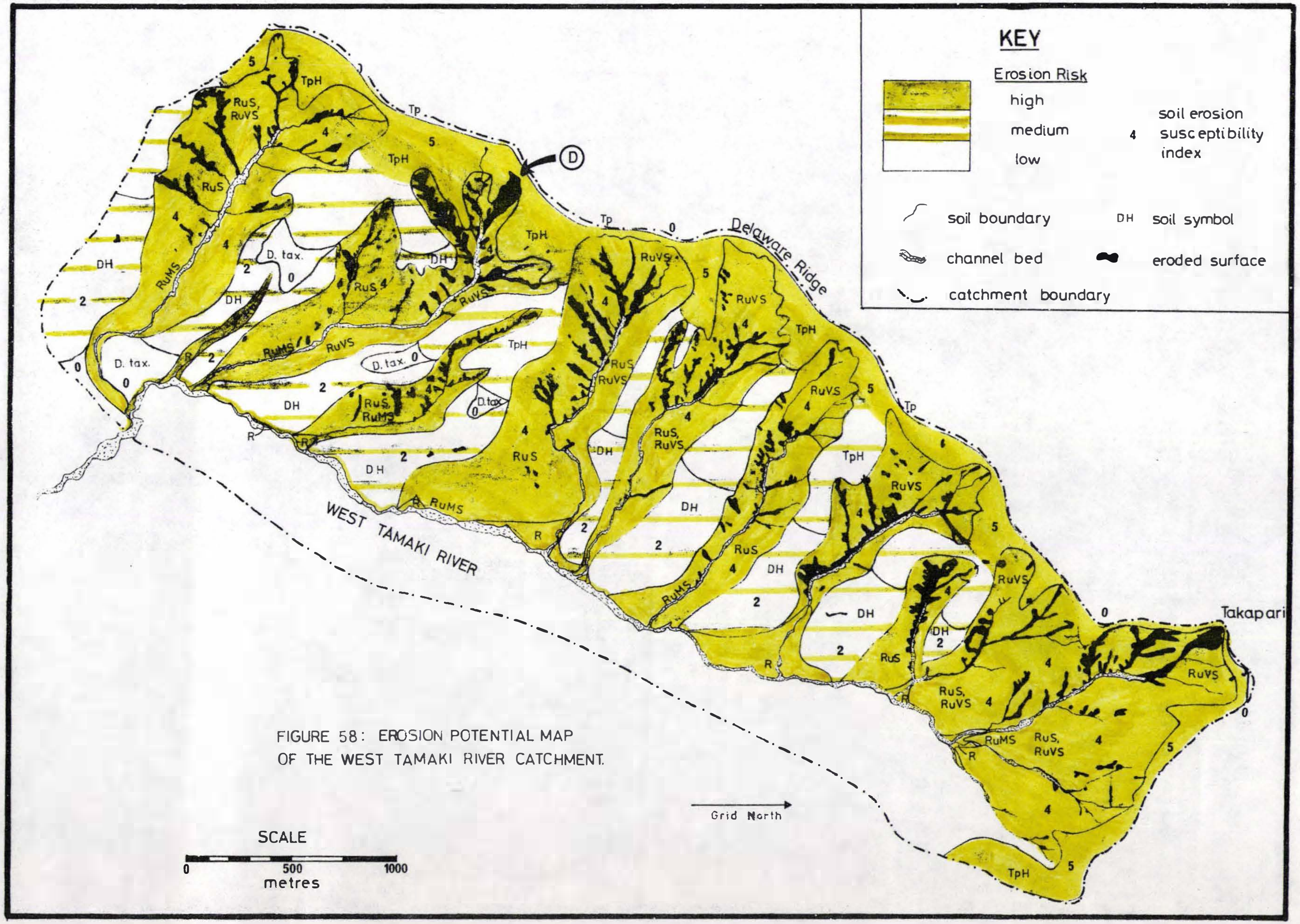


FIGURE 58: EROSION POTENTIAL MAP OF THE WEST TAMAKI RIVER CATCHMENT.

steepland soils, Recent soils and the upper part of the Takapari hill soils mapping unit. This area contains many of the existing erosion surfaces. The Ruahine steepland soils occur on the steep valley-sides and upper reaches of the subcatchments. These weakly structured, relatively cohesionless soils, together with the Recent soils, are found in a wide range of soil developmental stages with corresponding vegetation patterns also in various seral stages, both being controlled by erosion processes.

In contrast to the Ruahine steepland soils, the zone where Takapari hill soils occur contains less erosion scars. However, where these soils occur on convex creep slopes they have a high susceptibility to erosion in the form of: (a) mass movement, initiated within the solum or underlying bedrock and (b) creep, of soil and underlying colluvial materials. Many erosion scars occur at the boundary between these two soil mapping units, the Ruahine steepland soils slowly encroaching on the Takapari hill soils as erosion takes place. Fig. 7 shows a rockslide which occurs in Car Park Creek (marked D in Fig. 58) at the boundary between these two soil mapping units. As well as the deep terracette features which are seen in this area, Fig. 7 also shows an oval-shaped area bounded by a scarp which is about one metre in height, occurring above this rockslide. There is a high probability of this whole area responding to gravity collapse during, for example, an intense rainstorm. Thus revegetation programmes which attempt to revegetate existing eroded areas should be concentrated at sites such as this one. Revegetation of this site would subsequently increase the stability of the surface of the rockslide, decrease the shear stress of the oval-shaped area above it, and thus decrease the likelihood of erosion. It is important to note that this rockslide may be governed by a deep-seated slippage plane (as illustrated in Fig. 57b) which occurs at a weakness in the bedrock lithology or structure, and in this case any attempt to stabilise the surface of this inherently very unstable site would need to reduce shear stress within areas of bedrock exposure.

The Takapari hill soils extend down interfluves which bound the catchments of the Southern Ruahine Range, and in Car Park Creek extend down approximately to the 750 metre contour. Below the 750 metre contour the Dannevirke hill soils (erosion susceptibility index 2) occur with freely-draining profiles. The interfluve areas where these soils occur express a marked decrease in the number of existing erosion surfaces (see Fig. 58). Also, they are not susceptible to fluvial erosion processes. Thus, this area is considered to have a "medium risk" of erosion, being less susceptible than the convex creep slope and steep valley-sides, although more susceptible than the level to gently rolling areas of the catchments.

The most stable portions of the catchment are:

(1) the interfluves toward the base of the catchment, and their gently sloping toeslopes, where Dannevirke taxadjunct soils form, and

(2) the summit plateau, of the Southern Ruahine Range, where the Takapari peaty loams occur.

Table 16 indicates that these soils have lowest soil erosion susceptibility indices, and Fig. 58 shows that they are in an area where virtually no erosion surfaces occur, although the Dannevirke taxadjunct soils, where they extend to the channel wall, may be liable to some fluvial erosion in the form of channel widening and bank undercutting. These areas with their associated soils are considered to have a "low risk" of erosion.

In conclusion, much of the erosion which occurs in the Southern Ruahine Range is associated with specific areas within catchments; the location of which is related, in part, to the nature of the geomorphic surface (which is in turn related to the geology) and the characteristics of the soils on this surface. The convex creep slopes of the catchments where Takapari hill soils occur, are inherently highly susceptible to erosion in the form of creep and deep-seated mass movements. The very steep valley-sides of catchments where Ruahine steepland soils occur are severely eroded.

Evidence suggests that erosion occurs recurrently at the same vulnerable sites; both (1) on the valley-sides and (2) at the heads of the catchments particularly where the Ruahine steepland soils bound the Takapari hill soils. Thus maximum benefit from future revegetation programmes attempting to stabilise eroded and eroding areas will be gained to concentrating efforts specifically at these sites of maximum erosion susceptibility. This together with judicious planning of gravel storage in channel beds and at valley throats appears to be the method best suited to protection of the productive farmland downstream.

BIBLIOGRAPHY

BIBLIOGRAPHY

American Society of Agronomy Inc. 1965. "Methods of Soil Analysis, Part 1." Madison, Wisconsin, U.S.A. 770pp.

Bates, T.F., F.A. Hildebrand and A. Swineford. 1950. Morphology and structure of endellite and halloysite. Amer. Min. 35: 463-484.

Bates, T.F. 1959. Morphology and Crystal Chemistry of 1:1 layer Lattice silicates. Amer. Min. 44: 78-114.

Baver, L.D., W.H. Gardner and W.R. Gardner. 1972. "Soil Physics". 4th ed. John Wiley & Sons, Inc. N.Y. 498pp.

Bear, F.E. (Ed.) 1969. "Chemistry of the Soil". 2nd ed. Van Nostrand Reinhold Co. 515pp.

Beck, A.C. 1968. Gravity Faulting as a Mechanism of Topographic Adjustment. N.Z. Jl. Geol. Geophys. 11: 191-199.

Blakely, R.J. 1977. "Downstream River Management Related to Erosion Processes in the South-eastern Ruahine Range", in "Field Excursion to Southern Ruahines" (Ed. by V.E. Neall) handbook for 25th Jubilee Conference of N.Z. Soc. of Soil Science. p.37-44.

Blakemore, L.C. 1977. Exchange Complex Dominated by Amorphous Material (ECDAM). Unpubl. document of N.Z. Soil Bureau, Lower Hutt, 5pp.

Bloom, A.L., W.S. Broecker, J.M.A. Campbell, R.W. Matthews and K.S. Mesolella. 1974. Quaternary Sea Level Fluctuations on a Tectonic Coast: New ^{230}TH/^{234}U Dates from the Huon Peninsula, New Guinea. Quat. Res. 4: 185-205.

Boellstorff, J.D. and M.T. Te Punga 1977. Fission-track ages and correlation of Middle and Lower Pleistocene sequences from Nebraska and New Zealand. N.Z.Jl. of Geol. and Geophys. 20 (1): 47-58.

Bradshaw, J.D. 1975. The Kaikoura Orogeny - a provocation. Prog. and Abstr. of Geol. Soc. of N.Z. Inc. Annual Conference, 1975, Kaikowa p.1-2.

Brougham, G.G. 1977. "South-eastern Ruahines. Progress Report on Investigation and Channel Improvements." Unpublished Manawatu Catchment Board Report. 41pp + appendices.

Butler, B.E. 1959. Periodic phenomena in landscapes as a basis for soil studies. C.S.I.R.O., Australia, Soil Publication No. 14.

Campbell, I.B. 1973. Pattern of Variation in Steepland Soils: Variation on a Single Slope. N.Z. Jl. of Science 16: 413-434.

Campbell, I.B. 1975. Pattern of Variation in steepland soils: soil differences in complex topography. N.Z.Jl. of Science 18: 53-66.

Colenso, W., 1884. "In Memorium. An account of visits to and crossings over the Ruahine mountain range Hawke's Bay, New Zealand; and of the natural history of that region; performed in 1845-1847". Hawke's Bay Philosophical Institute. 72p.

Conacher, A.J. and J.B. Dalrymple. 1977. The nine-unit landsurface model: an approach to pedogeomorphic research. Geoderma 18, (112): 1-154.

Corker, R.B. 1977. Saturated Hydraulic Conductivity Measurements on the Tokomaru silt loam. Dip. Ag. Sc. thesis, Massey University.

Cowie, J.D. 1964. Aokautere Ash in the Manawatu District, New Zealand. N.Z.J. Geol. Geophys. 7: 67-77.

Crompton, E. 1952. Some Morphological Features associated with poor soil drainage. Jl. of Soil Science 3, (2): 277-289, with 2 plates.

Cunningham, A. 1977. "Introduction". in "Field Excursion to Southern Ruahines" (Ed. by V.E. Neall) handbook for 25th Jubilee Conf. of N.Z. Soc. of Soil Science p6-8.

Cunningham, A. and P.W. Stribling 1977. "A situation review and proposals for intergrated management of the Ruahine Range and the rivers affected by it". Unpubl. report prepared for the Ruahine Range Control Scheme Committee. 151pp.

Cumberland, K.B. 1944. "Soil Erosion in New Zealand - a geographical reconnaissance". Soil Conservation and Rivers Control Council, Wellington, 227pp.

Elder, N.L. 1965. Vegetation of the Ruahine Range: An Introduction.Trans. of the Royal Soc. of N.Z. (Botany) 3 (3): 13-66.

Ewart, A. 1968. The petrology of the Central North Island rhyolitic lavas. Part 2 - Regional petrography including notes on associated ash-flow pumice deposits. N.Z. Jl. of Geol. and Geophys. 11 (2): 478-545.

FAO/UNESCO 1974. Soil Map of the World. Vol. 1 Legend. UNESCO Press, Paris.

Farmer, V.C. (ed.) 1974. "The Infrared Spectra of Minerals". Mineral Soc. Monography 4. Publ. by Miner Soc., London 539pp.

Fieldes, M. and A.V. Weatherhead 1966. Mineralogy of Sand Fractions of New Zealand Soils. N.Z. Jl. of Science 9 (4): 1006-1021.

Fleming, C.A. 1962. New Zealand Biogeography. A Paleontologists Approach. Tuatara 10 (2): 53-108.

Fleming, C.A. 1963. Evidence for Ecologically Significant Changes in Climate during the post-glacial period in New Zealand. Proc. N.Z. Ecol. Soc. No. 10: 48-52.

Fleming, C.A. 1973. The Quaternary Record for Australia and New Zealand. Royal Soc. of N.Z. Bull. 13.

Fleming, C.A. 1975. "The Geological History of New Zealand and its Biota" in Biogeography and Ecology of N.Z., Dr W. Junk B.V. Publ. The Hague (Ed. G. Kuschel).

Furkert, R.J. and M. Fieldes. 1968. Allophane in New Zealand Soils. 9th Intern. Congr. of Soil Science Trans. Vol. III Paper 14:133-141.

Gard, J.A. (Ed.) 1971. " The Electron-Optical Investigation of Clays." Mineral Soc. Monograph 3. Alden Press, Oxford, 383pp.

Gibbs, H.S. 1954. Soils and Agriculture of Matakaoa County. N.Z. Soil Bureau Bull. No. 11 52pp.

Gibbs, H.S. 1962. Steepland Soils and their problems. Paper presented at International Soil Conference, N.Z. N.Z. Soil Bureau Publ. No. 279 16pp.

Gradwell, M.W. 1968. Compaction of Pasture Topsoils Under Winter Grazing. 9th Intern. Congr. of Soil Science Trans. Vol. 3 Paper 44, p429-435.

Gradwell, M.W. 1971. Methods for Physical Analysis of Soils. N.Z. Soil Bureau Scientific Report 10C

Gradwell, M.W. and E.Z. Arlidge, 1971. Deterioration of Soil Structure in the Market Gardens of the Pukekohe District, New Zealand. N.Z. Jl. of Agric. Res. 14 (2): 288-306.

Grant, P.J. 1965. Major regime changes of the Tukituki River, Hawkes Bay, since about 1650 A.D. Jl. of Hydrology (N.Z.) 4 (1): 17-30.

Grant, P.J. 1966. Variations of Rainfall Frequency in Relation to Erosion in Eastern Hawke's Bay. Jl. of Hydrology (N.Z.) 5 (2): p. 73-30.

Grant, P.J. 1966. Variations of Rainfall Frequency in Relation to Erosion in Eastern Hawke's Bay. Jl. of Hydrology (N.Z.) 5 (2): p.73-86.

Grant, P.J. 1977. Recorded channel changes of the Upper Waipawa River, Ruahine Ranges, N.Z. Water and Soil Dvsn., M.O.W.D. Water and Soil Tech. Publ. No. 6 22pp.

Grant, P.J. 1978. Major erosion periods in the Ruahine Range since the 13th century and their impact on the vegetation. Unpubl. paper presented at N.Z. Ecol. Soc. (Inc.) Conf. 1978, Massey Univ. N.Z.

Hathaway, R.L. 1977. "Revegetation Research, Ruahine Ranges", in "Field Excursion to Southern Ruahines" (Ed. by V.E. Neall) handbook for 25th Jubilee Conference of N.Z. Soc. of Soil Science p.45.

Hayward, J.A. 1976. The Hydrology of a Mountain Catchment and its implications for Management. A paper presented at Soil and Plant Water Symposium, D.S.I.R. Palmerston North.

Hodgson, J.M. (Ed.) 1974. "Soil Survey Field Handbook". Soil Survey of England and Wales, Tech. Mono. No. 5, Harpendon 99pp.

Horton, R.E. 1933. The Role of Infiltration in the hydrologic cycle, Trans. Amer. Geophys. Union Vo. 14: 446-460.

Hubbard, C.B., M. Marden, V.E. Neall and J.A. Pollok, 1978. The Relationship of geology and soils to erosion in the southern Ruahine Range. Unpublished paper presented at N.Z. Ecol. Soc. (Inc) Conf., 1978, Massey Univ. N.Z.

International Society of Soil Science Commission 1. 1963. Soil Physics Terminology, Bull. No. 23: 7-10.

Ives, D. 1970. Methods of Survey and Descriptive Terminology used during a detailed soil survey of a high country catchment in N.Z. Soil News, Special Conference Number p.266-280.

Ives, D. 1972. Problems of Correlation in Mapping a High Country Catchment. Suggested Method of Soil Series Determination in N.Z. Soil News 20 (1) 3-12.

Jackson, R.J. 1966. Slips in Relation to Rainfall and Soil Characteristcs. Jl. of Hydrology (N.Z.) 5 (2): 45-53.

James, I.L. 1973. Mass Movements in the Upper Pohangina Catchment, Ruahine Range. Jl. of Hydrology (N.Z.) 12 (2): 92-102.

Jenny, H. 1941. "Factors of Soil Formation". McGaw-Hill, N.Y. 281pp.

Kenney, D.R. and J.M. Bremner, 1967. Determination and Isotope-Ratio Analysis of Different Forms of Nitrogen in Soils: 6. Mineralizable Nitrogen. Soil Sci. Soc. of America Proc. 31 (1):34-39.

Kerr, P.F. 1959. "Optical Mineralogy" 3rd ed. McGraw-Hill Book Co. 442pp.

Kingma, J.T. 1959. The Tectonic History of New Zealand. N.Z.Jl. of Geol. and Geophys. 2 (1): 1-55.

Kirkman, J.H. 1977a. The Formation of Allophane and Halloysite from Rhyolitic and Andesitic Tephras.in Summaries of Papers pres. at N.Z. Soc. of Soil Sci. Jubilee Conf., 1977.

Kirkman, J.H. 1977b. Possible Structure of Halloysite Disks and Cylinders observed in some New Zealand Rhyolitic tephras. Clay Minerals 12: 199-216.

Kohnke, H. 1968. "Soil Physics". publ. by McGraw-Hill Book Co. 224p.

Laffan, M.D. and E.J.B. Cutler. 1977. Landscapes, soils, and erosion of a small catchment in the Wither Hills, Marlborough. N.Z. Jl. of Science 20: 37-48.

Leamy, M., D. Milne, B. Pullar and J.G. Bruce. 1973. Paleopedology and Soil Stratigraphy in the New Zealand Quaternary Succession. Inqua. Congress Absracts.

Leopold, L.B., M.G. Wolman and J.P. Miller. 1964. "Fluvial Processes in Geomorphology", Freeman, San Francisco. 522pp.

Logan, I.R. 1978. Wild animals of the Ruahine mountains: their introduction, establishment and control. Unpubl. paper presented at N.Z. Ecol. Soc. (Inc.) Conf., Massey Univ., N.Z.

Loveday, J. (Ed.) 1974. "Methods for Analysis of Irrigated Soils". Common. Agric. Bureaux Tech. Comm. No. 54. 208pp.

Mackenzie, R.C. (Ed.) 1972. "Differential Thermal Analysis." Vols 1 &2. Academic Press , London & N.Y.

Marden, M. 1977. "Relationship of Geology to Erosion in the West Tamaki Catchment, South-eastern Ruahine Range". in "Field Excursion to Southern Ruahines" (Ed. by V.E. Neall), handbook for 25th Jubilee Conference of N.Z. Soc. of Soil Science p.9-15.

Marshall, T.J. 1967. " Relations between Water and Soil." Common. Agric. Bureaux Tech. Comm. No. 50 91pp.

Martin, R.S. 1978. " Report on Hydrology, Southeastern Ruahine Investivation," unpubl. report of Manawatu Catchment Board.

McCraw, J.D. 1973. Quaternary Airfall Deposits of New Zealand . in "Quaternary Studies", Roy. Soc. of N.Z. Bull. 13 p.35-45.

McDonald, D.C. 1961. A Survey of Some Physical Properties of New Zealand Soils from Greywacke parent material. N.Z.Jl. of Agric. Res. 4 (land 2): 161-176.

McGlone, M.S. and W.W. Topping. 1973. Otiran Pollen Diagrams from Tongariro Region, North Island, New Zealand. Inqua Congress Abstracts.

Meeuwig, R.O. 1971. Soil Stability on High-Elevation Rangeland in the Intermountain Area. U.S. Forest Service Res. Paper Int. 94 10pp.

Mehra, O.P. and M.L. Jackson. 1959. Constancy of the Sum of Mica Unit Cell Potassium Surface and Interlayer Sorption Surface in Vermiculite-Illite Clays. Soil Sci. Soc. of Am. Proc. 23 (2): 101-105.

Metson, A.J. 1956. Methods of Chemical Analysis for Soil Survey Samples. N.Z. Soil Bur. Bull. No. 12 208pp.

Mildenhall, D.C. 1973. Vegetational Changes in the New Zealand Quaternary based on pollen studies, with brief comments on the Pliocene background. Inqua Papers - An Introduction, N.Z. Quaternary p.20-23.

Milne, J.D.G. 1973a. Upper Quaternary Geology of Rangitikei Drainage Basin, North Island, N.Z. Ph.D. thesis, Victoria University of Wellington.

Milne, J.D.G. 1973b. Cold Climate Episodes in the Last 250,000 years, recorded by Aggradational Gravels and Loess Beds in North Island, New Zealand. Inqua Congress Abst. p.239.

Milne, J.D.G. 1973c. Map and Sections of River terraces in the Rangitikei Basin, North Island, New Zealand. N.Z. Soil Survey Rep. No. 4.

Moar, N.T. 1961. Pollen diagrams from the western Ruahine Range - N.Z. Jl. Science 4 (2): 350-359.

Moar, N.T. 1966. Post-glacial vegetation and climate in New Zealand. In Sawyer, J.S. (ed.). " World climate from 8000 to 0 B.C. London," Roy. Met. Soc. p155-156.

Molloy, B.P.J. 1969. Evidence for Post-Glacial Climatic Changes in New Zealand. Jl. of Hydrology (N.Z.) 8 (2): 56-63.

Mosley, M.P. 1977. "Southeastern Ruahine investigation report on erosion and sedimentation". Unpublished Manawatu Catchment Board report. 105pp + appendices, corrections.

Mosley, M.P. and R.J. Blakely. 1977. The Coppermine Landslide, South Eastern Ruahine Range. Soil and Water 13 (6): 16-17. and 32-33.

New Zealand Soil Bureau 1954. "General survey of the soils of North Island, New Zealand". D.S.I.R. Soil Bureau Bull. no. 5. Govt. Printer, Wellington.

New Zealand Soil Bureau. 1968. "Soils of New Zealand". D.S.I.R. Soil Bureau Bull. No. 26 (1-3). Govt. Printer, Wellington.

Nicholls, J.L. 1970. Ruahine Forest Class Map with accompanying notes. N.Z.F.S. Mapping Series 6, Sheet 13.

O'Loughlin, C.L. 1974. The Effect of Timber Removal on the Stability of Forest Soils. Jl. of Hydrology (NZ) 13 (2): 121-134.

O'Loughlin,C.L. and A.J. Pearce.1976. Influence of Cenozoic Geology on Mass Movement and Sediment Yield Response to Forest Removal, North Westland, New Zealand. Bull. of the Intern. Assoc. of Engineering Geology 14: 41-46. Krefeld, 1976.

Pang, Lim Chin. 1969. The Mapping and Pedologic Interpretations of the Soils in Woodville District. M. Sc. Geol. thesis Victoria University of Wellington.

Parfitt, R.L. and W.J. McHardy. 1974. Imogolite from New Guinea Clays and Clay Miner. 22 (4): 369-371.

Parham, W.P. 1969. Formation of halloysite from feldspar: low temperature artificial weathering versus natural weathering. Clays and Clay Miner. 17: 13-22.

Pereira, H.C. 1955. Assessment of Structure in Tropical Soils. Jl. Agric. Sci. 45 (4): 401-410.

Pohlen, I.J., C.S. Harris, H.S. Gibbs, J.D. Raeside. 1947. Soils and some related Agricutural aspects of mid Hawkes Bay. D.S.I.R. Bulletin No. 94.

Poole, A.L. 1973. Protecting Ruahines more important than Saving Manapouri. Soil and Water 9 (4): 27.

Pullar, W.A. and K.S. Birrell. 1973. Age and Distribution of Late Quaternary pyroclastic and associated cover deposits of the Rotorua and Taupo area, North Island, N.Z. N.Z. Soil Survey Report 1.

Rhea, K.P. 1968. Aokautere Ash, Loess and River Terraces in Dannevirke District, N.Z. N.Z.Jl. Geol. Geophys. 11: 685-92.

Rice, E.L. and S.K. Pancholy. 1974. Inhibition of nitrification by Climax Ecosystems. III Inhibitors other than tannins. Amer. J. Bot. 61 (10): 1095-1103.

Rice, C.I. and G.W. Kunze (Eds.) 1964. "Soil Clay Mineralogy - A Symposium" Univ. of N. Carolina Press, Chapel Hill, 330p.

Richards, L.A. (Ed.). 1954. " Diagnosis and Improvement of Saline and Alkaline soils." USDA Handbook 60 159pp.

Rijkse, W.C., 1974. "Soils" in Land inventory survey, Woodville County. Dept. of Lands and Survey.

Rijkse, W.C. 1977. Soils of Pohangina County, North Island, New Zealand. N.Z. Soil Bureau Bull. No. 42. 70pp. 2 maps, extended legend.

Ross, C.W. and G. Mew. 1975. Current thoughts on some Westland Gley Podzols - should they be re-classified? N.Z. Soil News 23 (3): 78-90.

Russell, E.W. 1973. "Soil Conditions and Plant Growth", 10th ed. Longman, London 849pp.

Schumm, S.A. 1975. Episodic Erosion: A Modification of the Geomorphic Cycle. A Proceedings Vol of 6th Ann. Geomorph. (attachment of Schumm, 1977).

Schumm, S.A. 1977. " South-eastern Ruahine Investigation - Consultant's Appraisal of erosion processes." Unpublished Manawatu Catchment Board Report with attachments.

Selby, M.J. 1970. "Slopes and Slope Processes". Publ. No. 1 of Waikato Branch of N.Z. Geographical Soc. (Inc.) 59pp.

Shepard, F.P. and J.R. Curray. 1967. "Carbon-14 Determination of sea level changes in stable areas. from "Progress in Oceanography" Vol. 4 (Quat. History of the Ocean Basins). Pergamon Press, Oxford and N.I. P.283-291.

Smith, G.D. 1978. A preliminary Proposal for Reclassification of Andepts and Some Andic Subgroups. Unpubl. memo to N.Z. Soil Bureau, Wellington. 20pp.

Smith, R.M. and D.R. Browning. 1946. Some suggested laboratory standards of subsoil permeability. Soil Sci. Soc. Amer. Proc. 11:21-26.

Soil Science Society of America, 1975. "Glossary of Soil Science Terms." 34pp. Publ. by Soil Sci. Soc. of America, Madison, Wisconsin, U.S.A.

Soil Survey Staff, USDA. 1975. "Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys". Soil Conserv. Serv., USDA, Agric. Handbook, No. 436. 754pp.

Soons, J.M. 1976. Late Quaternary Environments in the South Island of New Zealand. 25th Intern. Geol. Congress Abstr. Vol. 2: p511.

Sowers, G.B. and G.F. Sowers. 1970. "Introductory Soil Mechanics and Foundations". 3rd ed. publ. by The Macmillan Co., London, 556p.

Spörli, K.B. 1974. Torlesse supergroup, North-east Ruahine Range. Abstract from N.Z. Geol. Soc. Inc. Conference, Wellington.

Spörli, K.B. and A.B. Bell, 1976. Torlesse Melange and Coherent sequences, Eastern Ruahine Range, North Island, New Zealand, N.Z. Jl. of Geol. and Geophys. 19 (4): 427-447.

Strahler, A.N. 1971. "The Earth Sciences". 2nd ed. Publ. by Harper Intern., Harper and Row, N.Y. 681pp.

Strand, S. 1977. The Vegetation and Management of the West Tamaki Catchment. in "Field Excursion to Southern Ruahines" (ed. V.E. Neall) Field handbook for 25th Jub. Conf. N.Z. Soc. of Soil Science, p21 - 27.

Stevens, G.R.1974. "Rugged Landscape". Publ. by A.H. & A.W. Reed, 286pp.

Stevens, P.R. 1968. A chronosequence of soils near the Franz Josef Glacier. Ph.D. thesis deposited at the George Forbes Memorial Library, Lincoln College, 2 vols. 389pp.

Stephens, P.R. 1975. Determination of procedures to establish priorities for erosion control as determined in the southern Ruahine Ranges, New Zealand. M.Agr.Sc. Thesis, Massey University.

Stephens, P.R. 1977. "Erosion in the Upper West Tamaki Catchment", in "Field Excursion to Southern Ruahines" (ed. V.E. Neall). Field handbook for 25th Jub. Conf. N.Z. Soc. of Soil Science p27-36.

Taylor, N.H. and I.J. Pohlen. 1970. "Soil Survey Method" N.Z. Soil Bur. Bull. 25. 242pp.

Terzaghi, K. 1950. Mechanism of Landslides in "Application of Geology to Engineering Practice". Berkley Volume, Geol. Soc. of America p83-123.

Thom, B.G. 1974. Coastal erosion in Eastern Australia. Search 5 (5).

Townsend, W.N. 1973. "An Introduction to the Scientific Study of the Soil". 5th ed., publ. by Edward Arnold 209pp.

U.S.D.A. 1967. Re:Application of the Soil Classification System in Developing or Revising Series Concepts and in Naming Mapping Units. U.S.D.A. Soil Conservation Service, Soils Memorandum - 66, 21pp.

Varnes, D.J. 1958. "Landslide types and processes". In "Landslides and engineering practice". Eckel, E.B. ed. National research council publ. 544, Highway research board special report 29. p.20-47.

Walker, D. 1966: A commentary on botanical data from New Guinea, Australia and New Zealand. In Sawyer, J.S. (ed.). "World climate from 8000 to O.B.C.". London Roy. Met. Soc. p149-153.

Ward, R.C. 1975. "Principles of Hydrology". 2nd ed. Publ. by McGraw Hill Publ. Co Ltd. 367pp.

Water and Soil Division, M.O.W.D. 1971. "Land Use Capability Survey Handbook". Wellington, N.Z. 138pp.

Wellman, H.W. 1948. Tararua Range Summit Height Accordance. N.Z. Jl. of Science and Tech. 30B:123-127.

Wells, N. and R.J. Furkert. 1972. Bonding of Water to Allophane. Soil Science 113 (2): 110-115.

Wilson, A.T., C.H. Hendy and C.P. Reynolds. 1973. New Zealand Temperature During the Last Millenia. Inqua. Congress. Abstracts: p408.

Wilson, M.J. 1975. Chemical Weathering of Some Primary Rock-forming Minerals. Soil Science 119 (5): 349-355.

Abbreviations used in Soil Profile Descriptions

org. = organic

decomp. = decomposed

dk. = dark

lt. = light

v. = very

wk. = weak

mod. = moderately

dev. = developed

f. = fine

mdm. = medium

cse. = coarse

extmy = extremely

sl. = slightly

irreg. = irregular

gwk. = greywacke

APPENDIX 1: CLASSIFICATION OF LANDSLIDES/ABBREVIATED VERSION

TYPE OF MOVEMENT		TYPE OF MATERIAL			
		BEDROCK		SOILS	
FALLS		ROCKFALL		SOILFALL	
SLIDES		Rotational	Planar	Planar	Rotational
	Few Units	SLUMP	BLOCK GLIDE	BLOCK GLIDE	BLOCK SLUMP
	Many Units		ROCKSLIDE	DEBRIS SLIDE	FAILURE BY LATERAL SPREADING
FLOWS		ALL UNCONSOLIDATED			
		ROCK FRAGMENTS	SAND OR SILT	MIXED	MOSTLY PLASTIC
	Dry	Rock Fragment Flow	Sand Run Loess Flow		
			RAPID EARTHFLOW	DEBRIS AVALANCHE	SLOW EARTHFLOW
	Wet		SAND OR SILT FLOW	DEBRIS FLOW	MUDFLOW
COMPLEX		COMBINATIONS OF MATERIALS OR TYPE OF MOVEMENT			

(Varnes , 1958)

APPENDIX II: SOIL CHRONOSEQUENCE IN THE WEST TAMAKI RIVER CATCHMENT (to accompany Fig. 16)

SOIL SYMBOL (see Fig. 16)	SOIL DESCRIPTION cm (depth)	LOSS ON IGNITION -% of dry soil-	VEGETATION	ESTIMATED AGE
soil A (see fig. 19)	0 +2-0 organic litter & humus		podocarp-hardwood (many podocarps have been milled out)	>770yrs
	Ah 0-10 dk brown (10YR 3/3); v. stony silt loam; well dev. mdm nut structure; firm; many roots.	25		
on terrace opposite No. 1 Creek	AB10-29 brown/dk brown (10YR 4/3); v. stony silt loam; friable; mod. dev. mdm nut structure; common roots.	18		
	Bw29-88 dk yellowish brown (10YR4/4); stony silt loam; friable with gritty feel; mod. dev. cse blocky; few roots.	13		
	C greywacke gravels			
	R greywacke bedrock			
Soil B	0 +4-0 org. litter and humus		"	"
on terrace opposite No. 2 Creek	Ah0-17 dk brown (10YR 3/3); stony silt loam; well dev. mdm nut structure friable; many roots	21		
	AB17-32 brown/dk brown (10YR 4/3); stony silt loam friable; mod dev mdm nut structure common roots	15		
	Bw32-60 dk yellowish brown (10 YR 4/4); stony sandy loam; friable with gritty feel; wk. dev. cse. blocky structure; few roots	11		
	C 60+ greywacke gravels			

APPENDIX II contd.

SOIL SYMBOL	SOIL DESCRIPTION cm (depth)		LOSS ON IGNITION -% of dry soil -	VEGETATION	ESTIMATED AGE
Soil C on No. 2 Creek fan	0 +2-0	org. litter,		podocarp-hardwood (including rimu, rata, kamahi, coprosmas, pseudopanax, ferns, lancewood)	approx. 770yrs
	Ah0-12	dk brown (10YR 2/2); extmy stony silt loam; firm; mod. dev. mdm nut structure; many roots	28		
	Bw12-52	dk brown (10YR 3/3); extmy stony silt loam; firm; mod. dev. mdm blocky structure; few cse roots	10		
	C 52+	greywacke gravels			
Soil D (see figure 21) on Whiteywood Creek fan	0+2-0	org. litter		podocarp-hardwood (rimu's dominate; with rata, ferns, lianes, pepperwood)	"
	Ah0-15	v dk brown (10YR 2/2); extmly stony silt loam ; firm; mod. dev. mdm nut structure; many roots	20		
	Bw15-55	dk brown (10YR 3/3); extmy stony silt loam; firm; wk dev. mdm blocky structure; few coarse roots	7		
	C 55+	greywacke gravels			
Soil E on No. 1 Creek fan	0+3-0	org litter		podocarp-hardwood (podocarps with buried bases; many small shrubby plants).	approx. 98 yrs.
	Ah0-10	v dk greyish brown (10YR 3/2); stony loamy sand; soft-hard; wk dev.f.crumb structure; many roots	10		
	1(C) 10-46	greywacke gravels	4		
	Ahb46-47	v dk greyish brown (10YR3/2); stony silt loam; firm with gritty feel; mod. dev. f-mdm nut structure; few dead roots.	8		
	Bwb 67-104	brown/dk brown (10YR [illegible]/3); stony sandy loam; firm; wk dev. mdm blocky structure.	5		

APPENDIX II contd.

SOIL SYMBOL	SOIL DESCRIPTION cm (depth)		LOSS ON IGNITION -% of dry soil-	VEGETATION	ESTIMATED AGE
Soil E contd.	(2) Cb 104+	greywacke gravels			
Soil F on Hut Creek fan (Stanfield Hut)	0+3-0	org litter			
	Ah0-14	v dk greyish brown (10YR3/2); extmy stony loamy sand; soft-sl hard; wk dev. f. crumb structure; many roots.	13	Red beech (<u>Nothofagus fusca</u>)	approx. 98 yrs
	C 14+	greywacke gravels	4		
Soil G on terrace below Hut Creek	0+3-0	org litter		mahoe dominate with pepperwood, grasses, lianes; thistle; foxgloves	98 yrs
	Ah0-22	v dk brown (10YR2/2) extmy stony loamy sand; loose; wk dev f crumb structure; many roots	10		
	C22+	fresh greywacke gravels	3		
Soil H on terrace below No. 1 Creek	0+1-0	org litter			
	Ah0-12	v dk brown (10YR2/2) extmy stony loamy sand; loose; wk dev f crumbs; many roots	9	"	"
	C12+	fresh greywacke gravels	3		
Soil J on Car Park Ck fan	0+3-0	org litter		mahoe dominate, with lemonwood and various broadleaves	< 98 yrs > 40 yrs
	Ah0-12	v. dk greyish brown (10YR3/2); extmly stony loamy sand; sl hard; wk dev v.f-f crumb structure; many f roots	10		
	C12+	fresh greywacke gravels	3		
Soil K on terrace below Car Park Creek fan	0+9-0	org litter		pasture with some remaining lemonwood, coprosmas, horopito	"
	Ah0-10	v dk greyish brown (10YR3/2); extmly stony loamy sand; loose, wk dev. f crumbs around roots otherwise structureless; many f roots	4		
	C10+	fresh greywacke gravels	3		

APPENDIX IV NITROGEN MINERALISATION DATA FROM A LABORATORY EXPERIMENT FOR THE TAKAPARI PEATY LOAM, (Tp)

DEPTH OF SOIL SAMPLE (3 replicates)	INORGANIC-N*		% OF INORGANIC-N			
			NH_4-N		NO_2+ NO_3-N	
	average	range	average	range	average	range
	µgN/g air-dry soil		%			
0-20cm	434	422-447	97	92-99	3	1-8
20-50cm	108	103-114	97	97-98	3	2-3

(Macgregor, pers. comm.)

* Inorganic N was measured after incubation for 14 days, at 20°C using the method of Keeney and Bremner (1967).

NOTES

(1) The above data indicate that substantial amounts of nitrogen are present in the soil, potentially available for plant use.

(2) In contrast to normal agricultural soils, a large percentage of the inorganic-N produced is in the ammonium form.

(3) Nitrification of the ammonium form to nitrite and nitrate can be inhibited, which may be due at least in part to the following adverse conditions for microbial activity:
  1) a low soil pH, being approximately 4.5,
  2) waterlogging, during the winter months,
  3) the presence of certain tannins, tannin derivatives, phenolic acids and flavonoids, produced by the organic matter (Rice and Pancholy, 1974).

APPENDIX V PHOSPHATE RETENTION VALUES FOR THE DANNEVIRKE TAXADJUNCT, AND DANNEVIRKE HILL SOILS

SOIL NAME	HORIZON	PHOSPHATE RETENTION VALUE %	
Dannevirke hill soils	Ah	83	
	Bw	90	*
Dannevirke taxadjunct	Ah	97	*
	Bw	99	*
	C	79	

* Phosphate retention values >90%; a value suggested by Blakemore (1977) as a condition which is satisfied when the soils exchange complex is dominated by amorphous material.

NOTES

(1) High phosphate retention values for the Dannevirke soils suggest that a large proportion of their exchange complexes are dominated by amorphous materials.

(2) It is likely that these amorphous materials are weathered from volcanic ash, within the soil.

(3) When the exchange complex of the soil is dominated by amorphous materials, the soil may be classified as an Andept (Soil Survey Staff, USDA, 1975) or Andisol (G. Smith, 1978). This presumably equates with the yellow-brown loam soil group (alvic soils) of the New Zealand genetic soil classification.