SOIL RESOURCE SURVEY
OF THE
SUMNER REGION, PORT HILLS,
CANTERBURY

Presented in partial fulfilment
of the requirements for the Degree
of Master of Science
in the
University of Canterbury

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by

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1976

ABSTRACT

The growing concentration of population in metropolitan centres commonly results in the spread of urban areas onto land with a high value for food production. This aspect of urban growth represents poor allocation of resources and in many countries is creating agricultural and urban land use problems of large scale and complexity. The formulation of sound solutions to these problems requires comprehensive regional planning which recognizes the existence of a limited resource base to which both rural and urban development must be correctly adjusted in order to ensure a pleasant and habitable, but efficient, environment for people to live in.

The soil resources of a region are one of the most important elements of the natural resource base influencing both rural and urban development. Therefore, a need exists in any comprehensive planning programme to examine not only how land and soils are presently used but how the soils can best be used. This requires an area-wide soil survey which maps the geographic location of the various kinds of soils; measures their physical, chemical, engineering and hydrological properties; and interprets these properties for land use and planning purposes. Knowledge of the characteristics and suitability of soils are one of the most important tools which can be used to integrate rural and urban development within the limits of the natural resource base.

This paper describes in detail the distribution and characteristics of soils in the Sumner region, Port Hills,

Canterbury in relation to their significance to land use planning. The significance of erosion to land use in the Sumner region is discussed and a general suitability assessment of the soils for land use is attempted.

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CHAPTER I

INTRODUCTION

1.1 BACKGROUND TO THE INVESTIGATION

The growth of urban areas has often been characterised by land use allocation problems associated with the spread of outer suburban areas onto land formerly of high value for food production. Such land use problems are present in the city of Christchurch where the urban area has expanded rapidly since the Second World War. In Christchurch, land of low value for agriculture which is now available and suitable for residential development is limited in extent. As a result, much housing development has displaced horticulture and other forms of intensive agriculture as the principal land use on soils which are best suited for food production.

Land use planning should be based on the inventory and analysis of the physical and social variables influencing the use of a particular site. By studying such variables in specific areas and placing them in a regional perspective considerable progress can be made towards planning a rational and efficient land use pattern for the resources of the Christchurch region as a whole.

In considering the future growth of Christchurch city, residential development should be guided away from areas of high value for food production and onto areas with a relatively low potential for food production.

One area to which planners are looking for future residential development is the Port Hills, immediately to the south of Christchurch city. The land use of the Port Hills is currently dominated by extensive pastoralism and the soils are of relatively low value for food production.

The area at the eastern end of the Port Hills extending from Moncks Valley to Godley Head has been considered to have a number of potential sites for urban development. This region, which for the purposes of this study shall be referred to as the Sumner region, is 1190 ha in area comprising the slopes and ridges of Clifton, Scarborough and Godley Head and the valleys between each (Fig. 1). The land ranges from gently sloping on the valley floors to steep on the ridges which rise from sea level to a maximum altitude of 450 metres. The physical characteristics of the region strongly influence land use by variations in soil, slope, parent material and erosion features. Before decisions can be made regarding significant changes in the use of land in the region detailed inventory of these physical parameters need to be made so that the limitations they impose on urban or rural land use can be assessed. Once the nature and degree of these limitations are outlined, further study of their specific properties can be made to see if the limitations can be remedied or their influence reduced.

1.2 OBJECTIVES AND METHOD OF APPROACH

The contribution of this study to the future land use of the Sumner region is an inventory and interpretation of the factors of soil, parent material, slope and erosion hazard.

The objectives of the study are:

(i) to study in detail the soil pattern of the Sumner region and to outline the relationships between soils, parent material and slope; and their significance to the erosion features present

(ii) to identify soils in the Sumner region suitable for certain types of land use

(iii) to lay a foundation on which further study of other soil properties and soil-use relationships in the Sumner region can be made.

The reason for studying the soil factor is the influence that the physical resources of the region appear to have in defining land use. A soil survey includes study of the physical characteristics of a region since the character of any soil is the product of the interaction of the soil-forming factors. By gaining knowledge of the soil-forming factors progress can be made towards an understanding of the soils and the erosion patterns and interpreting their effect upon land use and the effect of land use upon them.

Soil mapping is only the initial stage of understanding soils and their behaviour. Measurements of soil properties are required to back up the soil survey to provide information so that specific problems can be dealt with correctly when they arise. Interpretations made from such measurements in one area can be applied to similar soils in other areas. The measurement of specific soil properties is beyond the scope of this survey but it is essential that they be studied in the future.

The basic steps of this study in outlining the soil factor for planning in the Sumner region are:

(i) A soil survey of the area to identify the different effects of parent material, climate and topography in their roles as soil-forming factors. It was apparent from cursory examination of the area that these factors were most significant in determining the soil pattern, the soil properties and the way in which the soil would behave under specific uses. Considerable time was devoted to the soil survey to gain as much information as possible about the pedology and geomorphology of the study area in order to try and understand the relationships between the soil and erosion patterns present.

(ii) A survey of the distribution and degree of the different types of erosion present.

(iii) The aggregation of the data collected to identify limitations for certain types of land use imposed by the interaction of the factors studied.

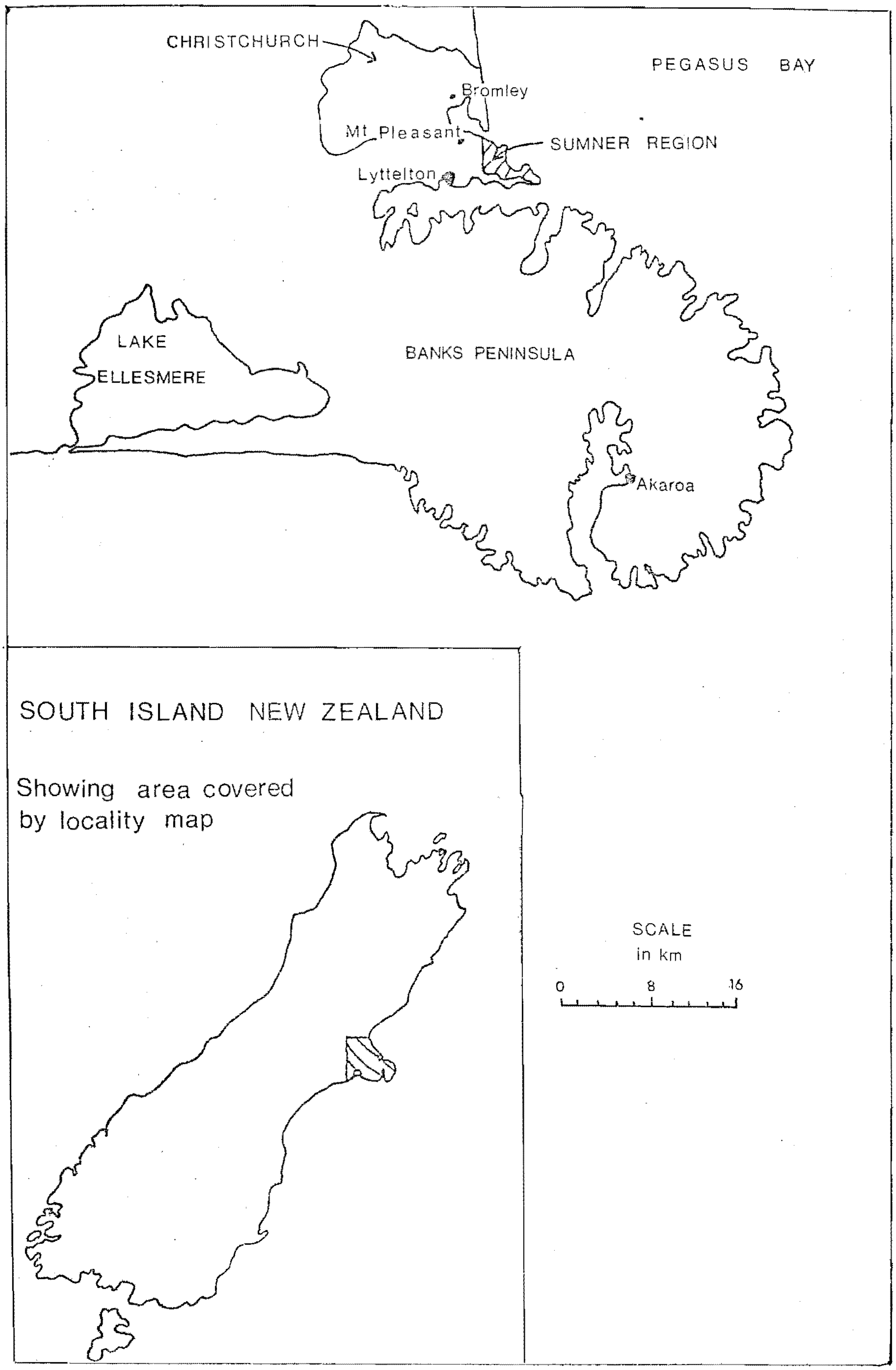


Fig. I Locality Map.

CHAPTER II

METHODS

2.1 SELECTION OF STUDY AREA

The Sumner region of the Port Hills was selected for this study because it is an area that may undergo significant land use changes in the future. At present land use is dominated by extensive pastoralism but a wide range of other uses occur including residential, horticultural, recreational and military uses. The land forms of the Sumner region tend to dominate land use patterns as they do in most parts of the Port Hills and because of this the data gained and the interpretations made in the Sumner region are likely to be of general application to other parts of the Port Hills. The soils in the residential areas of Sumner and Redcliffs were omitted from this survey because of a shortage of time but their study would be a useful extension of the survey.

2.2 SOIL SURVEY

2.2.1 Preparation

The initial preparation for the study was aimed at identifying broad landscape units to observe differences in the way the soil-forming factors were combined. It consisted of stereoscopic examination of air photographs of scale 1:10,000 taken in September 1973 by N.Z. Aerial Mapping Ltd. Boundaries delineating changes in landform, vegetation and the type and severity of erosion were outlined on the air photographs. The broad boundaries were checked in the field by a reconnaissance survey and agreed generally with those plotted in the laboratory. Erosion on a number of sites had exposed many soil profiles enabling quick and easy comparison of soils.

The soil parent materials consist of loess, basalt, mixtures of loess and basalt, and dune sand. Slopes range from easy rolling on sections of the ridge crests to very steep on the backslopes which are broken by bluffs, to flat on the valley floors. Soil profiles vary according to parent material and position on the slope. Aspect also influences soil morphology. Variations in soil properties were observed over small distances due to changes in parent material.

It was decided to survey in detail the soils of each type of landform so that variations in the soil-landform relationships could be observed across the study area as the soil survey proceeded.

2.2.2 Detailed Soil Survey

The initial stages of the detailed soil survey consisted of broad traverses across and down representative areas of each landform. Use of a soil auger enabled rapid comparisons of soil properties such as horizon thicknesses, texture, colour etc. and soil pits were dug at key sites to make detailed profile descriptions. Exposures resulting from erosion and road cuttings were also examined. Soil descriptions were made in accordance with Taylor and Pohlen (1970). From this part of the survey the relationships of soil to parent material and landform were established.

Broad soil units were identified by defining the key properties of each different soil observed. The key properties diagnostic of each soil horizon were grouped in such a way that each soil could be identified by the types of horizons that it contains. Thus, each soil has its own combination of key or diagnostic horizons identifying the visual form of its profile. The combination of diagnostic horizons for each soil makes up its profile form. The diagnostic horizons and profile forms established were then applied to the whole of the study area to check the validity and accuracy with which they had been defined. As the soil survey progressed more data relating to specific soil properties were collected and variations within the profiles of each map unit and within each diagnostic horizon were established. This enabled limits for each diagnostic horizon and profile form to be defined. The boundaries between soils with different profile forms and their slope phases were plotted on air photographs in the field.

The diagnostic horizons and specific properties of each profile form were used to identify soil series. This was done mainly by correlation of the soil forms and their diagnostic properties with the series defined by the soil survey of Heathcote County (Fitzgerald, 1966) and information from Raeside and Rennie (1974), N.Z. Soil Bureau Staff (1968) and E.J.B. Cutler (pers. comm.). The soil series were then divided into soil types on the basis of topsoil texture. The soil types were further subdivided into soil phases on the basis of slope and erosion. Soil phases were defined as in Taylor and Pohlen (1970). Soil complexes and associations were used to define mapping units where two or more series were intimately mixed and could not be differentiated satisfactorily on the map scale used. In most cases these variations were due to differences in parent material over short distances.

It should be noted that it is not possible to have complete uniformity within a soil mapping unit because of microsite differences which cause variations in the soil properties. Thus, a map unit may comprise more than one profile form and where this occurs the soils are mapped as complexes or associations. In making the soil survey the detail of field examination of the steepland was lower than on the rolling land because the alternatives for use are fewer.

2.2.3 Erosion Survey

During the initial preparation stage of the soil survey the distribution of erosion features was studied by stereoscopic examination of the air photographs. The patterns and intensity of the different types of erosion were noted. During the field studies of the soil survey the types and intensity of erosion for each soil mapping unit were observed and the pedological properties which appeared to be significant in influencing the different types of erosion were also noted at each site. The different types of erosion were described according to Soil Bureau Staff (1974).

The erosion state was classified according to the dominant type of erosion that is expressed by each soil mapping unit given the particular history of land use to which each soil unit has been subjected. Although different types of erosion may occur on the same soil unit it was considered appropriate to map the type of erosion that most affected the present land use of each unit. Where different types of erosion occurred together on the same soil unit identification of the dominant type was gauged qualitatively by observing the degree of surface expression of each erosion type and where possible noting the degree to which the pedological properties of the soil expressed the intensity of the various types of erosion that had occurred.

A qualitative ranking system of intensity for each type of erosion was defined by field observations of each erosion type from all areas of the landscape. On this basis each type of erosion was described as being of slight, moderate or severe intensity.

2.3 COMPILATION OF SOIL AND EROSION MAPS

During the initial stereoscopic analysis of landforms tentative soil boundaries were drawn on the air photographs.

Upon differentiation of the soils into series, types and phases these soil boundaries were re-examined in the laboratory and in the field and any modifications necessary were made to suit the scale and purpose of the proposed soil map. Profile descriptions recorded in the field were compared with each other to check the accuracy with which the soil series had been defined.

A base map of the study area was made at a scale of 1:8,000 based on the City of Christchurch District Planning Scheme map series. The boundaries of the study area and reference features such as the coastline, stream lines, bluffs, roads and fence lines were added. The soil mapping unit boundaries were transferred from the air photographs to the base map using an aero-sketchmaster (Carl Zeiss, model m243e). It is noted that some error exists in such transcription due to distortion in the air photographs and in transferring data from the air photographs to the base map. However, soil boundaries are not usually precise linear features but represent gradations in soil properties so that small errors are not necessarily serious.

The erosion map was compiled in a similar manner to the soil map using the same base map but with the soil units included. In this way erosion can be related to the soil type, parent material and slope present at each site. The types and degree of erosion were transferred to the base map using information gained from the field and air photograph surveys.

2.4 COMBINATION OF FACTORS STUDIED

By describing and mapping the soils, parent material, slope and erosion condition of the study area information was collected from which interpretations for future use could be based. All the factors studied were considered together and land use experience from similar soils was obtained from within and outside the study area so that limitations for certain uses could be identified. This also enabled topics which require future study to be identified.

CHAPTER III

ENVIRONMENTAL FACTORS INFLUENCING SOIL FORMATION

3.1 CLIMATE

Only a general picture of the climate in the Sumner region can be obtained from the climatological and rainfall data available because of the low number of observations in the study area and the distance from other recording stations. From the data available it can be inferred that the area has a dry maritime climate.

The only rainfall station in the study area is at Godley Head, although stations at Mt Pleasant, Lyttelton and Bromley are within 3 km of the study area (Fig. 1). Annual rainfall at Godley Head is variable with a mean of 553 mm per annum and a range from the extremes of 333 mm to 869 mm (Table I). Godley Head has the lowest mean annual rainfall of all stations in Canterbury (N.Z. Meteorological Service 1975). Mean monthly rainfall at Godley Head does not vary greatly in distribution during the year although the months of April to July are clearly wetter than the rest of the year while September to November is the driest period.

The principal rainbearing winds are those which accompany the cold frontal systems from the south and Banks Peninsula has a 'rainshadow' type influence on the climate of the north-eastern end of the Port Hills as is shown by the low annual rainfalls of Godley Head, Bromley, Lyttelton and Mt Pleasant (Table I). In winter, mist and cloud associated with the prevailing easterly and north-easterly winds often cover the ridges above 240 m in altitude and, in general, rainfall increases with altitude so that the summits of the main ridges receive slightly more precipitation than do the valleys. From the data in Table I it can be seen that rainfall decreases west to east from Mt Pleasant (635 mm) and Lyttelton (588 mm) to Godley Head (553 mm). This factor and proximity to the sea is reflected by an increase in the presence of salts and carbonate concretions in the soils in the east.

Variations in the intensity, duration and frequency of heavy rainfall events strongly influence the incidence of erosion events since slope stability is closely related to soil moisture conditions. The maximum amounts and intensities of rainfall that can be expected in a certain time period need to be known so that correct design of excavations and buildings can be made to cope with any problems of instability that are likely to occur. Such rainfall information is most valuable if the relationships between soil moisture and the conditions for slope failure are accurately known and understood. For the Port Hills region in general, the relationships between rainfall intensity, soil moisture and slope stability are poorly understood and require further study. Table II expresses the probability of certain amounts and intensities of rainfall that are likely to occur over a series of yearly intervals.

Data recorded at Bromley (Table III) show that temperatures are highest in December, January, February and March and lowest in June, July and August. Temperatures in the study area are likely to be slightly different from those at Bromley, being cooler at higher altitudes and slightly warmer in the sheltered, north-facing valleys of Taylor's Mistake, Sumner and Moncks Valley. In the study area differences in temperature and soil moisture due to aspect are noticeable. The north and north-west-facing slopes are warmer and drier than those on the south and south-east due to

TABLE I

MEAN MONTHLY AND ANNUAL TOTALS OF RAINFALL

(a) Mean monthly and annual rainfall (mm)

(b) Maximum monthly and annual rainfall (mm)

(c) Minimum monthly and annual rainfall (mm)

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Christchurch	(a)	53	44	53	53	75	59	67	50	47	46	47	57	651
(1894-1974)	(b)	139	176	172	226	233	191	221	197	156	158	166	202	997
Altitude 7 m.	(c)	5	1	3	6	10	4	6	2	4	1	8	1	379
Godley Head	(a)	39	41	38	56	70	51	63	44	37	31	38	45	553
(1935-74)	(b)	103	173	125	298	226	139	237	167	161	70	155	171	869
Altitude 138 m.	(c)	6	0	0	8	5	2	4	8	5	2	7	8	333
Mount Pleasant	(a)	50	37	38	81	85	59	62	56	43	47	50	27	635
(1964-74)	(b)	80	104	83	338	127	99	111	103	77	88	112	43	916
Altitude 137 m.	(c)	26	11	9	20	47	9	9	25	14	25	12	12	454
Lyttelton														
(1941-70)	(a)	41	41	46	51	76	58	64	51	38	43	38	41	588
Altitude 5 m.														
Bromley	(a)	39	35	39	78	74	49	56	47	34	35	43	35	564
(1961-74)	(b)	67	91	107	275	120	110	126	85	81	88	104	130	843
Altitude 9 m.	(c)	23	7	9	15	36	8	15	20	10	3	11	9	372

TABLE I contd

		Summer (Dec Jan Feb)	Autumn (Mar Apr May)	Winter (Jun Jul Aug)	Spring (Sep Oct Nov)	Annual
Christchurch (1894-1969)	(a)	157	181	176	140	654
	(b)	345	408	408	355	997
	(c)	29	60	59	26	379
Godley Head (1935-1969)	(a)	130	166	157	109	552
	(b)	368	373	385	314	869
	(c)	47	61	53	26	333

TABLE II

RAINFALL DEPTH - DURATION - FREQUENCY RELATIONS EXPECTED FOR CHRISTCHURCH (mm)

	TIME INTERVAL									
Years	10 mins	20 mins	30 mins	1 hr	2 hr	6 hr	12 hr	24 hr	48 hr	72 hr
2 yr	5	7	8	11	15	28	40	55	69	74
5 yr	8	10	12	16	21	35	51	73	92	100
10 yr	9	12	15	19	24	40	59	85	107	118
20 yr	11	14	17	22	28	45	66	96	121	134
50 yr	13	17	21	26	32	51	76	111	139	156
Maximum intensity recorded (1929-66)	14	18	22	30	35	48	66	105	128	141

TABLE III

MEAN TEMPERATURE NORMALS (^{o}C, 1941-70)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Christchurch	16.8	16.8	15.0	12.2	9.1	6.3	5.9	7.3	9.8	12.0	14.0	15.5	11.7
Bromley	16.8	16.5	15.0	12.3	9.5	6.8	6.4	7.5	9.7	11.7	14.0	15.3	11.8

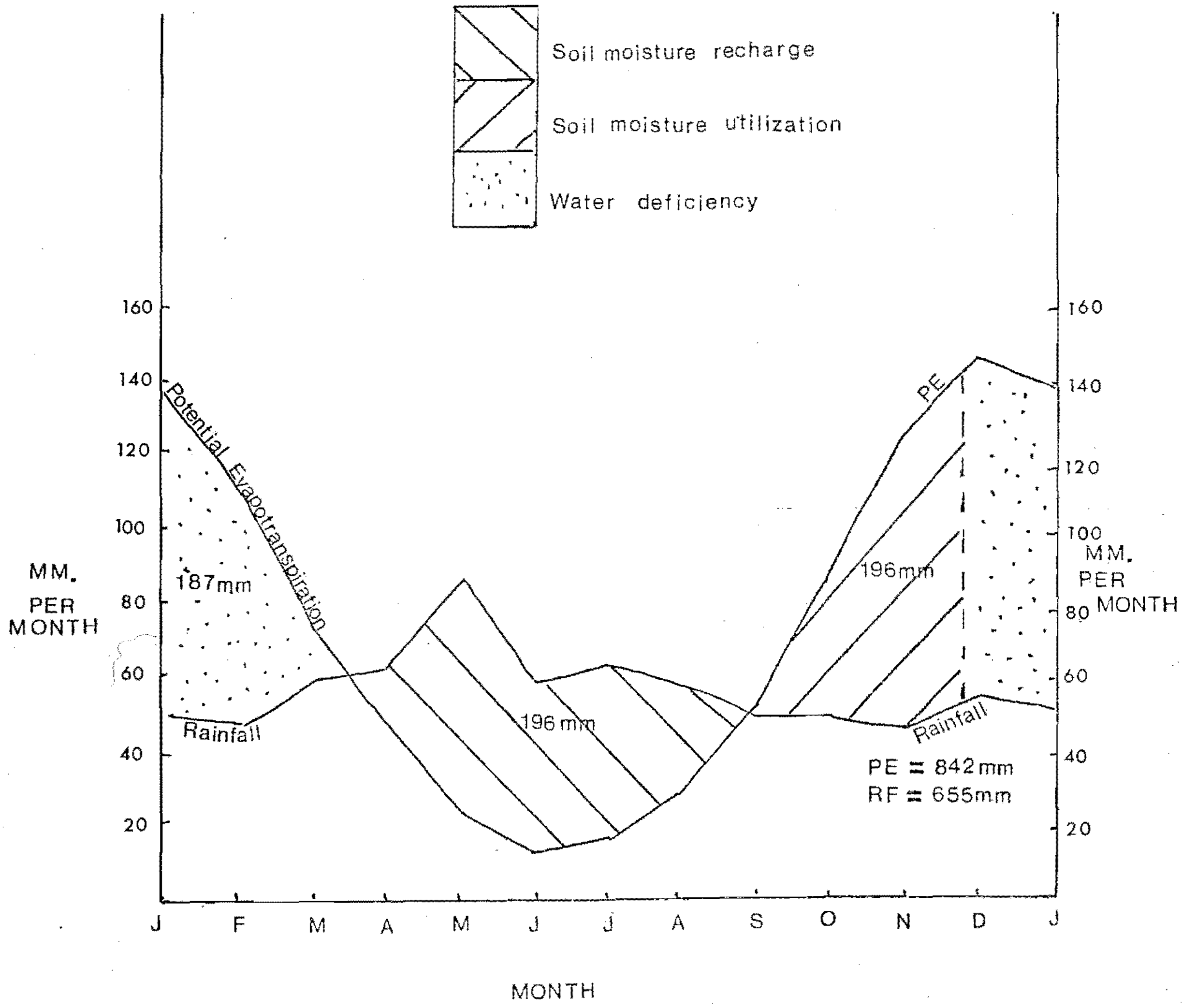


Fig. 2 Evapotranspiration diagram for Christchurch (Data 1940-75).

the direction and angle of sunshine as well as the effects of the Fohn type north-west winds. These winds, although only forming 7-10% of the total winds, are hot, dry and gusty accentuating the dryness of the north-west slopes, especially in summer. Mean relative humidities recorded at the Christchurch Magnetic Observatory show a significant decrease for the months of October, November, December and January due to the prevalence of the north-west winds in those months.

Evapo-transpiration data is not available for Godley Head but the evapo-transpiration graph prepared from climatological data for Christchurch (Fig. 2) shows the main variations in moisture regime during the year. In general, the water balance in the study area is likely to have a longer period of water deficiency than is shown in Figure 2 because of lower rainfall and higher evaporation rates than those of Christchurch. The period of water deficiency in Christchurch lasts for 4 months between December and March so in the Sumner area it probably lasts for about 5 months from November to March. Plant growth is severely limited by the summer drought especially on excessively drained and well drained slopes and this is a major factor restricting the agricultural productivity of the area. The degree of water deficiency varies slightly with aspect and the east-facing slopes remain moist for slightly longer periods than the west-facing slopes. The water deficiencies are highest on all slopes near Godley Head and on the dry slopes facing the north-westerly winds in other parts of the study area.

3.2 VEGETATION

Vegetation is not important in differentiating soils in the Sumner region since most of the soils have a similar vegetation cover. However, the state of the vegetation is very important in influencing erosion. The natural vegetation of the northern slopes of the Port Hills was tussock grassland which included xerophytic species adapted to the dry climate (Fitzgerald, 1966). Since European occupation of the area the vegetation has been modified, mainly by grazing.

In discussing the natural plant community of the northern slopes of the Port Hills, Boyce (1939) considers that the natural vegetation was dominated by silver tussock (*Poa caespitosa*), blue tussock (*Poa colensoi*), fescue tussock (*Festuca novae-zelandiae*) and blue wheat grass (*Agropyron scabrum*). He suggests that blue wheat grass was the most widespread and more abundant than the others on dry exposed ridges such as those of the Sumner region. Matagouri (*Discaria toumatou*) and speargrass (*Achiphylla* sp.) were common and isolated clumps of cabbage trees (*Cordyline australis*) were also present. Small shrubs found in rocky and sheltered sites included pohuehue (*Muehlenbeckia* sp.), shrub fuchsia (*Fuchsia colensoi*) and juvenile forms of kowhai (*Sophora* sp.).

The present vegetation is grassland of variable composition in which silver tussock and introduced grasses are dominant. On the moister south-east-facing slopes the tussocks are closely spaced while on the drier north-west-facing slopes they are widely spaced or absent. The introduced grasses are mainly low-producing pasture species and are dominated by browntop (*Agrostis tenuis*) with Yorkshire fog (Holcus lanatus) on the moister slopes and danthonia (Notodanthonia sp.) on the drier slopes. On shallow soils cocksfoot (Dactylis glomerata) is dominant and on gentle slopes forms a thick grassy mat covering the soil surface. Isolated clumps of cabbage trees and Pinus radiata are present on deeper soils.

On poorly drained sites, including the valley floors, jointed rush (Leptocarpus simplex) is common, occurring with a thick mat of introduced grasses mainly Yorkshire fog and clovers. The sand dune zone of Taylor's Mistake supports a vegetation of lupin (Lupinus arboreus) and maram grass (Ammophila arenaria).

3.3 GEOLOGICAL HISTORY

The hills of the Sumner region form the northern rim of a volcanic crater centered in Lyttelton Harbour and the underlying rocks are basaltic and andesitic lavas and agglomerates of the Lyttelton Group which is of Pliocene age. The basalts and andesites are locally intruded by trachyte dikes also of Pliocene age (Liggett and Gregg, 1965).

During the Plio-Pleistocene period when the eruptive activity of the Lyttelton volcano was ceasing and Banks Peninsula was still an island, the present landscape features began to develop. This can be inferred from the fact that the loess present in the Sumner area is thought to be of Upper Pleistocene age (Griffiths, 1973), suggesting that the landforms on which it rests is older. The climate of the Pleistocene was cool and moist and dissection of the flanks of the volcano by short, fast flowing streams occurred leaving distinct interfluves between the stream valleys e.g. Clifton and Scarborough ridges. The central areas of the Lyttelton volcano were eroded and drowned to form the erosion caldera of Lyttelton Harbour. Sea level fluctuations occurred in the Pleistocene and coastal erosion truncated spurs and caused oversteepening of slopes in Taylor's Mistake, Sumner and Moncks Valleys. The dissection of the volcano to its present degree was probably completed by the Middle to Upper Pleistocene.

During the Otira Glaciation of the Upper Pleistocene the outwash gravels of the Canterbury Plains were deposited and joined the island of Banks Peninsula to the mainland. At this stage the infilling of the valleys of the Port Hills began and wind-blown loess was deposited over much of the area. The loess deposits of the Sumner area are of the Birdlings Flat Formation laid down in the Upper Pleistocene. The origin of the loess is thought to have been the flood plains and fan of the Waimakariri River which extended east and south beyond Banks Peninsula during a period of lower sea level in the Upper Pleistocene (Griffiths, 1973). Loess deposits of considerable thickness also occur in areas sheltered from the strong north-westerly winds so that it is likely that easterly and south-westerly winds were also important in transporting material besides the north-westerlies.

It is likely that the loess cover was thicker and more extensive than at present (Griffiths, 1973) but because of the hilly and steep terrain on which it was deposited much of the loess cover has now been removed and some of it redeposited on lower slopes. Griffiths suggests that this downslope movement was probably induced by freeze-and-thaw processes in the periglacial environment during the Pleistocene. Relict solifluction deposits from this period were observed in the Sumner area. It is not known how much loess was deposited or how much was removed by erosion after each cycle of deposition in the glacial and interglacial periods.

Infilling of the valleys in the Sumner area was hastened by the erosion of the loess cover, the deposition of sediments from the estuary of the Avon and Heathcote Rivers and the formation of beach dune systems across the lower portions of the valleys. On the lower slopes and valley floors accumulation of silty alluvium derived from the erosion of the loess-covered interfluves is still continuing. Intensive wave action in the Pleistocene and Holocene has resulted in the varied coastal geomorphology of the study area. Features include cliffs, stacks, caves, wavecut platforms, beaches, the outlet to the Avon-Heathcote Estuary and the entrance to the drowned river system forming Lyttelton Harbour.

3.4 TOPOGRAPHY

The major landforms of the Sumner region consist of the slopes and ridges of Godley Head, Scarborough and Clifton and the valleys between each. The ridges slope at 10-12° away to the north-east from the caldera rim forming the north side of Lyttelton Harbour. The ridges vary in length with those of Clifton and Scarborough both being approximately 3.2 km long while the shorter ones forming Godley Head are both approximately 1.6 km long. The width of each ridge across the summit and shoulder positions reaches a maximum of 1 km on Clifton, 0.5 km on Scarborough and 0.8 km on Godley Head. Clifton is the most westerly of the ridges, sloping down from Mt Pleasant (500 m) and branching into Clifton Spur and Richmond Hill at its seaward end. Scarborough is a single ridge and Godley Head consists of two small ridges - one running between Taylor's Mistake and Harris Bay while the other is a broad, gently sloping one forming Godley Head itself. Each ridge is truncated at its seaward end by coastal cliffs, the highest of which are Whitewash Head (107 m) and Godley Head (140 m). The altitudes of the midsections of each ridge are: Clifton 198 m, Scarborough 165 m and Godley Head 135 m.

Slope positions of the landscape are defined according to Soil Bureau Staff (1974) and are shown in Figure 3 with the range of slope gradients that occur on each position.

Summit positions of the landscape include easy rolling ($3-7^{o}$) and rolling slopes ($7-13^{o}$). These steepen, often sharply through strongly rolling ($13-20^{o}$) shoulder positions into long areas of backslope which range in gradient through moderately steep ($20-28^{o}$), steep ($28-38^{o}$) and very steep ($>38^{o}$) slopes. The backslopes are usually broken by bluffs up to 30 m high which drop into the fans forming the footslopes. The footslopes are strongly rolling to moderately steep but decrease in gradient to rolling and easy rolling as they merge into the toeslopes. The slope gradients of the valley floors are gently undulating ($1-3^{o}$) or flat ($0-1^{o}$).

3.5 SOIL PARENT MATERIAL

The soil parent material is a most important factor

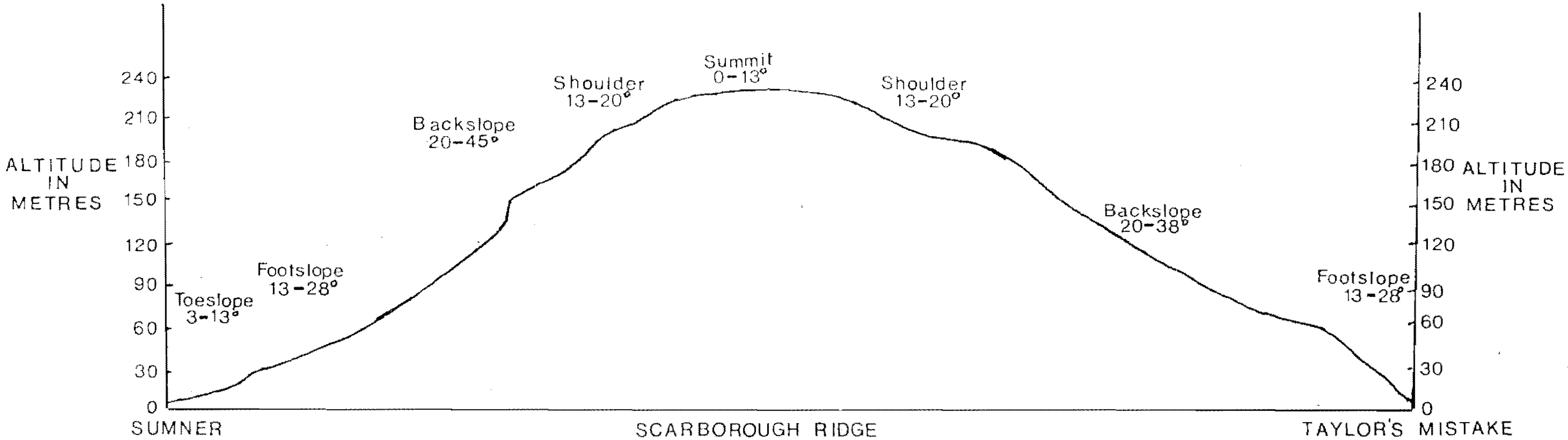


Fig. 3 Cross-section of Scarborough Ridge showing slope positions and gradients.

in determining the soil characteristics and as a factor influencing slope stability. Four groups of parent material were differentiated as follows:

- Basalt
- Loess
- Mixed loess and basalt
- Dune sand.

3.5.1 Basalt rock

Shallow regoliths (less than 45 cm deep) derived from basalt rock cover approximately 10% (120 ha) of the study area. This regolith type has patchy areal distribution (Map 1) occurring mainly on the ridge summits, shoulders and backslopes from which the loess cover has been removed. It usually occurs in association with rock outcrops and bouldery ground surfaces and often has a gradational boundary with regoliths of mixed loess and basalt where an increase in the loess content occurs downslope from, or in small depressions between, the shallower areas.

The soils formed on basalt are brown granular loams. They are bouldery and thin (5-45 cm) but have good structural development and are subject to sheet erosion and solum creep where slopes are strongly rolling to steep.

3.5.2 Loess

Soils derived from loess parent material cover approximately 65% (600 ha) of the study area. The loess is of the Birdlings Flat Formation deposited in the Upper Pleistocene and is composed mainly of quartzo-feldspathic minerals with very minor accessory minerals and some secondary clay minerals (Griffiths,1973). It has silt loam to fine sandy loam textures and is distinctly calcareous, containing calcium carbonate concretions which occur individually at varying depths in the loess. Salts are commonly precipitated on exposed faces in the loess and in the soil profiles and their presence increases with proximity to the sea. Layering of the loess similar to that observed by Griffiths was noted at a number of sites although the degree of layer expression is variable.

Loess occurs on all slope positions in the landscape but its thickness is variable. Footslope sites are usually thickest (up to 8 m) where the loess deposited by aeolian processes is overlain by water-transported loess derived from the erosion of loessial soils further upslope. The loess cover on the ridge summits is variable in thickness (0-2 m) and is often thin because the initial deposits there were relatively thin and have since been subjected to intensive erosion by solifluction in the Pleistocene and sheet wash in the Holocene. Deposits of the shoulder positions are discontinuous in distribution and variable in thickness (0-4 m). Where deposits are thicker loess deposited by aeolian processes is mixed with surface accumulations of erosion products derived from the summits. Loess thicknesses on the backslopes vary according to slope and intensity of erosion ranging from a maximum of 2 m thick on moderately steep sites to thin ($<$0.4 m) or absent on the steep and very steep slopes. The slope gradient and erosion processes on the backslope result in material being regularly transported through this slope position.

Generally, the loess cover is thickest in the west of the study area and although it thins toward Godley Head the textures in that area are slightly coarser suggesting proximity to a local source near Godley Head. On most sites erosion processes have greatly modified the local thicknesses of the loess cover and on accumulative sites such as the fans rejuvenation and burial of soils is common.

The soils formed on loess are yellow-grey earths and yellow-grey earth intergrades (Table V). They commonly have grey, weakly structured topsoils and subgammate, mottled, fragic subsoils. The fragipan is extremely hard when dry and has a high bulk density and low porosity which impedes vertical movement of water.

The soils derived from loess have developed under conditions of winter wetting and summer drying producing deep vertical cracks in the regolith in response to seasonal changes in the moisture balance. Tunnel-gully erosion occurs on the dry aspects where the changes in the moisture regime are greatest and cracking has lead to the formation of tunnels and the open gullies that result from the collapse of the tunnelled soil. Debris avalanches may occur on the moist easterly aspects where cracking has enabled water to penetrate into the subsoil and when soil moisture conditions reach suitable levels the factors of internal friction and cohesion contributing to shear strength may be decreased to the point where failure may occur. In regoliths where the fragipan is well developed failure occurs along the top of the pan but in shallow deposits, or where the fragipan is weakly developed, failure usually occurs at the contact between the loess and the underlying basalt. The lack of cohesion and weak structure of loess makes it more prone to flow movements (e.g. debris avalanches) than slide movements when the regolith is saturated.

3.5.3 Mixed loess and basalt

This group has three components:

(i) Mixtures of loess and basalt on easy rolling to strongly rolling summits and shoulders

(ii) Colluvial mixtures of basalt and loess on strongly rolling to steep upper footslope and backslope sites

(iii) Mixtures of basalt and loess in poorly drained hollows on the ridge summits and shoulders.

The first group is related to the shallow basalt regolith described in 3.5.1 but has a significant loess component making it slightly deeper (up to 0.8 m) and less bouldery. The content of basalt fragments increases down the soil profile which often merges into a weathered zone of basalt overlying fresh rock. The weathering occurs mainly along joints in the rock and where it is intense spheroidal structures are present. Information from Leslie (1973) suggests that such regoliths may be the relicts of interglacial weathering in the Pleistocene and soil formation has been rejuvenated by additions of loess since then. Because of the basalt influence soils have moderate structural development and are subject to only slight sheet erosion and solum creep. The soils are brown granular loams covering 7% (90 ha) of the Sumner region (Map 1).

The colluvial mixture of basalt debris and washed loess on the steeper slopes is generally thin (< 0.5 m) where basalt content is high but thickens (up to 0.7 m) where the ratio of loess to basalt increases. The basalt material in this unit is usually fresh and unweathered. Because of the steep slope gradients sheet erosion is severe and eroded material is regularly passing through this site so that the regolith is weakly compacted and soil development is poor. Soils usually have thin, weakly structured topsoils and horizons are bouldery and weakly expressed. They are steepland brown granular loams and cover 10% (120 ha) of the Sumner region (Map 1). Debris avalanches may occur if soil moisture conditions reach high enough levels to enable slope failure and tunnel-gullying occurs on dry aspects where the loess content is high. On strongly rolling slopes, oval lobe-shaped mounds occur and are thought to be solifluction deposits. They are up to 2 m thick and are composed of loess mixed with basalt fragments which are often weathered.

The regolith group of mixed basalt and loess in poorly drained sites on the ridgetops is limited in extent and has patchy distribution covering only 2% (24 ha) of the study area (Map 1). It is moderately thick (0.5-0.9 m) with the watertable varying seasonally from 10-50 cm below the surface. The regolith is weakly structured and shear strength is likely to be low but because it occurs in depressions in the landscape it is not actively eroding. The soils are brown granular loams intergrading to gley soils.

3.5.4 Dune sand

These parent materials cover 4% (50 ha) of the Sumner area. They occur on flat land at the base of the valleys and are formed from both stable and accumulating beach dune deposits. They have sand textures and are weakly compacted so that drainage through them is rapid although site drainage is poor in the backbeach zone behind the dunes. They are subject to wind erosion if the vegetation cover is removed.

The above discussion has outlined the general nature of the parent material and regolith types as they affect soil formation and slope stability. The distribution of parent material types is shown by Map 1 and the accompanying legend.

Further study of the physical, chemical and mechanical properties of the regolith and their influence on its behaviour is beyond the scope of this study but they should be investigated in detail before any changes in land use are considered.

3.6 RELATIONSHIPS BETWEEN LANDFORMS, PARENT MATERIAL AND SOILS

Broad relationships between landform elements, soils and parent material are summarised in Table IV.

The soils on the summit areas, although moderately regressive have A/B/C profiles on sites with deep loess parent material. Where loess regolith has been removed shallow A/C profiles are present. The summits are usually gently convex in cross-section and erosion is slight with sheet erosion and creep being the dominant types.

The shoulders are convex in shape and the regolith is often variable in depth. The soils are mainly loessial and although moderately to strongly regressive have A/B/C profiles. In soils derived from loess, tunnel-gullies are common and often severe on dry aspects.

The backslopes are convex and strongly regressive with a range of regolith types of which mixed loess and basalt is most common. In loess regoliths soil B horizons are present but where the regolith is mixed or shallow subsoil horizons are weakly defined or absent. The backslopes show severe sheet erosion and slight to moderate tunnel-gully and mass movement forms of erosion depending on the nature of the soil parent material.

REGOLITH	LOESS (colluvial)	LOESS (colluvial)	LOESS (colluvial)	BASALT, MIXED	LOESS (insitu and colluvial)	BASALT, MIXED	LOESS (insitu)	
SOIL SERIES	Horotane	Heathcote	Scarborough	Kiwi Evans Windsor	Takahe Clifton Godley	Windsor Cashmere	Takahe	
EROSION TYPE	-	-	Tunnel-gully Debris avalanche Sheet	Sheet Creep	Tunnel-gully Debris avalanche Sheet, Creep	Sheet Creep	Sheet Tunnel-gully Creep	-

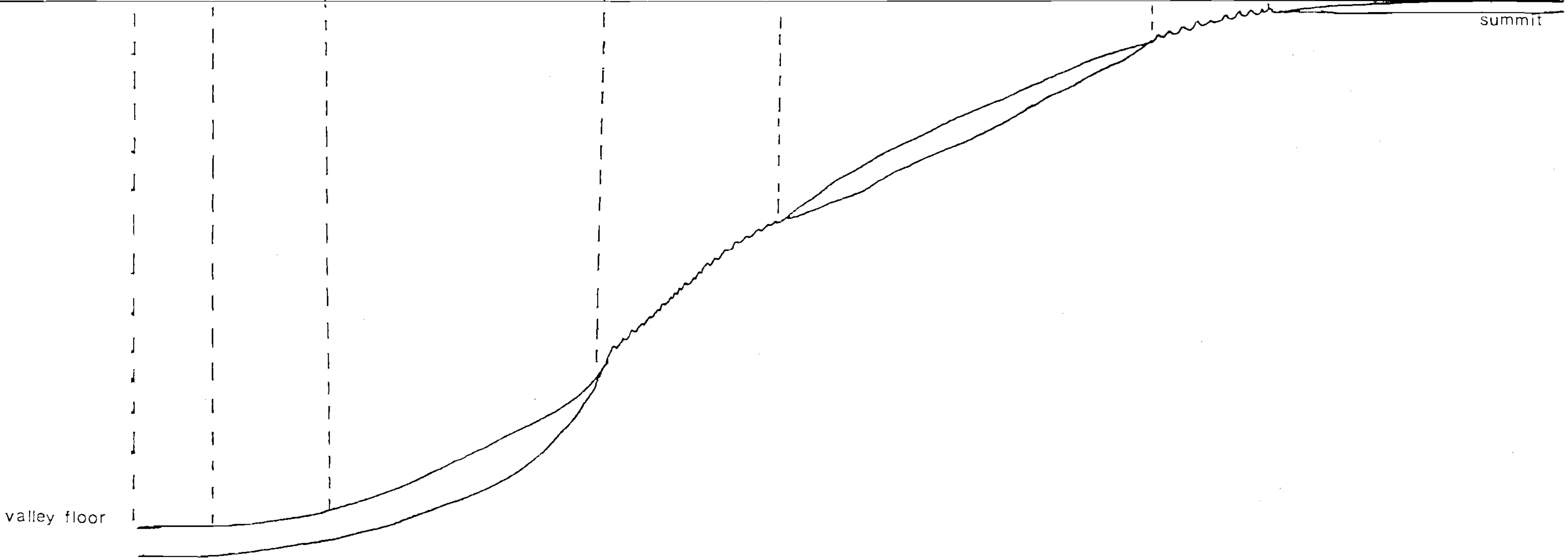


Fig.4 Typical ridge cross-section showing the relationship between regolith, soils and erosion.

The footslopes form concave-shaped fans which are moderately to strongly regressive in their upper sections but which tend to become accumulative towards their toes. Basalt debris is common in the fan heads but the loess content of the regolith increases in mid fan and toe fan positions. The B horizon in the soil is weakly developed at the fan heads but is better developed in mid and toe fan sites. The fan sites receive considerable amounts of runoff water from the shoulders and backslopes but the soils are usually well drained. The susceptibility of soils to erosion by tunnel-gullying, debris avalanche and sheet wash is moderate on the head and mid fan positions.

The toeslopes have a gently concave shape and the soils have weakly developed A/B/C profiles. The toeslopes are actively accumulating detrital material washed from the upper slopes and tunnel-gullies from the footslopes discharge material onto them. Soil erosion is slight and, where present, occurs in the form of sheet wash and solum creep.

The valley floors are strongly accumulative with the soil parent material consisting of loess and basalt alluvium derived from the surrounding slopes.

3.7 LAND USE

The dominant land use on the ridges and slopes is extensive grazing of sheep and cattle. This form of land use is economically marginal because of the rugged topography and poor pasture growth under the droughty summer conditions. Intensive agriculture in the form of market gardening is practised on a small scale on easy rolling and rolling sites on Clifton ridge. Recreational uses of land

Landform Element	Slope Range	Parent Material Type(s)	Nature of Soils	Drainage	Erosion
Summit	$3-13^{o}$	Loess Basalt	Weakly to Moderately Regressive	Moderately well drained	Slight - sheet - creep
Shoulder	$13-20^{o}$	Loess Mixed Basalt	Moderately to strongly Regressive	Well drained	Moderate - sheet - creep - tunnel-gully
Backslope	$20-45^{o}$	Loess Mixed Basalt	Strongly Regressive	Excessively drained	Severe - tunnel-gully - debris avalanche - sheet - creep
Footslope	$13-28^{o}$	Mixed Loess	Moderately to weakly Regressive	Well drained	Moderate - tunnel-gully - sheet - debris avalanche
Toeslope	$3-13^{o}$	Loess	Accumulative	Moderately well drained	Slight - creep - sheet
Valley Floor	$0-3^{o}$	Loess Dune sand	Strongly accumulative	Imperfectly drained	Nil

TABLE IV Relationships between landform, regolith, soil, drainage and erosion in the study area are varied and include the Richmond Hill Golf Course; the reserves of Barnett Park (40 ha), Nicholson Park (3.6 ha), and Taylor's Mistake (6.7 ha); and a number of tracks which are actively used for walking and horse-riding around the hills and beaches. Part of the Summit Road scenic route passes through the area and the valleys, ridges, estuary and sea beyond contribute to the view from this road. Residential areas include the seaward ends and lower slopes of Clifton, Richmond Hill and Scarborough ridges, while baches are scattered along the foreshore between Taylor's Mistake and Godley Head.

CHAPTER IV

SOILS

4.1 PREVIOUS WORK

No detailed studies of the soils which occur in the Sumner region have been published and the only information that exists is of a general nature.

The most detailed contribution to the knowledge of soils in the study area is that of Raeside and Rennie (1974). They mapped the area administered by the Christchurch Regional Planning Authority on a scale of 1:63,360 during their study of the soil factor in the long-term planning of land use in the Christchurch region. Their mapping units were broad and were based mainly on differences in topography and parent material. The mapping units of Raeside and Rennie have been subdivided in this survey to show the variations in the soil pattern more accurately although where possible their soil names have been retained and defined more precisely.

Fitzgerald (1966) made a soil survey of Heathcote County immediately to the west of the study area on a mapping scale of 1:25,000. Many of the soils present in the Sumner region also occur in hilly portions of Heathcote County and Fitzgerald's survey was used to identify and correlate many of the mapping units of this survey (Appendix 1). His mapping units are broader than used here and have also been subdivided where necessary.

General descriptions of a number of soil series which occur in the study area are noted in the general survey of the soils of the South Island (Soil Bureau Staff 1968).

4.2 GENERAL DESCRIPTION OF SOILS

4.2.1 Physical properties

The broad soil pattern of the Sumner region is related mainly to the distribution of the various parent material types and the physical properties of each soil largely reflect the nature of its parent material.

Textures of the loessial soils on the hilly land are dominantly silt loams in the topsoil often with an increase in clay content down the profile towards the lower B horizon. Soils derived from loess with fine sandy loam texture in the topsoil were mapped mainly on the hills in the east. Bouldery soils are widespread occurring on the summits and shoulders of the ridges from which the loess cover has been removed. They also occur on steep slopes where the influence of the basalt occurs in the form of bedrock or colluvium.

Topsoils range in depth from 6 cm in bouldery soils to 26 cm in moist loess soils. On loess they are dark grey in colour but where basalt is present they are grey brown to dark brown depending on the strength of the basalt influence. Subsoils are mainly yellowish brown on loess and under basalt influence are brown or dark brown.

Weakly developed nutty or crumb and granular structures in the topsoils are common on loess but under basalt influence structural development increases and nutty structures are often well developed. Most subsoils in loess show prismatic structure with a well developed, compact hardpan or fragipan while soils strongly influenced by basalt show blocky structured subsoils. The degree of structural development in subsoils on mixed regolith is generally poor due to the heterogeneous composition of the material and the presence of a significant loess component.

4.2.2 Chemical properties

Owing to a shortage of time the chemical properties of the soils were unable to be analysed. Fitzgerald (1966) and Raeside and Rennie (1974) list chemical data for their respective study areas but differences in factors such as rainfall, water balance and salt inputs to the soils are likely to make the applicability of their data to the Sumner region doubtful. Future studies for land use in the Sumner region should include study of the chemical properties of the soils.

4.3 DETAILED DESCRIPTION OF SOILS

The soils of the Sumner region have been arranged according to parent material and the following broad groups are recognised:

- soils on loess
- soils on mixed loess and basalt
- soils on basalt
- soils on dune sand.

Details of the subdivision of these major groups into series and types (together with their map symbols) are as listed below. Soils with severely eroded phases are shown with the letter 'e'. Slope classes listed on the map legend are not shown here.

(i) Soils on loess

Clifton silt loam	CF1
Clifton silt loam, eroded	CF1e
Clifton fine sandyloam, eroded	CF3e
Godley fine sandy loam	G3
Godley fine sandy loam, eroded	G3e
Heathcote silt loam	H1
Horotane silt loam	Ho1
Scarborough silt loam	S1
Scarborough silt loam, eroded	S1e
Scarborough bouldery silt loam	S2
Scarborough bouldery silt loam, eroded	S2e
Takahe silt loam	T1
Takahe silt loam, eroded	T1e

(ii) Soils on mixed loess and basalt

Cashmere bouldery silt loam	C2
Evans bouldery silt loam	E2
Kiwi silt loam	K1
Kiwi silt loam, eroded	K1e
Redcliffs bouldery silt loam	R2

(iii) Soils on dune sand

Taylor's Mistake sand	Tm5
Waikuku loamy sand	Wa4

4.3.1 Soils on loess parent material

Clifton series

These soils occur on backslope positions on the south-east aspects of the main ridges. Sites range from 60 to 300 metres above sea level (a.s.l.) and slopes are strongly rolling to steep. Soil drainage ranges from well drained on strongly rolling sites to somewhat excessive on steep sites but the soils remain moist for longer periods than many of the other hill soils because of lower evapo-transpiration rates due to the aspect which is shady and does not receive the full intensity of the dry north-westerly winds.

Vegetation consists of silver tussock, browntop and Yorkshire fog with rushes occurring in wet hollows. The microtopography is dominated by a large number of mounds which are 0.5 to 1.5 m high. Many landslide and slump scars are present. Clifton soils are subject to erosion by debris flow, debris avalanche and slumping following high intensity rainfall, especially on steeper sites. Tunnel-gullying, sheet erosion and solum creep also occur.

Clifton soils are mainly used for extensive grazing of sheep and cattle but are used for housing at Taylor's Mistake and problems of instability due to creep and debris avalanches have occurred there.

The main profile characteristics of Clifton soils are:

- Thick (up to 29 cm), grey, moderately structured topsoil horizons
- Argillic subsoil textures with distinct clay cutans on the peds
- Olive brown subsoil colours

- Prismatic subsoil structures that break to blocky
- Well developed gammate fragipan
- Salt and carbonates in the C horizon.

Variations in profile depth occur especially where soils have been eroded. Burial of soils occurs locally where the erosion products of debris avalanches have been deposited.

Clifton fine sandy loam occurs mainly on the east side of Scarborough ridge on strongly rolling and moderately steep topography. The depth of the regolith is variable ranging from 1 to 4 m. This soil commonly has salt accumulations and carbonate concretions in the C horizon. B horizons vary in texture from heavy silt to clay loam and their structure breaks from fine prismatic to fine blocky. The fragipan varies in the strength of its development and is most prominent on strongly rolling sites.

Clifton silt loam occurs mainly on the south-east sides of Clifton Spur and Richmond Hill covering the full range of slopes described for the series. The depth of the regolith is variable but is usually 1.5 to 2.5 m. The topsoils are thick with moderately developed nutty structure and the subsoils are argillic with prismatic structures breaking to well developed blocky structures. The fragipan is well developed and gammate.

Godley series

Godley fine sandy loam occurs east of Taylor's Mistake on rolling to moderately steep slopes on aspects ranging between north-east and north-west. It occurs mainly on ridge shoulders and backslopes in altitudes ranging from 18 to 200 m above sea level. Soils are somewhat excessively drained and dry out quickly during November and December with a water deficit lasting until March or April. The vegetation cover is made up of low-producing species mainly silver tussock and danthonia with some browntop. Because of the dryness in summer plant growth is limited and the soil surface is often exposed. Microtopography is dominated by small gently sloping mounds and the landscape is dissected by collapsed tunnel-gully systems now forming open gullies. Godley soils are subject to severe sheet and tunnel-gully erosion especially on moderately steep slopes where the vegetation cover is thin.

Godley soils are used for extensive grazing of sheep and cattle.

The main profile characteristics of Godley fine sandy loam are:

- Humic staining of peds in subsoil horizons
- Salt and carbonate accumulations in the subsoil
- Prominent accumulations of coarse brown iron nodules in the subsoil
- Weakly developed, nutty topsoil structures with moderately developed subsoil structures which break from prismatic to blocky
- A very hard, compact, well developed fragipan in the B3 horizon
- Fine sandy loam textures in the topsoil ranging to heavy silt loam in the subsoil.

The soils are generally about 1.0 m deep, formed on loess overlying basalt and are subject to strong influxes of salt from sea spray and the north-east winds blowing off the sea. Stainings of salt are common on ped faces lining cracks in the subsoil and the mobilization of humic material from the A horizon into the subsoil is also a feature of these soils. The prominent accumulations of iron nodules in the subsoil are diagnostic and the fragipan is well developed. Clay illuviation is shown by the presence of cutans in the lower B horizon. On moister sites the lower subsoil is subgammate and the salt and humic staining is not so evident.

Heathcote series

Heathcote silt loam occurs mainly on the rolling fans forming the lower footslopes in the valleys of Taylor's Mistake, Sumner and Redcliffs. These slopes are short and have been formed by the accumulation of loessial and bouldery material washed down from the slopes above. Tunnel-gullies open onto the lower footslope sites and with sheet erosion supply the slopes with alluvium. Heathcote silt loam is only slightly susceptible to erosion mainly by solum creep which is expressed by small mounds (40 cm high) and small terracettes (20 cm high). Soils are well drained except towards the toes of the fans where slopes are gentler and there is some seepage. Where soils are used for pasture browntop and Yorkshire fog are the dominant forms of vegetation.

Heathcote silt loam is used for pasture and housing in the study area but it is moderately fertile and is used intensively for market gardens and orchards in Heathcote, Avoca and Bowenvale valleys.

The main characteristics of Heathcote silt loam are:

- Thick (25 cm), darkly coloured topsoils
- Weakly developed structures in all horizons with weakly compacted subsoils

- Fragments of basalt incorporated into most horizons
- Yellowish red mottles in the B horizon
- Coarse textures in the subsoil horizons.

Heathcote silt loam consists of 25 cm of friable dark greyish brown silt loam that passes through a distinct boundary into a pale olive fine sandy loam with many fine distinct yellow and red mottles. Structures in the topsoil are weakly developed nutty and pass through weakly developed blocky structure into the subsoil which is massive. The subsoil is up to 70 cm deep although depth varies with site. Buried horizons at varying depths are present at a number of sites and in some places Heathcote silt loam overlies Horotane soils indicating that Heathcote soils are of more recent origin.

Horotane series

Horotane silt loam occurs on the valley floors and is formed on alluvium derived from loess and partly from basalt eroded from the surrounding hills. Slopes are generally under 3^{o} and face north, sloping gently towards the mouths of the valleys. Because of the low gradient the soils are poorly drained and water may lie on the ground surface for long periods especially in winter when water-logging is aggravated by seepage from the surrounding hills. Vegetation consists of clover, Yorkshire fog and jointed rush. Horotane silt loam is farmed with adjacent areas of hillslopes and fans for sheep and cattle fattening with some dairying. In Sumner and Moncks Valley residential development is encroaching on these soils.

The main profile characteristics of Horotane silt loam are:

- Poor internal drainage
- Dark coloured topsoils with gleying in the subsoil giving pale colours
- Iron stainings in the topsoil with mottles and black manganese nodules in the subsoil
- Fragments of weathered basalt in most horizons.

Horotane silt loam consists of 23 cm of very dark grey friable silt loam that passes through a sharp boundary into a greyish brown friable heavy silt loam with a few fine distinct black nodules and many prominent yellow and red mottles. The topsoil has a moderately developed fine nutty structure and the subsoil has a weakly developed fine to medium blocky structure.

Scarborough series

These soils occur on the strongly rolling to steep slopes forming the lower backslopes and upper footslope sites of the fans. They are derived from loess, the upper layers of which have accumulated by wash from the slopes above and overlie loess deposited by aeolian processes. The regolith is deep, up to 8 m on some sites. The altitudinal range of these soils is 10 to 60 m above sea level.

Scarborough soils are well drained to somewhat excessively drained depending on their site and aspect. Although actively accumulating, these soils are also subject to erosion by sheet wash, tunnel-gullying and debris avalanches. Tunnel-gullying is marked on moderately steep and steep slopes especially those facing north-west and debris avalanches are numerous on steep slopes with easterly aspects. Terracettes, mounds, debris avalanche scars, collapsed tunnel-gullies and open gullies form a distinctive microtopography and on higher slopes basalt boulders derived from bluffs upslope are scattered over the ground surface. Vegetation is varied with bracken, broom, wild blackberry and <u>pinus radiata</u> present while browntop and danthonia are the dominant grasses.

Scarborough soils are mainly used for extensive grazing of sheep and cattle while housing is present on strongly rolling sites in Sumner and Taylor's Mistake.

The main profile characteristics of Scarborough soils are:

- Silt loam textures in the topsoil increasing to heavy silt loam or clay loam in the subsoil
- Weak structural development in the topsoil with subsoil structures being prismatic breaking to blocky
- Clay cutans and salt accumulations on ped faces in the subsoil with calcium carbonate concretions in the loess parent material on excessively drained sites
- A moderately developed fragipan
- Distinct mottles in the B horizon
- A loess parent material which is deep, massive and nongammate.

Variation occurs in Scarborough soils with differing drainage conditions and erosion states. Well drained soils show strong mottling and well developed subsoil structures, features that are not so well expressed on sites that are excessively drained and strongly eroded.

<u>Scarborough bouldery silt loam</u> occurs on moderately steep to steep sites where basalt fragments from upslope are

incorporated into the soil profile. The topsoil consists of 15 cm of friable, very dark grey brown, bouldery silt loam with weakly developed crumb and granular structure. The subsoil consists of brown to yellowish brown heavy silt loam with fine indistinct strong brown mottles and moderately developed prismatic structure breaking to blocky. The fragipan is moderately developed without being gammate.

Scarborough silt loam occurs on strongly rolling to steep slopes and on some sites is subject to tunnel-gullying, sheet wash and debris avalanches. Profiles consist of a topsoil of 21 cm of very dark grey brown silt loam with weakly developed fine crumb and nutty structure. The subsoil shows 60 cm of olive brown heavy silt loam with well developed fine prismatic structure in the B2 horizon and many coarse strong brown mottles above the fragic horizon which is nongammate. Thick dark brown clay cutans are present in the B2 horizon of the subsoil.

Takahe series

Takahe soils occur on the ridge summits and shoulders that range in slope from easy rolling to strongly rolling. They occur at altitudes ranging from sea level to approximately 490 m and their loessial parent material is between 1.5 and 4 m deep. Because the main ridges face north they are very sunny and are exposed to the north-westerly winds so that evaporation rates are high and the soils suffer a moisture deficiency between November and March. Internal soil drainage is slow on gently sloping sites and in winter field capacity may be exceeded. On strongly rolling sites the soils are well drained and field capacity is rarely exceeded. Due to the moisture deficiency of the summer months plant growth is limited during that period and the grassland vegetation on Takahe soils is dominated by low producing species, mainly silver tussock, sweet vernal and browntop.

The microtopography of Takahe soils varies according to slope and aspect. On easy rolling slopes the microtopography is subdued with only gentle mounds being present. These mounds occur on all aspects but are larger on the moist south-east-facing slopes. The size and abundance of the mounds increase with slope and on strongly rolling slopes are up to 1m high and 4 m wide. Terracettes are also present on strongly rolling slopes with south-east aspects.

Takahe soils on strongly rolling slopes are subject to sheet erosion and tunnel-gully erosion which is severe on some sites. Where Takahe soils are cultivated the risk of wind and sheet erosion is considerable because the topsoils are weakly structured and break into fine particles if cultivated to too fine a tilth (Fitzgerald, 1966).

Takahe soils have a wide range of uses in the Sumner area. These include housing on the ridges of Clifton, Scarborough and Richmond Hill; recreation (golf course, walking and riding tracks); market gardening on Clifton; sheep fattening and semi-extensive grazing of sheep and cattle. Housing development occurs on all slope phases but controlled and efficient disposal of runoff from paved surfaces, roofs, and stormwater drains is necessary to prevent tunnel-gullying. Because of their gentle slopes and ridgetop positions Takahe soils have the widest range of potential uses of all the soils in the Sumner district provided that their use is well planned and well managed.

The main profile characteristics of Takahe silt loam are:

- Silt loam textures in the topsoil with an increase in clay down the profile reaching a maximum in the B2 horizon with heavy silt or clay loam textures
- Fine distinct yellowish red nodules in the upper part of the strongly mottled subsoils
- Gammation in the B3 or C horizons
- A well developed fragipan beginning at 50 to 65 cm beneath the ground surface
- Weakly developed fine nutty structures in the topsoils and moderately developed medium prismatic structures breaking to medium blocky in the subsoil overlying the massive, compact fragipan.

Takahe silt loam (0-5^{o} slopes) show a textural gradient down the profile and has 21 cm of a friable dark grey silt loam topsoil. This overlies 14 cm of firm, light yellowish brown silt loam with fine indistinct strong brown mottles which passes into a horizon of firm, light yellowish brown heavy silt to clay loam with many yellowish red nodules and mottles. This overlies a gammate fragic horizon consisting of an extremely hard, heavy silt loam which is light olive brown in colour and 40 cm thick. This horizon has abundant mottles and many nodules both of which are strong brown in colour. The C horizon consists of a massive, firm, grey brown silt loam.

Profiles on steeper slopes are similar to those on more gentle slopes but have variations in the intensity of mottles and nodules often due to the variations in microtopography. Aspect is also significant and mottles are coarser and more numerous on south-east-facing slopes where moisture is retained for longer than on north-facing slopes. Tunnel-gully erosion is most abundant on north-west-facing slopes.

4.3.2 <u>Soils on mixtures of loess and basalt parent material</u>

Cashmere series

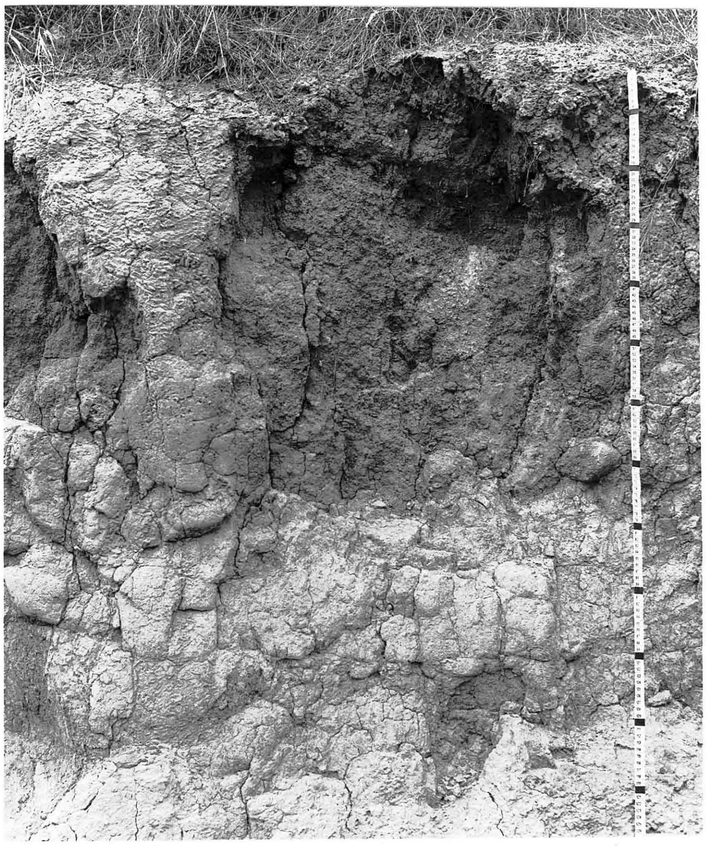
<u>Cashmere bouldery silt loam</u> is formed on mixtures of basalt and loess in which basalt is dominant. Profiles are shallow and vary in depth from 40 to 80 cm. This soil occurs on ridge summits and shoulders where loess has either been thinly deposited or removed by erosion in the past. Slopes are gently undulating to strongly rolling. Microtopography is usually weakly expressed but where soils are deeper and slopes are strongly rolling, small mounds are present. Internal soil drainage is better than in loessial soils because of the well developed soil structure and the high content of stones in the profile. Due to the basalt influence the nutrient status of the soils is high (Raeside and Rennie, 1974) and they give good pasture growth. The soils are stable and are used for sheep and cattle fattening in conjunction with Takahe and Windsor soils.

The main profile characteristics of Cashmere bouldery silt loam are:

- Well developed crumb and granular structures in the topsoil and moderately to well developed nutty structures in the subsoil
- Dark reddish brown topsoils over dark brown subsoils
- High content of weathered basalt fragments in the

Fig. 5 Profile of Godley fine sandy loam.

Fig. 6 Profile of Takahe silt loam.



subsoil and poor horizon differentiation in the subsoil

- Deep topsoils up to 25 cm deep.

The subsoil colour varies from dark brown to light reddish brown as the content of weathered basalt in the parent material increases and subsoil textures may be bouldery clay loams if the weathering is intensive. In deeper and not so well drained sites subsoils have distinct yellowish brown mottles.

Cashmere bouldery silt loam differs from Windsor bouldery silt loam in that it has a subsoil horizon which is thicker than the topsoil. Because the distribution of the loess cover is variable on the ridge summits and shoulders the two soils are often intimately mixed and grade into each other over short distances.

Evans series

Evans bouldery silt loam occurs on slopes ranging from strongly rolling to steep. It occurs on backslope positions and is formed on basalt mixed with varying amounts of loess. Profiles are shallow ranging in depth from 30 to 50 cm. Boulders litter the ground surface and are scattered through the soil. Rock outcrops are common and profile depth varies over short distances. The vegetation cover is dominated by silver tussock, cocksfoot, sweet vernal, browntop and clover. The soil is excessively well drained and runoff is rapid, the main type of erosion being sheet wash which may reach severe proportions under heavy rainfall when the soil surface is bared. Evans soils are used for extensive grazing.

The main profile characteristics of Evans bouldery silt loam are:

- Well developed nutty and granular topsoil structures and weakly developed nutty subsoil structures
- High concentrations of fresh basalt fragments which increase in quantity with depth
- Dark grey brown topsoils with dark yellowish brown subsoils.

Profiles consist of up to 21 cm of very friable, dark grey brown, bouldery silt loam passing through a diffuse boundary into a friable, dark yellowish brown soil with a bouldery, heavy silt loam texture.

Evans soils occur on similar sites to Windsor soils but differences in horizon depths and soil structure separates the two. They are often mapped as complexes.

Kiwi series

Soils of the Kiwi series occur mainly in backslope positions on slopes that face north or north-west and are moderately steep and steep. They also occur on strongly rolling shoulder sites forming a complex with Windsor soils. Their altitudinal range is 60 to 350 m above sea level. Kiwi soils are formed mainly from loess with varying mixtures of basalt. The soils are often stony or bouldery and range in depth from 15 to 70 cm overlying the basalt bedrock. The soils are excessively drained and have a low moisture holding capacity so that they dry out quickly in summer. The vegetation is grassland dominated by silver tussock, cocksfoot, browntop and clover. Rock outcrops are common and boulders are scattered over the ground surface while the bedrock is exposed where severe sheet erosion has occurred. Tunnel-gully erosion is present where the soils are relatively deep and the ratio of loess to basalt is high.

Kiwi soils are used for extensive grazing of sheep and cattle in conjunction with adjacent rolling and strongly rolling land.

The main profile characteristics of Kiwi soils are:

- Weakly developed structures in both topsoil and subsoil
- Weakly expressed subsoils
- Topsoils which are often thin depending on the intensity of sheet erosion that has occurred
- The presence of basalt fragments in most horizons but their influence on soil behaviour is variable depending on the loess content of the regolith
- Textures which range from silt loam in the topsoil to heavy silt loam in the subsoil
- A weakly to moderately developed fragipan.

Topsoils consist of up to 25 cm of a dark grey brown silt loam containing basalt fragments. This horizon passes through an indistinct boundary into a brown bouldery heavy silt loam. Topsoils are friable with a weakly developed fine nutty structure while subsoils are of firm to very firm consistence with a weakly developed coarse prismatic structure. Topsoil textures are dominantly silt loam although in some profiles the presence of basalt fragments may be sufficient to make the texture bouldery silt loam.

Redcliffs series

Redcliffs bouldery silt loam occurs in poorly drained basins and depressions on the ridge summits and shoulders where slopes are concave and range from gently undulating to strongly rolling. Parent material is usually a mixture of loess and basalt which has been washed into the site from the surrounding slopes so that the soils are actively accumulating material. Due to the poor drainage, water may lie on the ground surface for considerable periods in winter and pugging is common. The topsoil dries out over the summer but the subsoil retains enough moisture for plant growth. Yorkshire fog and clover are the dominant grasses present with rushes occurring at the base of large mounds formed by solum creep. Redcliffs bouldery silt loam is of limited extent and is mainly used for semi-extensive grazin in conjunction with Takahe, Clifton and Cashmere soils.

The main profile characteristics are:

- Thick brownish black topsoil horizon with iron staining along roots
- Moist topsoils of bouldery silt loam texture and subsoils of bouldery silty clay loam texture containing abundant yellowish red mottles and many manganese nodules
- Pale colours in the subsoil overlying a gleyed horizon
- Moderately developed soil structure in the topsoil and subsoil.

.4.3.3 Soils on basalt parent material

Windsor series

Windsor bouldery silt loam is a shallow soil derived from basalt and occurs on slopes ranging from easy rolling to steep. It ranges in altitude from 30 to 455 m above sea level and occurs on summit, shoulder and backslope positions. It occurs adjacent to rock outcrops and the ground surface is littered with many boulders while basalt fragments are numerous in the soil. Profiles range in depth from a few centimetres to 45 cm and the topsoil is thicker than the subsoil which may or may not be present. Soils range from well drained to excessively drained according to slope and because they are shallow the soils dry out very quickly in summer restricting plant growth. Silver tussock and cocksfoot are the dominant plant species present. The ground surface is not always covered and because the soils are shallow, runoff is high and sheet erosion occurs especially where slopes are strongly rolling to steep. Soils have been depleted in thickness where severe sheet erosion has occurred and in many places very thin (5-10 cm) remnants of the former soil cover are left.

Windsor bouldery silt loam is mainly used for extensive grazing in conjunction with Cashmere, Kiwi, and Evans soils and because of the intimate mixtures in which these soils occur they are often mapped as complexes. Windsor soils often grade into Cashmere and Evans soils as soil depth and the loess content increases.

The main profile characteristics of Windsor bouldery silt loam are:

- Shallow profiles (5-45 cm deep) in which the topsoil is thicker than the subsoil
- Topsoils that are very friable with well developed crumb structure and subsoils that are well structured where they occur
- Very dark brown soil colours
- Silt loam topsoils which have basalt fragments scattered throughout
- Little or no loess influence on soil development.

Windsor soils differ from Cashmere soils because they are very shallow and the subsoil is very thin or absent compared to a distinct subsoil horizon in the Cashmere soils.

The parent material of the Windsor bouldery silt loam is basalt while that of the Cashmere contains loess in varying proportions.

4.3.4 Soils on dune sands

Taylor's Mistake series

Taylor's Mistake sand is a very recent soil with weak profile development and is formed on subdued sand dunes behind the beach at Taylor's Mistake. The sand is derived from coastal erosion of the basalt cliffs in the area and is black in colour. Site drainage is poor due to the low-lying nature of the site but internal soil drainage is good because of the weak compaction and lack of structure in the sand. Where the soil surface is bared wind erosion may occur. This soil is zoned for recreation but is currently used for sheep and cattle fattening.

The main characteristics of Taylor's Mistake sand are:

- Weak structure and compaction of the sand
- Black colour of the sand parent material with gleying in the lower subsoil due to poor site drainage
- Iron stainings along root lines in the topsoil and mottles in the subsoil
- Sandy textures of all horizons.

Waikuku series

Waikuku loamy sand occurs on the floor of Moncks Valley and is formed on greywacke derived dune sand. The soils are very recent and soil development is shallow being only 30-40 cm deep. The area of Waikuku loamy sand in the study area is taken up entirely by Barnett Park but is used for housing in other areas of Redcliffs.

The main profile characteristics of the Waikuku loamy sand are:

- Weak profile development

- Friable, weakly structured topsoils with massive and single grain subsoil horizons

- Loamy sand textures in all horizons but with dark greyish brown colours in the topsoil overlying yellowish brown subsoils.

TABLE V

LEGEND OF SOILS
arranged pedologically

YELLOW-GREY EARTHS

Takahe series

Clifton series

Godley series

Kiwi series

INTERGRADES BETWEEN RECENT SOILS AND YELLOW-GREY EARTHS

Heathcote series

Scarborough series

YELLOW-BROWN SANDS

Waikuku series

BROWN GRANULAR LOAMS and related steepland soils

Cashmere series

Evans series

Windsor series

Redcliffs series*

RECENT SOILS from colluvium

Scarborough series**

Heathcote series**

Horotane series*

RECENT SOILS from sand

Taylor's Mistake series

* intergrading to gley soils

** intergrading to yellow-grey earths

CHAPTER V

EROSION

The stability of the soils and regolith are one of the most important physical factors determining the suitability of land for various uses. This chapter describes the types of erosion present, how they occur, the site factors that contribute to instability and the erosion hazard of the soils under various uses. The areal distribution of the types and degree of soil erosion are shown on Map 2.

5.1 OCCURRENCE AND TYPES OF EROSION

There are four main types of erosion present and they are defined according to Soil Bureau Staff (1974).

They are:

- sheet erosion
- solum creep
- tunnel-gully erosion
- debris avalanches.

Other types of erosion which occur but are not extensive include: wind erosion, rockfall, slumps and rill wash.

5.1.1 Sheet erosion

Sheet erosion is the downslope movement of soil material across the ground surface by moving water following the dislodging of soil particles by raindrop impact and surface flow. It usually occurs during high intensity rainfall after the soil pores have become saturated and infiltration is low. It may result in the removal of a uniform depth of soil from the ground surface resulting in a reduction in the thickness of the topsoil.

Almost all slopes which are strongly rolling to steep are subject to sheet erosion of varying intensity depending on the state of the vegetation cover and rate of water infiltration into the soil. Because of their weak topsoil structure and poor vegetation cover soils formed from loess are those most susceptible to sheet erosion on the steeper slopes. Mixed loess and basalt regoliths vary in their susceptibility to sheet erosion depending on the vegetation cover and the influence of the basalt in increasing structural development in the topsoil. The products of sheet erosion accumulate downslope on the foot-slopes and toeslopes where Scarborough, Heathcote and Horotane soils occur.

Sheet erosion is best controlled by maintenance of an adequate vegetation cover using species which can aid the improvement of the soil structure.

5.1.2 Solum creep

Solum creep is the slow imperceptible downslope movement of the soil mass by the movement of individual particles. It occurs mainly on easy rolling to moderately steep slopes on soils with loessial or mixed parent material and shows a surface expression of terracettes, surface ripples and mounds. Creep is most strongly expressed on moist south-east-facing slopes in Takahe, Clifton and Redcliffs soils but also occurs on Godley, Heathcote and Scarborough soils. Creep was probably more active in the past when the climate was cooler and more moist than it is at present. However, it still occurs following heavy rainfall when soil moisture conditions are high.

Solum creep is caused by the effects of wetting, drying and daily temperature changes which result in the expansion and contraction of the soil particles giving a net downslope movement of the mass. Temporary increases in load on the soil due to stock trampling and heavy rainfall also contribute to solum creep. Creep is not usually deep seated except in Redcliffs soils but the design of roads and buildings on soils affected by creep should take its effects into account.

5.1.3 Tunnel-gully erosion

Tunnel-gully erosion occurs in the soils derived from loess. It is most severe on dry, strongly rolling and moderately steep slopes that are well drained and where the vegetation cover is thin.

The sequence of tunnel-gully formation is similar to that described by Laffan (1973). Depletion of the vegetation causes dessication of the solum and shrinkage cracks develop from the surface deep into the subsoil. These are enlarged into subsoil voids in the B horizon overlying the fragipan. Linking up of the voids forms small tunnels over the pan and the flow of water downslope through them causes enlargement of the tunnels and the formation of outlets downslope. Enlargement of the tunnels causes the roof to collapse and the walls to cave in as a result of lateral erosion. Tunnelling is then rejuvenated in the collapsed debris on the floor of the tunnel and the fragipan is breached leading to the collapse of the sidewalls and open-gully formation.

The degree of gully development covers the full range described above and the depth to which gullying has occurred is variable depending mainly on the depth of the fragipan, its degree of expression and the depth to bedrock. Where regolith is less than 1.0 m deep and the fragipan is weakly developed tunnel-gullying may occur just above the contact with the bedrock. Where the loess is deep gullying extends to 2 m below the ground surface.

Tunnel-gullying poses a hazard for stock and makes farm units difficult to work; and causes undermining of tracks, roads and buildings. Thus, maintenance of the vegetation cover and the control of surface and subsurface drainage is very important in restricting tunnel-gully erosion.

5.1.4 Mass movement by debris avalanche

Debris avalanches occur mainly on moderately steep and steep slopes on the moist south-easterly aspects but occasionally occur on slopes facing north-west.

Debris avalanches occur in regoliths of loess or mixed parent material during or after high intensity rainstorms when the regolith is saturated and pore-water pressures are high. Failure is often associated with changes in the slope angle where soils are thin and where water has collected over the top of the bedrock or the fragipan. Failure is progressive and rapid occurring when the shear stress acting along a surface of potential failure exceeds the shear strength of the material along the failure surface. The depth at which failure occurs is variable. In most cases the failure surface is the contact between the regolith and bedrock but in some loess soils failure occurs along the top of the massive, compact fragipan. In such cases water percolating downslope along the top of the pan is sufficient to reduce the shear strength of the soil mass below the forces of shear stress acting along the failure surface so that failure is initiated and the soil mass is carried downslope rapidly.

Clifton and Scarborough soils on south-east aspects are those most susceptible to debris avalanches because their higher retention of moisture and their argillic subsoils result in low values of internal friction and cohesion thus contributing to low shear strength as the regolith becomes weakened by increases in moisture content.

The damage that debris avalanches can do to property is illustrated in Figure 7 which shows the extensive damage to a house caused by an avalanche at the base of Clifton spur on 21 August 1975 after a period of heavy rainfall in which 90 mm fell in 48 hours.

To stabilize potential or active landslide areas preventive or corrective measures are necessary. Major engineering structures may be uneconomic for preventing or correcting landslides unless they are necessary to protect property of high economic value. In most cases well designed surface and subsurface drainage is the most effective method of controlling slope instability (Root, 1958).

5.2 RELICT EROSION FEATURES

On some shoulder and backslope sites in Takahe and Clifton soils there are large mound or lobe-like micro-topographic features which may be relict solifluction deposits formed in a cooler, moister climate than the present.

They contain mixed regolith materials and at their heads are small depressions from which the soliflucted material was probably derived. These features are still potentially unstable and their engineering and mechanical properties should be studied before any structures are built in their vicinity.

5.3 SIGNIFICANCE OF LAND USE

The type and degree of erosion is strongly influenced by land use. Inherent physical factors of the landscape which influence erosion (e.g. regolith, aspect, slope, soil, climate) are largely fixed and are not modified by different land use practices but others are (e.g. drainage, vegetation cover). Land use decisions are often made in ignorance of the inherent site factors that influence slope stability so that the land use practices which follow, may also disregard the erosion factors that they modify (e.g. drainage, vegetation cover). The result of unsuitable land use is that the stability of slopes is often reduced and erosion accelerated. A good example is on Clifton spur where stormwater from street drains is disposed of onto the surface of loessial soils on strongly rolling and moderately steep slopes. Severe tunnel-gullying has resulted and in places has advanced to the stage of open gullies which are up to 2 m deep. The problem of water disposal is then handed on to land users further downslope and a channel draining an access road at the base of the open gullies becomes overloaded during heavy rainfall causing scouring of the channel banks and, in places, partial collapse of the access road. The problems of sediment disposal from the erosion of the open gullies and the drainage channel are also passed onto the users of the lower slopes.

5.4 SITE FACTORS CONTRIBUTING TO EROSION

The inherent physical characteristics of regolith and slope that influence erosion processes have been described in sections 3.4 and 3.5, respectively. The general characteristics of the soils in the study area have been described in section 4.3. The types of erosion and the pedological properties of the soil which influence them are summarized in Table VI in conjunction with regolith and slope.

The weak structural development of the loessial soils makes them particularly susceptible to these forms of erosion especially where the vegetation cover is thin and the soil surface is exposed enabling fissures to form as the soils dry out. The significance of fissuring in the solum to erosion is that it may initiate tunnel-gullying and debris avalanches because it enables water to penetrate directly into the subsoil. Where clay is present in the subsoil internal friction and cohesion between particles is reduced as the moisture content increases thus reducing the shear strength of the mass. The presence of the low porosity, high density fragipan in loess soils or bedrock in shallower soils increases the susceptibility to failure because they both restrict the vertical movement of water so that saturated conditions develop above them during heavy rainfall. Depending on the moisture conditions and the physical and chemical properties of the solum, tunnelling or flowage by debris avalanching may occur.

TABLE VI

RELATIONSHIP BETWEEN PEDOLOGICAL FACTORS, SLOPE, REGOLITH AND THE EROSION TYPES

Erosion type	Regolith	Slope	Soil series	Pedological factors	Other
Sheet erosion	Loess	Easy roll. - steep ($> 3^{o}$)	Godley Scarborough Takahe Clifton	- friable, weakly structured topsoils - dessication of topsoils	- inadequate vegetation - heavy rainfall - rapid runoff - summer drought
	Mixed	str. roll. - steep ($> 13^{o}$)	Kiwi		
			Evans	- dessication of topsoils	
	Basalt	str. roll. - steep ($> 13^{o}$)	Windsor		
Solum creep	Loess	Easy roll. - mod. steep ($3-28^{o}$)	Clifton Takahe Scarborough Godley Heathcote	- friable, weakly structured topsoil - subsoils of low permeability	- moist aspects - wetting and drying of soil particles - temperature changes - stock
	Mixed	Easy roll. - str. roll. ($3-20^{o}$)	Redcliffs	- friable, weakly structured soils - impeded internal drainage	

TABLE VI contd

Erosion type	Regolith	Slope	Soil series	Pedological factors	Other
Tunnel-gully	Loess	Easy roll. - steep (> 3°)	Takahe Godley Scarborough Clifton	- weak soil structures - argillic subsoils - vertical cracks of solum - permeable topsoils over impermeable fragipan	- dry aspects - poor vegetation cover
	Mixed	Str. roll. - mod. steep (13-28°)	Kiwi	- weak soil structure - vertical cracks - permeable topsoil over bedrock	
Debris avalanches	Loess	mod. steep - steep (> 20°)	Clifton Scarborough	- vertical cracks impeded internal drainage - permeable topsoil over impermeable fragipan - weak soil structure - argillic subsoils	- moist aspects - heavy rainfall
	Mixed	mod. steep - steep (> 20°)	Kiwi	- vertical cracks - shallow regolith - permeable topsoil over bedrock - weak soil structure	- potential failure surface at contact with basalt

CHAPTER VI

SUITABILITY OF SOILS FOR LAND USE

6.1 LAND USE SUITABILITY CLASSIFICATION

The soils have been evaluated for certain uses according to the extent to which their suitability is restricted by permanent limitations. The soils have been grouped into general suitability classes based on the limitations imposed by the combined effect of all the factors discussed in this study.

Bearing in mind the existing land uses of the Sumner region and experience of use from similar soils on other areas of the Port Hills the suitability of each soil type for the following land uses was considered:

horticulture - market gardening, orcharding, flowergrowing

grazing - extensive and intensive forms

residential - housing

recreation - walking and riding for scenic views

- parks for group activity e.g. picnicing.

Industrial uses were not considered because of their requirements for considerable areas of flat or gently sloping land which is not present in the Sumner region.

The suitability of soils for the various uses are described as high, moderate or low.

Soils with high suitability for specific uses are those in which there are few or no permanent limitations imposed by the combined effect of all the factors discussed. This class also includes soils with use limitations which can be overcome by careful and appropriate management, e.g. sheet erosion may be overcome by topdressing to establish and maintain a good vegetation cover.

Soils with moderate suitability for specific uses are those with some permanent limitations that restrict land use e.g. shallow soil, slope. This class also includes soils with limitations whose degree of expression can be reduced but not overcome by land management or structural design, e.g. some soils may fail if they are excavated unless correct engineering methods and preventive structures are used. Such precautions are usually very expensive.

Soils with low suitability for specific uses are those with permanent limitations that cannot be overcome or for which the cost of correction may effectively preclude certain uses e.g. market gardening on slopes exceeding 30°.

The general suitability of each soil type for the land uses listed are shown in Table VII. It is stressed that the suitability classes are only general and exceptions are likely to occur. It is the intention that the rankings show soils with which care should be exercised and further study of soil behaviour be undertaken before the land is used for the particular activity shown. The land uses which are most generally suited for each soil type were assessed from the suitability rankings established in this survey and by reference to Raeside and Rennie (1974).

Slope and its influence on the other factors provides the major limitation to all uses of moderately steep to steep backslope and upper footslope sites. Where the soils on these sites are derived from loess the susceptibility to erosion is usually high thus adding to the limitations.

TABLE VII

GENERAL SUITABILITY OF SOILS FOR LAND USE

(A rating of 1 means soil is well suited; 2 means moderately suited; 3 means poorly suited)

Map Symbol	Soil Type	Uses					Most suitable land uses
		Horticultural	Grazing	Residential	Recreation Walking	Recreation Parks	
CF3, CF3e	Clifton f.s.l.	2	1-2	2	1	2-3	Recreation - walking Extensive grazing Low density res.
CF1, CF1e	Clifton s.l.	2-3	1-2	2-3	1	2-3	Recreation - walking Extensive grazing
G, G3e	Godley f.s.l.	3	2	2	1	2-3	Recreation - walking Extensive grazing Low density res.
H1	Heathcote s.l.	1	1	1	2	2	Horticulture
Ho1	Horotane s.l.	1-2	1	1	2	1-2	Horticulture
S2, S2e	Scarborough b.s.l.	3	2	2	1-2	2	Grazing Recreation - walking Low density res.
S1, S1e	Scarborough s.l.	2-3	2	2	1-2	2	Extensive grazing Low density res. Recreation
T1, T1e	Takahe s.l.	2	2	1	1	1	Residential Recreation

TABLE VII contd

Map Symbol	Soil Type	Uses					Most suitable land uses
		Horticultural	Grazing	Residential	Recreation Walking	Recreation Parks	
C2	Cashmere b.s.l.	1-2	1	1	1	1	Residential Recreation
E2	Evans b.s.l.	3	3	3	1-2	3	Recreation - walking Soil conservation Extensive grazing
K1, K1e	Kiwi s.l.	3	3	3	1-2	3	Recreation - walking Soil conservation Extensive grazing
R2	Redcliffs b.s.l.	3	2	2	2	2	Recreation Extensive grazing
W2	Windsor b.s.l.	3	2	3	2	2-3	Recreation - walking Extensive grazing
Tm5	Taylor's Mistake sd.	3	2	1	2	1	Recreation - parks Residential
Wa4	Waikuku l.sd.	3	2	1	2	1	Recreation - parks Residential

Fig. 7 Damage caused by a debris avalanche in Kiwi soils.

Fig. 8 Open gully erosion resulting from dispersion of storm-water onto Clifton soils.

On most soils the droughtiness and excessive site drainage restrict plant growth in summer thus imposing limitations for horticulture and the establishment of good pasture for grazing. These features are accentuated on the yellow-grey earth soils where the fragipan hinders root development and the upward movement of water into the topsoil. The soils best suited for horticulture and grazing are the Heathcote and Horotane soils where these limitations are slight.

Heathcote, Takahe and Cashmere soils are well suited to residential uses because they are usually stable, gently to moderately sloping and have good drainage. On soils with moderate suitability for residential uses future advances in engineering design may effectively eliminate the limitations that currently exist thus bringing such soils into the high suitability class. However, until the time when such engineering techniques are available and are economic, care should be taken in building structures on these soils.

Most of the soils in the Sumner area are suitable for walking and riding to obtain scenic views. Those which are ranked as being well suited are those from which the best views can be obtained. The soils well suited for parkland use are those which are relatively stable and gently to moderately sloping without access to them being difficult. Soils suited for parkland often occur adjacent to soils which are well suited for walking and riding so that in designating land use, planners should make use of the interaction between associated uses and the inherent factors of the landscape that relate them geographically. For example, land set aside for parks could be used for picnicing etc., and tracks leading from them onto steeper land could be used for walking, riding and scenic viewing.

6.2 LAND USE PLANNING

In planning the land use of the Sumner region consideration should be given to the uses identified as those generally suitable for each soil area (see Table VII). The demands for each use should be placed in a regional perspective. Although this may result in some specific areas being used in ways that are not best suited to the soils present it is unavoidable since the aim of land use planning should be to maximise the total benefit gained from the use of the region's resources and to achieve a land use pattern which is as balanced as possible over the whole region.

6.3 RECOMMENDATIONS FOR FUTURE STUDY

6.3.1 Soil and regolith properties

The general suitability of the various soils for land use have been outlined on the basis of the limitations imposed by the factors of slope, parent material, erosion and the pedological properties of the soil. A modern detailed soil survey is incomplete without measured data on soil properties so that it is essential that future studies of the Sumner region provide such data in order that detailed soil interpretations can be made for a greater number of uses e.g. suitability for road cuts, embankments, specific horticultural uses. Measurements should be based on carefully selected samples that are representative of each of the mapped soils and their horizons. Data required include measurement of the following soil and regolith properties:

- engineering e.g. Atterberg limits, shear coefficients
- chemical e.g. cation exchange, soluble salts
- physical e.g. porosity, bulk density
- mechanical e.g. particle size, void ratio
- hydrological e.g. hydraulic conductivity,

water holding capacity.

The suitability of certain soil areas for the uses outlined in 6.1 are general only and detailed on site investigations should be made before changes in land use are proposed. This is necessary because of the variability of soil and regolith properties within the soil units shown on the map. By gaining more detailed information of the inherent site characteristics, limitations to specific uses may be reduced or corrected by appropriate land management and engineering design. Consultation should be made with specialists such as engineers, farm advisors etc., before land use zoning is made.

Interpretations of data gained from the study of the above mentioned soil properties can also be made to determine the most suitable intensity of use for each site. For example, study of the engineering properties of the soil may show that soils which are unsuitable for high density housing due to problems of slope and stability may be suitable for well spaced, low density housing if the best sites and designs are chosen.

6.3.2 Drainage

Conditions of soil moisture strongly influence slope stability. If residential uses are planned for soils currently in pasture, urban engineering may significantly modify the drainage pattern thus altering the soil-water relations affecting slope stability. Therefore studies of the hydrologic characters of the soils should be made before changes in land use are considered.

Factors to be studied should include characteristics of the water balance, the periodicity and significance of high intensity rain storms to erosion events, infiltration rates, permeability, storage capacity of the soils, significance of lateral water movement, the significance of a fragipan to water movement and storage; and the relationships between pore-water pressure and failure conditions. By making such studies, soils with limitations for particular uses can be identified and alternative sites can be investigated.

CHAPTER VII

SUMMARY AND CONCLUSIONS

7.1 OBJECTIVES

The objectives of this study of the Sumner region were:

(i) to study the soil pattern and to outline the relationships between soils, regolith and slope; and their significance to erosion

(ii) to identify soils which are suitable for certain types of land use

(iii) to lay a foundation on which further study of other soil and soil-use relationships can be based.

7.2 METHOD OF APPROACH

The objectives were achieved by the following methods:

(i) A detailed soil survey of the region to define the major soil series and to show the influence of parent material and slope in determining soil properties. Attention was also given to the influence of climate and vegetation on soil formation.

(ii) A survey of the type and degree of erosion as it related to the soil pattern to show how the distribution and intensity of erosion is related to soil, slope and regolith factors.

(iii) Limitations for certain uses of each soil were identified from the aggregation of the data obtained by the soil and erosion surveys. The limitations were assessed in terms of the suitability of each soil type for certain uses.

(iv) In observing broad limitations for certain uses data deficiencies relating to various soil properties and their behaviour were noted.

7.3 SUMMARY OF RESULTS AND CONCLUSIONS

The soil and erosion surveys have shown that it is essential to make inventory of environmental factors before assigning areas for certain land uses.

The detailed soil pattern is a reflection of the way the soil forming factors of the landscape are combined. These factors include climate, topography, parent material and vegetation so that a detailed soil survey is also an inventory of the main environmental factors that influence land use.

The landscape of the Sumner region consists of three main ridges, their sideslopes and the valleys between each. Slopes range from flat to steep over short distances and bluffs and rock outcrops are common. Soils on the ridges are regressive while those on the toeslopes and valley floors are accumulative.

The soils are derived from four types of parent material: loess, mixtures of loess and basalt, basalt and dune sand. Soils derived from loess are the most common, occurring on all slope positions of the landscape while mixed loess and basalt parent materials occur mostly on steep slopes and ridge summits from which loess has been eroded. Soils derived from basalt also occur on steep slopes and exposed ridge summits. Soils on dune sands occur on flat land at the mouths of the valleys.

The soils of each parent material group vary in their pedological and physical properties and consequently in the way they behave. Soils on loess are generally deepest with profiles reaching 2.0 metres deep on top of loess deposits which may be a further 2 to 4 metres deep. Soils on loess are usually pale in colour, of silt loam texture and have poor structural development with a fragipan horizon beginning at depths of 40 to 65 cm. If water is able to penetrate the subsoil and soil moisture conditions reach high levels then failure by tunnel-gullying or debris avalanching may occur. Weakly structured topsoils make soils derived from loess susceptible to sheet erosion on strongly rolling to steep slopes.

Soils on mixed loess and basalt vary in their pedological properties depending on slope and the ratio of loess to basalt. Basalt influence tends to increase structural development, nutrient levels, moisture retention and cohesion between soil particles. A full range of soils occurs from those with high basalt and low loess influence to those with low basalt and high loess influence. Soils are usually bouldery and profiles are generally shallow. Soils on mixed regolith with a high loess content are subject to tunnel-gullying and debris avalanching depending on aspect and soil moisture conditions. The most intense forms of erosion occur as sheet wash on steeper slopes where the vegetation cover is thin.

Basalt derived soils are fertile, very shallow, well structured and have a high proportion of basalt fragments in their profiles. They are rarely subject to slide phenomena and sheet erosion is common only on strongly rolling to steep slopes. Soils formed on dune sands are minor in occurrence and are young with weakly developed profiles.

Slope and stability of the soils and their parent materials are the major environmental factors influencing land use in the Sumner region. When soil moisture conditions are high the susceptibility to all types of erosion generally increases as slope gradient increases. Debris avalanche movements are most common on moist south-east-facing aspects while tunnel-gullying and sheet erosion are most common on dry north and north-west-facing slopes.

Past and present forms of land use have had a significant influence on stability and because of a lack of understanding of soil properties and their behaviour poor management has often accentuated the intensity of erosion when good management could have reduced it. Limitations to land use are governed by the particular requirements of each use and the properties of each soil so that some soils are more suited to specific uses than others. This is one reason why detailed study of soil properties is essential.

Instability during heavy rainfall is the major limitation for residential, recreational and horticultural use of loessial soils on slopes that are moderately steep to steep. On loessial soils which are easy rolling and rolling there are few limitations for residential and recreational uses but drought, wind and sheet erosion may cause moderate limitations for horticulture. Steep slopes, sheet erosion and shallow soil depths are the major factors limiting residential and horticultural uses of soils derived from mixed parent material. Depth also limits such uses of basalt derived soils. The soils on dune sand have few limitations except for a slight susceptibility to wind erosion if the soil surface is exposed. The main limitations for pastoral use on most soils are the drought conditions of summer when plant growth is limited. In the past over-stocking has depleted the pasture cover thus enhancing sheet and tunnel-gully erosion.

In the Sumner region the soils most suitable for residential uses are the Takahe, Cashmere, Heathcote and Horotane series while soils of the Heathcote, Horotane and Cashmere series are best suited for horticultural uses. With the exception of the Kiwi, Evans and Windsor series most of the soils are suitable for extensive grazing but only those capable of supporting adequate pasture for the whole year should be used for semi-extensive or intensive grazing. Most of the soils are suitable for the recreational activities of walking and riding for scenic viewing but some have limitations of slope and possibly stability for use as parkland. The soils best suited for parks are those of the Takahe, Horotane, Heathcote, Cashmere, Taylor's Mistake or Waikuku series.

This study has shown the importance of soil and the soil-forming factors in limiting land use and illustrates the need for detailed soil and regolith studies in land use planning. By identifying the limitations for use imposed by the soil factor further specific studies of the soil properties and other physical environmental factors can be planned and carried out within the framework of limitations established by this study. Following the detailed study and assessment of specific aspects of the physical environment the framework of limitations can be used to guide the future study and assessment of the social and economic factors affecting land use. Once <u>all</u> the relevant factors have been assessed planning ordinances can be established and efficient land use allocation can be made in terms of local, regional and national perspectives.

ACKNOWLEDGEMENTS

I wish to thank the following for their help in the preparation and completion of this study:

My supervisor, Mr E.J.B. Cutler of the Soil Science Department, Lincoln College, whose encouragement and advice is greatly appreciated.

Professor K. F. O'Connor of the Tussock Grasslands and Mountain Lands Institute, Lincoln College, for his advice and guidance.

Mr W. F. Rennie of Soil Bureau, D.S.I.R., Lincoln, for drawing the soil map and taking the photographs.

Miss A.P.M. Rosevear for the rapid and efficient typing of this report.

REFERENCES

BAKER, R. F. and MARSHALL, H. C. 1958. Control and correction. In "Landslides and engineering practice." Highway Research Board Special Report 29. NAS-NRC Publ. 554: 150-187. Washington, D.C.

BOYCE, W. R. 1939. An ecological account of tussock grassland and other plant communities of Cashmere Valley and adjacent areas on the Port Hills, Canterbury. Thesis, M.Sc., University of New Zealand.

CHRISTCHURCH CITY COUNCIL. 1972. City of Christchurch district scheme. 172 pp.

CHRISTCHURCH CITY COUNCIL. 1974. City of Christchurch open space and recreation report. Christchurch City Council, City Engineers Department. 104 pp.

FITZGERALD, P. 1966. Soils of Heathcote County, Canterbury, New Zealand. N.Z. Soil Bur. Report 1/1966. 33 pp.

GIBBS, H. S. 1945. Tunnel-gully erosion on the Wither Hills, Marlborough. N.Z. Journal of Science and Technology 27A: 135-46.

GRIFFITHS, E. 1973. Loess of Banks Peninsula. N.Z. Journal of Geology and Geophysics Vol. 16: 657-676.

IVES, D. W. 1973. Loess in Canterbury. N.Z. Journal of Geology and Geophysics Vol 16: 587-610.

LAFFAN, M. D. 1973. The soils and tunnel-gully erosion of a small catchment in the Wither Hills, Blenheim. Thesis, M.Ag.Sci.(Hons), Lincoln College, University of Canterbury, N.Z. 196 pp.

LESLIE, D. M. 1973. Effects of basement lithology, regolith, and slope on landslide potential, Otago Peninsula, New Zealand. N.Z. Soil Bur. Scientific Report 12. 25 pp.

LIGGETT, K. A. and GREGG, D. R. 1965. The geology of Banks Peninsula. N.Z.D.S.I.R. Information Series 51: 9-25.

MILLER, D.E.K. 1971. Soil properties affecting tunnel-gully erosion. Thesis, M.Ag.Sci., Lincoln College, University of Canterbury, N.Z. 140 pp.

NEW ZEALAND METEOROLOGICAL SERVICE. 1975. Climatic and Meteorological recordings. Unpublished. Wellington.

RAESIDE, J. D. 1964. Loess deposits of the South Island, New Zealand, and the soils formed on them. N.Z. Journal of Geology and Geophysics Vol. 7: 811-838.

RAESIDE, J. D. and RENNIE, W. F. 1974. Soils of Christchurch region, New Zealand: the soil factor in regional planning. N.Z. Soil Survey Report 16. N.Z. Soil Bur. 74 pp.

ROOT, A. W. 1958. Prevention of landslides. In "Landslides and engineering practice". Highway Research Board Special Report 29. NAS-NRC Publ. 554: 113-149. Washington, D.C.

SOIL BUREAU STAFF. 1968. General survey of the soils of the South Island. N.Z. Soil Bur. Bull. 27. 404 pp.

SOIL BUREAU STAFF. 1974. Revised soil survey method. 2d ed. N.Z. Soil Bur. Bull. 25 (in press).

SOIL CONSERVATION SERVICE. 1965. Soil survey, Tompkins County, New York. U.S.D.A. Series 1961, no. 25. U.S. Govt Printing Office, Washington, D.C. 241 pp.

SOIL SURVEY STAFF, 1973. Soil taxonomy. U.S.D.A. Soil Conservation Service. Washington, D.C. 330 pp.

TAYLOR, N. H., and POHLEN, I. J. 1970. Soil survey method. Reprint. N.Z. Soil Bur. Bull. 25. 242 pp.

TERZAGHI, K. and PECK, R. B. 1967. Soil mechanics in engineering practice. 2d ed. Wiley, New York. 729 pp.

VAN DER EYK, J. J., MACVICAR, C. N. and DE VILLIERS, J. M. 1969. Soils of the Tugela Basin: a study in subtropical Africa. Natal Town and Regional Planning Reports, Vol. 15. Town and Regional Planning Commission, Natal, South Africa.

VARNES, D. J. 1958. Landslide types and processes. In "Landslides and engineering practice." Highway Research Board Special Report 29. NAS-NRC Publ. 554: 20-47. Washington, D.C.

YOUNG, A. 1972. Slopes. Geomorphology, Text 3. Oliver and Boyd, Edinburgh. 288 pp.

APPENDIX I

CORRELATION OF SOIL SERIES WITH OTHER SOIL SURVEYS

THIS SURVEY	HEATHCOTE COUNTY (Fitzgerald, 1966)	CHCH REGION (Raeside & Rennie, 1974)
Takahe	Takahe	Takahe
Clifton	Takahe hill complex	Takahe hill soils
Scarborough	Takahe hill complex	Takahe hill soils
Godley	-	Takahe hill soils
Cashmere	Cashmere	Cashmere
Kiwi	Kiwi	Kiwi
Evans	Evans	Evans
Windsor	Evans	Evans
Heathcote	Heathcote	Heathcote
Horotane	Horotane	Horotane
Waikuku	Waikuku	Waikuku
Redcliffs	-	-
Taylor's Mistake	-	-

APPENDIX II

SOIL PROFILE DESCRIPTIONS

1. Clifton series

Soil Type:	Clifton silt loam
Classification:	Yellow-grey earth
Map Sheet:	NZMS 1 SHEET S 84/2
Grid Reference:	098507
Topography:	Slope 26°. Aspect: South-east. Landform: convex backslope. Elevation: 183 m.
Drainage:	Well drained
Parent Material:	Loess
Land Use:	Extensive grazing of sheep and cattle.

Profile:

A 18 cm	very dark grey (10YR 3/1, moist) silt loam; friable; weakly to moderately developed fine nutty structure; many roots; indistinct boundary;
AB 10 cm	dark grey brown (10YR 4/2, moist) silt loam; friable; moderately developed medium nutty structure with many fine worm casts; many roots; indistinct boundary,
B_2 28 cm	light olive brown (2.5Y 5/3, moist) clay loam; many medium prominent strong brown (7.5YR 5/6, moist) mottles; hard; moderately developed medium blocky structure with many continuous distinct dark brown (10YR 3/3, moist) clay cutans on ped faces; few roots; distinct boundary,
B_{3x} 25 cm	yellowish brown (10YR 5/4, moist) heavy silt loam; grey gammate veins and iron staining in structural fissures; very hard; moderately developed medium prismatic structure; few roots; distinct boundary,
C 20 cm+	yellowish brown (10YR 5/5, moist) silt loam; weakly subgammate; firm; weakly developed coarse prismatic structure.

2. Godley series

Soil Type:	Godley fine sandy loam
Classification:	Yellow-grey earth
Map Sheet:	NZMS 2 SHEET S 84/5
Grid Reference:	128488
Topography:	Slope 23°. Aspect: north. Landform: convex upper backslope. Elevation: 168 m.

Drainage:	Excessively drained
Parent Material:	Loess
Land Use:	Extensive grazing of sheep and cattle.

Profile

A 10 cm	very dark brown (10YR 2/3, moist) fine sandy loam; weakly developed fine nutty structure; many insect borings; many roots; indistinct boundary,
B_1 10 cm	olive brown (2.5Y 4/4, moist) silt loam; many fine indistinct strong brown (7.5YR 5/8, moist) mottles; firm; moderately developed medium prismatic structure breaking to fine prismatic structure; many distinct dark grey brown (10YR 3/2, moist) organic coatings on ped faces; few roots; distinct boundary,
B_2 40 cm	light olive brown (2.5Y 5/4, moist) heavy silt loam; many coarse prominent strong brown (7.5YR 5/8, moist) mottles; hard; moderately developed medium prismatic structure breaking to fine blocky structure; common large prominent brown (7.5YR 5/4, moist) iron nodules; many coarse distinct organic streaks along ped faces; few roots; indistinct boundary,
B_{3x} 39 cm	light yellowish brown (10YR 6/4, moist) silt loam; many medium distinct strong brown (7.5YR 5/8, moist) mottles; extremely hard when dry; well developed coarse prismatic structure; few discontinuous distinct dark brown (7.5YR 3/2, moist) clay on ped faces; common very large prominent brown (7.5YR 5/4, moist) nodules; few small distinct salt accumulations on ped faces along structural fissures; distinct boundary,
C 20 cm+	yellowish brown (10YR 5/4, moist) gravelly fine sandy loam; firm; massive; few small distinct salt accumulations; few fine distinct calcium carbonate nodules.

3. Scarborough series

Soil Type:	Scarborough silt loam
Classification:	Recent soil intergrading to yellow-grey earth
Map Sheet:	NZMS 2 SHEET S 84/5
Grid Reference:	104491
Topography:	Slope 22^{o}. Aspect: north-west. Landform: concave mid fan position on footslope. Elevation: 45m.
Drainage:	Well drained
Parent Material:	Loess colluvium

Land Use:	Semi-extensive grazing.

Profile

A 21 cm	very dark grey brown (10YR 3/2, moist) silt loam; friable; weakly developed fine crumb and nutty structure; many insect borings; many roots; indistinct irregular boundary,
B_1 16 cm	olive brown (2.5Y 4/4, moist) heavy silt loam; few fine distinct strong brown (7.5YR 5/8, moist) mottles; friable to firm; weakly developed fine prismatic structure breaking to fine blocky structure; few insect borings; some roots; indistinct boundary,
B_2 25 cm	light olive brown (2.5Y 5/4, moist) clay loam; many coarse prominent strong brown (7.5YR 5/6, moist) mottles; firm; well developed medium prismatic structure breaking to fine blocky structure; few discontinuous distinct dark brown (7.5YR 4/3, moist) clay cutans on ped faces; some roots penetrating between peds; indistinct boundary,
B_3 18 cm	light yellowish brown (2.5Y 6/4, moist) heavy silt loam; many coarse distinct strong brown (7.5YR 5/8, moist mottles; hard; massive to weakly developed coarse prismatic structure; few discontinuous distinct dark brown (7.5YR 5/8, moist) clay cutans on ped faces; distinct boundary,
C 16 cm+	light yellowish brown (10YR 6/4, moist) silt loam; firm; massive.

4. Takahe series

Soil Type:	Takahe silt loam
Classification:	Yellow-grey earth
Map Sheet:	NZMS 2 SHEET S 84/5
Grid Reference:	117492
Topography:	Slope 14°. Aspect: north-east. Landform: convex shoulder. Elevation: 245 m.
Drainage:	Well drained
Parent Material:	Loess
Land Use:	Extensive grazing.

Profile

A 17 cm	very dark grey brown (10YR 3/2, moist) silt loam; very friable; weakly developed fine nutty structure breaking to fine crumb structure; some worms; few insect borings; many roots; indistinct boundary,

B_1 14 cm
17
31

light yellowish brown (2.5Y 6/3, moist) silt loam; few very fine distinct reddish yellow (7.5YR 6/8, moist) mottles; firm; moderately developed fine prismatic structure breaking to fine blocky structure; very few small distinct yellowish red (5YR 4/8, moist) ir nodules; some roots; indistinct boundary,

B_2 26 cm
31
57

light yellowish brown (2.5Y 6/4, moist) heavy silt loam; abundant medium prominent strong brown (7.5YR 5/6, moist) mottles; hard; well developed medium prismatic structure breaking to fine blocky structure; few discontinuous indistinct pale brown (10YR 6/3, moist) clay coatings on ped faces; common small and large distinct yellowish red (5YR 4/8, moist) nodules; few roots; indistinct boundary,

B_3 9 cm
66

light olive brown (2.5Y 5/4, moist) heavy silt loam; subgammate; hard; well developed fine prismatic structure breaking to fine blocky; common discontinuous distinct brown (10YR 4/3, moist) clay cutans; indistinct boundary,

C 40 cm
6

light olive brown 2.5Y 5/4, moist) silt loam; subgammate; extremely hard; moderately developed coarse prismatic structure; indistinct boundary,

C_x 60 cm+

yellowish brown (10YR 5/4, moist) silt loam; very firm; massive.

5. Kiwi series

Soil Type:	Kiwi silt loam
Classification:	Yellow-grey earth
Map Sheet:	NZMS 1 SHEET S 84/2
Grid Reference:	089498
Topography:	Slope 34^{o}. Aspect: north-west. Landform: convex backslope. Elevation: 240 m.
Drainage:	Excessively drained
Parent Material:	Loess mixed with some basalt fragments
Land Use:	Extensive grazing.

Profile

A 26 cm

dark grey brown (10YR 4/2, dry) silt loam with some basalt fragments; very friable; weakly developed fine to medium nutty structure breaking to fine crumb structure; many roots; some worm casts; indistinct boundary,

B 30 cm

brown (10YR 5/3, dry) heavy silt loam with basalt fragments; very firm to hard; weakly to moderately developed coarse prismatic breaking to fine blocky structur few roots; distinct boundary,

on	scoriaceous basalt.

6. Windsor series

Soil Type:	Windsor bouldery silt loam
Classification:	Brown granular loam
Map Sheet:	NZMS 2 SHEET S 84/5
Grid Reference:	092493
Topography:	Slope 7°. Aspect: north-east. Landform: convex summit. Elevation: 395 m.
Drainage:	Well drained
Parent Material:	Basalt
Land Use:	Extensive grazing.

Profile

A 22 cm	very dark brown (7.5YR 2/2, moist) bouldery silt loam; very friable; well developed fine crumb and granular structure; abundant roots; some worms; distinct boundary,
C	basalt rock.

7. Cashmere series

Soil Type:	Cashmere bouldery silt loam
Classification:	Brown granular loam
Map Sheet:	NZMS 1 SHEET S 84/2
Grid Reference:	125511
Topography:	Slope 18°. Aspect: north-west. Landform: convex shoulder. Elevation: 120 m.
Drainage:	Somewhat excessively drained
Parent Material:	Basalt mixed with some loess
Land Use:	Recreation reserve.

Profile

A 20 cm	dark reddish brown (5YR 2/2, moist) bouldery silt loam; very friable; well developed fine crumb and granular structure; many roots; many worm casts; indistinct boundary,
B 26 cm	dark brown (7.5YR 3/2, moist) stony clay loam; friable; moderately developed fine blocky structure; many roots; some worms; distinct boundary,
C	basalt rock.