PEDOGENESIS AND VEGETATION TRENDS IN
THE ELEFULVIC AND ELDEFULVIC ZONES
OF THE NORTH - EAST BEN OHAU RANGE,
NEW ZEALAND.

A thesis
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of the requirements for the Degree
of
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in the
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A.C. Archer

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CHAPTER I
INTRODUCTION

A. Location and outline to the area of study.

The Twin Stream catchment is one of several transverse valleys in the Ben Ohau Range which flows into the Tasman River (Figure 1). It is approximately 44 sq km in area and is bounded by the Whale Stream in the south and the Bush Stream in the north, with the Ben Ohau Range on the western boundary. The catchment forms part of the 19,000 ha station of Glentanner which is run by Mr I.K. Ivey.

In 1965 Grasslands Division of the Department of Scientific and Industrial Research established a field station at 800 m. Since then a further field station has been located at 1,400 m. These two field stations form the focal point for plant and ecological studies into the mid and high altitude grasslands.

B. Reasons for the selection of Twin Stream and purpose of present study.

i) The area is located on a precipitation gradient between the humid and per-humid zones (1,500 - 3,000 mm). This enables the study of the varying effects of moisture on the soils and vegetation within a relatively small area.

ii) The area includes a set of well preserved ground surface of different ages and altitudes.
iii) Access is relatively easy to mid-altitude by landrover tracks.

The growing pressures on the demands of marginal lands for pastoralism, forestry, recreation and water resources have resulted in a land-use conflict which can only be resolved by the compilation and interpretation of land resource data and subsequent classification of land into its various uses in accordance with scientific findings.

At present the widely used system of land use capability classification is based upon very meagre basic land resource data and in many instances information upon soils and vegetation is almost completely lacking. This applies particularly to extensive areas of mountainous terrain which are grouped under broad land use capability classes of VII, VIII even though they are very different in terms of erosion, revegetation potential, yield and quality of water.

The overall purpose of this project therefore is to study the natural process which influence and control the development of soils and vegetation in the sub-alpine and the alpine zones of the Twin Stream catchment with the view of contributing more quantitative resource data from which reliable interpretations and evaluations can be made.
CHAPTER II
REVIEW OF LITERATURE

This literature review includes research which is relevant to this study and is not intended to be a comprehensive review on the subject of alpine environments.

The review has been organised under four main headings:

A) Zonal concepts of mountain environment in New Zealand.
B) Mountain climates.
C) Mountain soils of the humid and perhumid zones.
   1. Zonal concepts
   2. Soil physical properties
   3. Chemical properties
   4. Pedogenesis and soil classification
   5. Soil-plant relationships
D) Literature referring to the Ben Ohau Range.

A) ZONAL CONCEPTS OF MOUNTAIN ENVIRONMENTS

The boundary between limits of the subalpine and alpine zones has been debated for many years. However, it is generally accepted that the lower limit is related to the uppermost limits of tree growth. Hackett and Hartley (1965) define the boundary thus:

"Treeline (Timberline) denotes the boundary between subalpine forest and alpine meadow (Beaman, 1962). Some consider the upper edge of the continuous forest to be timberline, while others recognize it as the altitude of the highest tree, and still others accept a mid-point between these extremes."
In New Zealand one of the first authorities to differentiate the alpine and subalpine zones ecologically was Cockayne (1899). Zotov (1947) later defined the zones between lowland, montane and subalpine. With reference to climax grasslands and climax forest, Wardle (1963) considered a New Zealand altitudinal zonation based on the occurrence of several plant taxa. His zones have been represented in Table 1.

East of the main divide, because of the rain shadow effect and the poor tree flora, Costin (1967) noted that the alpine and subalpine zones are not clearly defined because of the overlapping of the alpine and subalpine biota. A number of authors, namely Connor (1964), Molloy (1964), Mark (1965) have indicated the dynamic nature of the subalpine, alpine transition on the eastern ranges and the tendency for the downward migration of plants through cultural disturbances particularly relating to Polynesian and European fires (Connor, 1964, Molloy, 1964).

B) MOUNTAIN CLIMATE

Climatological data have been obtained from only a few and widely separated localities. Garnier (1958) has very briefly considered mountain climates in the main ranges of the South Island and classified the alpine zones as cool superhumid, the upper limit merging into the frost climates of the perennial snow and ice zone. Coulter's study (1967) of the superhumid climate of Cupola Basin and the humid climate of Black Birch indicated the marked contrasts that exist between these two regions.
with regards to sunshine hours, precipitation and evapotranspiration. In an investigation of the climate of the Craigieburn Range, Morris (1965) recorded periods when frost occurred in the mid and high altitudes during each month of the year. He concluded that compared with the continental regions of the northern hemisphere summer temperatures in the New Zealand mountains were lower, and winter and early spring temperatures were milder. These differences could have a considerable effect on vegetative growth. Mark (1965), in the mountains of Central Otago at similar altitudes, recorded lower mean air temperatures by as much as $2^\circ C$ than those recorded further north in the Craigieburn Range. He also found that frost could occur at any time of the year.

Mark and Bliss (1970), found summer precipitation in alpine environment of Central Otago to be low, but they maintained that total precipitation far exceeds the estimated potential evapotranspiration.

In a number of studies relating to the effects of micro-climate on vegetation, Mark and Baylis (1963) noted the interaction of aspect and altitude as they effect temperature, exposure and snow duration in determining the distribution of snow tussock communities. Burrows (1967) also pointed out the importance of snow cover in relation to the distribution of various species of snow tussock. Archer and Collett (1971) studied the effects of vegetative cover on temperature and moisture. They stressed the contrast in microclimate between different aspects and concluded that northern and western aspects
were associated with relatively high diurnal range of temperature with alternating surface cooling and heating. The southern aspects were characterised by a distinct seasonal rhythm associated with snow and snow-free periods. The results of snow investigations in the Craigieburn Range (Morris and O'Loughlin, 1965) reflected the relatively mild winters experienced in New Zealand mountains. More reference will be made to snow in a later section.

C) MOUNTAIN SOILS OF THE HUMID - PERHUMID ZONES.

1. Zonal concepts

Taylor and Pohlen (1962), with reference to the energy status of the soils, regarded the altitudinal limits of various zones somewhat differently to other zonal concepts. Table 2 has been presented showing Wardle's floristic zone and a number of climatic indices, as compared with those of Taylor and Pohlen. There is general agreement throughout with the base of the subalpine zone at 3,000 ft (914 m). However, with the subalpine, alpine transition Taylor and Pohlen disagree markedly with the floristic and climatological concepts. Thus we find the alpine soils merging with what climatologists would regard as a sub-nival zone, and the subalpine soils occupying a very wide altitudinal belt 1,500 ft (457 m) above the climatic timberline.

In Soil Bureau Bulletin 27 (1968), alpine soils are defined as:

"Above about 5,000 ft in the South Island on the main ranges. They are not true soils but delineate..."
the area above the zone of continuous plant and soil cover."

Vucetich (1969) in an account of the Canterbury soils, refers to alpine soils as:

"Soils confined to favoured situations where alpine herbs and mat plants have protected the ground surface and allowed the sand and silt to accumulate. The alpine soil is stony, friable and contains little organic matter."

Description of mountain soils taken from Soil Bureau Bulletin 27 (Table 3), indicate that these soils have been grouped within a very broad altitudinal range. For example, the Moonlight soils range from between 1,000 - 5,500 ft (304 - 1,600 m) and the Spencer soils from 3,500 - 6,500 ft (1,066 - 1,981 m). These broad sets tend to reflect the lack of quantitative data which would, if available, isolate these soils into more discrete classes.

These various concepts of altitudinal zonation have naturally lead to a wide divergence of opinions relating to the zonality of mountain soils, thus Molloy (1964), in the Mount Torlesse area, has referred to the zonal alpine soils as "a strongly enleached upper eldefulvic soils".

2. Soil physical properties.

Tables 4a and 4b summarise soil physical data published by McDonald (1961) and Molloy (1964) and Archer and Collett (1971). The mechanical analyses in Table 4a reflect the extreme variability of organic matter and mineral fractions.
Bell's (1973) study of the soils on Mount Owen showed a similar size range with the fine fractions derived from schist, but the clay fraction from soils formed from the marble were considerably higher. There is some variation in the total porosities recorded by McDonald and Molloy. This variation will have considerable effect upon the saturated permeabilities of the soils, and hence upon their hydrological potential.

Little has been published concerning soil moisture characteristics of the high country yellow-brown earths. However, the available data does reveal (Table 4b) a high degree of variability of moisture constants amongst soils of the same zone. For example, Molloy's values (line 3) for the alpine soils of Mount Torlesse are considerably lower than Archer's values (line 4) for soils at similar altitudes from the region of higher precipitation. These high moisture constants recorded by Archer characterize the podzolised yellow-brown earths of the perhumid zone with a relatively high organic matter content, as opposed to Molloy's degraded alpine soils which have lost large quantities of humic material through erosion.

In a comparison of the upland yellow-brown earths and high country yellow-brown earths of Otago, Leamy (1971) found that both classes had fine and weakly developed structures. However, there was some difference regarding kinds of structure; crumb structure predominates in the high country yellow-brown earths and nut structure in the upland soils. Colours for both A and B horizons were similar but there is some contrast in texture; upland
soils have silt loam, whilst high country soils have sandy loam and loamy sand textures.

Because of the weak structures which characterize the yellow-brown earths, these soils have a certain degree of inherent instability which can be aggravated by cryoturbic processes. Gradwell (1954, 1955 and 1957) summarised his findings of frost studies in Marlborough on a Molesworth gravelly sandy loam:

i) Three inches of snow cover were sufficient to protect the underlying soil from overnight freezing and needle ice formation.

ii) Needle ice was more common on sunny than on shady aspects in mid-winter.

iii) Needle ice was observed to tear grass roots on the uphill side of turf remnants.

iv) Diurnal ranges of temperature were approximately halved where the soil was covered or shaded by tussock.

This work was substantiated by Greenland and Owens (1967) and Soons and Rayner (1968) and later confirmed in controlled laboratory conditions by Soons and Greenland (1970).

3. Chemical properties.

In Leamy's (1971) comparison of the high country yellow-brown earths and upland yellow-brown earths in Otago, high country yellow-brown earths differ from the upland soils in the following respects:
i) pH values are slightly lower (pH 4.6 - 5.4).

ii) Carbon nitrogen ratios are higher.

iii) Cation exchange capacity lower and less variable.

iv) He records that Ludecke (1966) found slightly lower values of total phosphorus.

v) Phosphate retention higher.

The study of the subalpine and alpine soils of Mount Torlesse (Molloy, 1964) showed some chemical differences between the alpine and subalpine soils:

i) The subalpine soil particularly on the scrub-tussock site had a higher carbon nitrogen ratio than the alpine tussock soil.

ii) The soils of the subalpine tussock site had higher total exchangeable bases and consequently a higher percentage base saturation.

iii) At high altitude, there is a phosphorus deficiency regardless of slope.

Ives and Cutler (1971) studying the dry hygrous high country yellow-brown earths in the Mowbray catchment also found that increase in altitude was associated with increase in leaching of the soil. They further recorded that phosphorus transformations in steepland soils substantiated previous findings of Walker and Adams (1959). These findings may be briefly stated as follows:

i) A marked decrease of total phosphorus with increasing age.

ii) A marked decrease of amount of available phosphorus with morphological development (increasing age).
iii) The percentage of available phosphorus to total inorganic phosphorus \((P_a + P_f)\) decreases with age.

In the hygrous soils of the steepland Kaikoura set Ross (1971) found some variation in the chemistry between soils on different aspects and recorded that south aspect soils were:

i) more acid,

ii) cation exchange capacity is higher;

and that soils on the north aspect had:

i) greater organic matter per profile,

ii) more positive allophane test as per Fieldes and Perrott (1966)

iii) greater total and available phosphorus.

McCraw (1962) described an alto-sequence in the Old Man Range in Central Otago. The soil at an altitude of 1,585 m (5,200 ft) had the lowest pH and base saturation of the whole sequence. Alpine soils by Archer et al. (1973), above the Malte Brun lateral moraine at an altitude of 1,737 m (5,700 ft) had a higher base status (possibly because it is more rejuvenated by the drift régime) than the soils described by McCraw. On the Owen Range in Nelson, Bell (1973) found a higher nutrient status with soils formed on marble compared with those having developed on the schist, and that soils were progressively leached with an increase in altitude.

4. Pedogenesis and soil classification.

The older New Zealand classification tended to
emphasise the skeletal nature of steepland soils and their inherent instability (Taylor, 1948). Taylor and Cox (1956) stated that steepland soils are relatively unstable and are periodically rejuvenating from erosion. From Taylor's understanding of steepland soils he regarded these soils in the genetic classification for New Zealand Soils (Taylor and Pohlen, 1962) to be dominantly skeletal with many intergrades to other classes.

Cutler (1961) took a broader view of the problem of classifying steepland soils. He classified zonal steepland soils on the basis of moisture and temperature regions, and regarded these soils as being not all necessarily unstable, particularly on parent material composed of schist. Further he noted the local importance of lateral seepage.

Gibbs (1962) in discussing the problems of steepland soils adopted Taylor's concepts and referred to high country yellow-brown earths and podzolised yellow-brown earths under a series of sub-classes. These have been indicated below:

i) 

\[
\begin{array}{c}
\text{ELDEFULVIC} \\
\text{CLINI-ELDEFULVIC} \\
\text{FULVI-ELDECLINIC}
\end{array}
\]

ii) 

\[
\begin{array}{c}
\text{ELDEPODIC} \\
\text{CLINI-ELDEPODIC} \\
\text{PODI-ELDECLINIC}
\end{array}
\]

On the Old Man Range of Central Otago McCraw (1962)
designated soils at 4,000 ft (1,219 m) as high country yellow-brown earths (Eldefulvic soils) and above 5,000 ft (1,524 m) as alpine yellow-brown earths (Elefulvic soils). He differentiated these latter soils on the basis of weaker structures and lower base status for the soils at higher altitudes. Molloy (1962) adopted Bulter's K cycle concept of erosion and deposition phases to interpret some features of pedogenesis in high country yellow-brown earths in Canterbury. He suggested that since the end of the Otiran Glaciation there has been periodic erosion of soils at high altitudes in the alpine zone and a redeposition in the subalpine zone.

From more recent work on Mount Torlesse, Molloy (1964) came to the following conclusions:

i) The Kaikoura set could be divided into two classes: subalpine and alpine on the basis of morphology, physical and chemical properties, climate and vegetation.

ii) Both soils are polygenetic.

iii) Subalpine soils occur between 3,000 ft (914 m) - 4,300 ft (1,310 m). Their zonal expression is a fulvi-podic soil from weakly argillized greywacke.

iv) Repeated cultural practices have degraded it to a strongly enleached "lower clini-eldefulvic soil".

v) Alpine soils occur beyond 4,300 ft (1,310 m).
Their zonal expression is a "strongly enleached upper eldefulvic soil" from weakly argillized greywacke. These have been degraded to a "strongly enleached upper clini-eldefulvic" soil.

vi) Soil formation commenced in early post-glacial times probably between 3,000 - 10,000 years B.P. achieving maximum profile stability around post-glacial climatic optimum between 3,000 - 5,000 years ago.

The Kaikoura soil set is one of major steepland soil sets. Taylor's definition of these soils has already been considered. Vucetich (1961) stressed their variability and varying degree of susceptibility to erosion.

Ives and Cutler (1972) described the influence of topography on Kaikoura soils indicating the dynamic nature of the steepland environment.

In a study of the characteristics of the upland yellow-brown earths and the high country yellow-brown earths, Leamy (1971), c.f. page 9, considered the main morphological characteristics. These may be summarised as follows:

i) A horizons of both high country yellow-brown earths and upland yellow-brown earths are dark coloured and friable with weakly developed structures.

ii) B horizons are distinguished by their yellow-brown colours.
iii) C horizons are normally stony and thin.

iv) The boundary between A and B horizons is more diffuse in the upland yellow-brown earths.

v) As shown in the soil map of the world (Dudal, 1968), both classes have sombric A horizons and cambic B horizons.

Archer et al. (1973) described two soils at an altitude of 1,737 m on the Malte Brun moraine near Mount Cook. One soil developed on the riser of a solifluction terrace had been subjected to cryoturbatic processes and was regarded as an alpine variant of the podzolised yellow-brown earths. The other soil is slightly thicker developed on moraine and drift was found to be a weakly weathered podzolised yellow-brown earth.

In a study of the high alpine vegetation of Central Otago Mark and Bliss (1970) found that the alpine yellow-brown soils formed on schist had varied textures from silty loam to sandy loam, but both A and B horizons were free from stones. This concurred with McCraw (1965), who considered that the fine fraction had probably been derived from loess. Cutler (pers. comm.) regarded the solum of the Obelisk soils as variable in depth and stoniness but that there were areas of fine textured soils which had probably been derived from loess.

5. Soil-plant relationships.

As species of Chionochloa are the most widespread form of herbaceous vegetation growing on the mountain soils it is not surprising that the relationship of this
genus to soils has received more attention than any other form of plant growing in these regions. Barker (1953) in her study of the tussock grassland communities found low-tussock related to Hurunui soils and tall tussock (Chionochloa genus) to Kaikoura soils.

Wraight (1960) in the Hokitika catchment attempted to relate species of Gramineae to soil characteristics. He found that Chionochloa flavescens was largely confined to weakly weathered and weakly leached soils. In a later survey of the Wairau catchment Wraight (1963) found a high degree of modification of the catchment through grazing and erosion, and that Notodanthonia setifolia and, to a lesser extent Festuca matthewsii, have partially recolonized some soils of eroded sites. The former plant occurs as an induced grassland following the destruction of the forest.

Connor (1965) refers to the distribution and zonation of tall-tussocks in the middle Rakaia Valley as follows:

i) Chionochloa flavescens favours sunny aspects and coarse textured soils.

ii) Chionochloa rigida prefers fine textured soils on shaded aspects.

iii) Chionochloa rubra grows on gleyed soils on terraces and basins.

Wraight (1967) found that Chionochloa pallens and Chionochloa crassiuscula are predominant on the moister podzolised soils of the Spenser set, whilst on the Kaikoura silt loams, Chionochloa pallens, Chionochloa
flavescens and Chionochloa macra are dominant. Mark and Burrell (1966) recorded Chionochloa flavescens associated with Chionochloa crassiuscula on poorly drained soils. Burrows (1967) also found Chionochloa flavescens on poorly drained soils but stressed its preference for well drained sunny aspects.

Burrows (1967) in a study of alpine grasslands made the following observations with regards to the distribution of species of Chionochloa:

i) Chionochloa rigida grew on a wide range of soils, from lithosols to yellow-brown earths.

ii) Chionochloa flavescens prefers well drained soils.

iii) Optimum development of Chionochloa flavescens is on immature well drained soils.

iv) Chionochloa rubra grows on gleyed soils.

v) Chionochloa crassiuscula generally prefers "immature peats" and gleyed soils.

vi) Both Chionochloa australis and Chionochloa oreophila are found ranging from shallow lithiskelic soils to shallow podzols.

A study of the various responses to soil nutrients of tall-tussock was made by Molloy et al. (1970) and O'Connor et al. (1972). Molloy et al. found that Chionochloa rubra and Chionochloa rigida appear to have a wider ecological "valance" (Danserau, 1957) than Chionochloa flavescens and Chionochloa macra. O'Connor found that Chionochloa rigida and Chionochloa macra had a negative
response to lime and superphosphate. Both *Chionochloa rubra* and *Chionochloa flavescens* indicated a positive response in tillering and leaf elongation with the addition of both lime and superphosphate.

With regards to the distribution of vegetative cover in relation to soils in the alpine zone Mark and Bliss (1970) found that the depth of solum under cushion plants increased from 3 cm on the most exposed sites to at least 50 cm under herbfield. Profile differentiation and organic matter content also increased from cushion to herbfield. The vegetation of snow banks that melt early in the season had well developed A, B and C horizons. They further noted the alternate banding of fine material which sometimes characterized these soils.

In a previous study in Central Otago Billings and Mark (1961) studied the zonation of plants in relation to frost patterned soils. They found that the solifluction terraces had the most varied soils and that the vegetation was distinctly zoned in accordance with the relative depth of the solum. On the tread of the terrace cushion plants were dominant. As the soils became deeper and habitats more protected on the upper part of the rise *Celmisia viscosa* was dominant followed by a zone of *Chionochloa flavescens* and then again by *Celmisia viscosa*, *Drapetes lyallii* and *Phyllachne colensoi* at the foot of the rises.

Similar zonation of life-forms on solifluction terraces was recorded by Archer et al (1973) at Malte Brun, Mount Cook.
D) LITERATURE REFERRING TO THE BEN OHAU RANGE

1. Geology and Pleistocene deposits

The New Zealand Geological Survey Map (1967) records the study region of Twin Stream as complex consisting of:

i) superficial morainic deposits in the lower eastern part, followed by schistose, non-foliated greywacke in the central part,

ii) indurated greywacke of the chlorite subzone I in the western part.

The primary minerals consisted of 80% quartz and orthoclase feldspar. Accessory minerals include minor amounts of albite, oligoclase, biotite, chlorite, sphene, epidote, zircon, apatite and tourmaline. In his chrono-sequence of the moraines of the Pukaki catchment, Speight (1963) included the front faces of the Twin Stream catchment into the Pukaki Landform Association with the remnant of the Maryburn Landform Association on the upper benches of the South bank of the catchment. In the more recent 4 mls to the inch geological survey map (1967) of the region, the chronology is similar, except that Speight's Maryburn Landform Association has been extended into a northern part of the catchment along the high structural benches. A comparison of the chronology has been included in Table 5.

McGregor (1967) followed on Speight's work in describing and mapping the more recent Aranuiian moraines which were formed by valley and cirque glaciers subsequent
to the retreat of the Pukaki ice. McGregor stated that he was unable to observe Birch Hill moraine termini in the Twin Stream which could be correlated with those in the Whale Stream. However, in a smaller northern sub-catchment deposits resembling those described by him are evident. McGregor's correlation of the Aranuian and late Otiran stages have been summarized in Table 6.

2. Climate

There is in general a paucity of climatological records for the Ben Ohau Range. Those that exist refer generally to rainfall obtained from manual rain gauges which have been maintained by runholders close to homesteads in the valley. Over a ten year period previous to 1965, 1,778 mm of precipitation had been recorded at Glentanner homestead.

Garnier (1958) subdivided the Central part of the South Island into a number of climatic regions. That part of the Tasman Valley which includes the Twin Stream falls into four sub-regions:

i) cool, humid

ii) cool, superhumid

iii) cold alpine climate

iv) frost climate.

These climatic sub-zones may be said to characterise the montane, subalpine, alpine and the transition to snow and ice (nival zone) respectively.

More specific work with climatological implications
was made by Archer (1970) who studied snow characteristics over an altitudinal range in relation to accumulation and ablation. From this work a number of conclusions can be drawn:

i) During 1966-1967 the majority of precipitation came from the N.W. direction. N.W. weather was not only associated with snow falls but also rapid ablation.

ii) A profound contrast in the distribution of snow between the shaded and sunny aspects was recorded.

iii) A gradual accumulation of relatively high density snow followed by a rapid melt, is characteristic of the climate.

This work was further extended to study the interaction between microclimate, soils and vegetation at high altitudes. (Archer and Collett, 1971). It was found that soils and vegetation show strong aspect differences because of the microclimate, and that differences in soil and plant communities were related to a difference in soil moisture régime. Evidence was presented to show that even in a superhumid zone dry periods could lead to some soils dropping below field capacity. Mean annual temperatures recorded at Mount Cook (Archer et al., 1973) were 1°C or 2°C higher than those recorded by Mark and Bliss (1970) in parts of the Central Otago mountains.
3. Soils

Figure 2 is a section from the soil map (1:253,440) of the western part of the Mackenzie Country. Changes in the soil pattern show a close relationship to trends of precipitation from yellow-grey and dry hygrous yellow-brown earths at the lower part of the gradient to the high country yellow-brown earths at the upper end of the gradient.

Few data are available to compare elements of high altitude soils. However, two topo-sequences of soils at Twin Stream north-south and east-west transects, Figures 3 and 4 (Soil Bureau Soil Map, 1968 and extended legend) indicate the spatial relationship of these soils to one another.

4. Vegetation

The first comprehensive vegetation survey of the Ben Ohau Range was made by Connor (1964) who used the Zurich-Montpellier system for synthesising plant communities. From his synthesis tables one can summarise his findings. On Tekoa steepland soils at lower altitudes, (below 3,500 ft (1,066 m)) Chionochloa rigida and Festuca matthewsii occur. At higher altitudes above 3,500 ft (1,066 m) this grassland occurs on Kaikouran steepland soils. Floristically these communities were similar in having a high constancy for Poa colensoi and Raoulia subsericina although the communities developed on the Tekoa soils had high scale of significance and abundance for Chionochloa rigida.
At the higher altitude 4,500 ft (1,371 m), Connor referred to the two relevés in this zone as alpine. These two communities were again on Kaikouran steepland soils. Floristically they showed some similarities with the previous communities at lower altitude but they also included *Celmisia lyallii*.

More recently in the Twin Stream catchment Archer and Collett (1971) described three plant communities in the alpine zone and related them to different soils and moisture. *Chionochloa oreophila* was associated with a high moisture status on flushed eleclinic soil. The intermediate community was dominated by *Celmisia lyallii* growing on strongly enleached yellow-brown earths, and at the driest end of the spectrum a wide range of plants were associated with the degraded yellow-brown earths.

Studies related to mountain soils have generally been confined to a few widely dispersed type localities. These studies have also tended to be concentrated in the drier eastern coastal and central parts of the South Island mountains. Both the pedologist and botanist have worked independently over a broad altitudinal range and there is some divergence of views in terms of zonal concepts in relation to the distribution of the alpine and subalpine soils.

The extreme paucity of environmental data have tended to oversimplify processes which have arisen from concepts made within limited areas. As a result steepland and other mountain soils have tended to be equated with instability, and all influenced by an active drift régime related to periodic erosion and deposition.
CHAPTER III
METHODS AND EXPERIMENTAL PROCEDURE

A. GEOGRAPHICAL BOUNDARIES AND OBJECTIVES

Prior to the commencement of this project the author was familiar with the area as work had already been carried out into characterising some aspects of the environment (see review of literature). For the study it was therefore decided to establish an altitudinal base line of about 1,100 m (3,600 ft). The purpose of this was to include the complete Ferintosh surface (McGregor, 1967) moraine which formed an important physiographic component in the mid-altitude part of the catchment. The boundaries of the study extended into the uppermost western part of the catchment from the floor of the braided Twin Stream headwaters (see Plate 1) up to the limits of the vegetation. In the central northern part of the catchment the boundary extended to the uppermost vegetated surface of the Twin Basin onto the most recent moraine. The lower limit of the basin is formed by the older Birch Hill moraine which is clearly breached by the stream (Plate 1). The lower limits of both Pyramid and Mount Mary Basins are close to the 1,100 m contour (3,600 ft) which intersects the Ferintosh surface.

The objectives of the project can be summarised as follows:

1) to describe and classify soils in accordance with New Zealand Soil Bureau technical classification (Taylor & Pohlen, 1962);
ii) to analyse soils in relation to altitude, aspect and physiography;

iii) to study the effects of the interaction of these variables upon pedogenesis;

iv) to measure climate with particular reference to soil moisture;

v) to describe and analyse plant communities;

vi) to prepare a soil map with a scale of 360 m = 2.5 cm.

B. INSTRUMENTATION

A sparsity of climatic data have in the past handicapped our understanding of some of the processes which influence pedogenesis and vegetation. This project was, however, fortunate in having several instruments which had previously been installed in the area throughout a wide altitudinal range. In Plate 1 sites of climatological instruments have been designated by X. Instruments are mechanically operated. However, within the limits of the instruments, records throughout the period 1966-1972 proved to be reliable. The type of equipment used is outlined below:

1) Hygrothermographs (Lambrecht of Göttingen) consisted of a bimetallic element with a standardised permix grid for humidity measurements. The bimetallic element was calibrated to record a temperature range of
between -35 to +45°C. The humidity range was from 5 to 100% relative humidity. The limits of temperature error were ±1.5% and that for humidity ±2.5%.

ii) Three-pen distance thermograph (Plate 2) had 3 flexible capillary tubings of 1 m length and 3 plain bulbs with No.1 lead immersion casing. The temperature range was from -35 to +45°C. The limits of the temperature error were ±2% of the total measuring temperature range.

iii) Standard maximum and minimum thermometers (Lambrecht) - the limits of the temperature error were below 0°C, ±1.5°C, and above 0°C, 1.0°C.

iv) Symons pattern earth thermometer were sunk at 30 and 90 cm depths. Temperatures range from -5°C to 40°C. There were manufactured by Zeal of London.

v) Mechanical wind recorders manufactured by Lambrecht, recorded mean hourly values with a velocity range of 0.5 to 60 m/sec.

vi) Standard raised evaporation tank of local manufacture, was installed for measuring evaporation.

vii) For recording evaporation on steepland terrain the Piche atmometer was used. This was a
graduated cylinder. The evaporation surface consisted of filter paper discs 30 mm diameter. This instrument was manufactured by Lambrecht.

viii) Standard copper manual rain gauges of 5 in (127 mm) and 8 in (203 mm) diameter were used.

ix) Snow sampling equipment was standard snow tubes, weights and beam balance of Italian manufacture.

1. Location of instruments.

i) Lower field station (F.S. on Plate 1), altitude: 853 m (2,800 ft):

One three-pen thermograph recording air and soil temperatures at surface, -5 cm and -30 cm depths. Instruments sited in a screen recording air temperature and humidity. One mechanical wind recorder and one copper rain gauge.

ii) Scots, north and south aspect, altitude: 1,250 m (4,100 ft):

One (Plate 2) hygrothermograph at each site and also a three-pen thermograph recording soil temperature at surface, -5 - 10 cm depths, at each site.

iii) Pyramid Basin, E.S.E. aspect, altitude: 1,480 m (4,850 ft):

A hygrothermograph recording air temperature and humidity. Soil temperatures recorded by
one three-pan thermograph at surface, -5 cm and -10 cm depths. One copper manual rain gauge.

iv) Pyramid Basin, altitude: 1,554 m (5,100 ft):

Air temperatures recorded at 30, 90, 180 cm high, soil temperature at surface -2, -5, -10 cm depths (Plate 3).

v) Pyramid Basin, altitude: 1,737 m (5,700 ft):

Air temperature and soil temperatures at surface, -5, -10 cm depths.

vi) Low part of Mount Mary Basin, N.E. aspect, altitude: 1,219 m (4,000 ft):

Air temperature and soil temperature at surface, -5 and -10 cm depths.

vii) Evaporation measurements were made in various parts of the S.E. and E. aspects of Pyramid Basin and the North aspects of Mount Mary Basin using the Piche atmometer. These measurements were maintained over several weeks and also on short term intervals on an hourly basis over a 24 hour period. Evaporation records were obtained from the raised pan which was permanently sited at the lower field station. Daily totals were continuous over a fifteen month period from 1968-1969.

viii) Soil moisture was determined gravimetrically, on a dry weight basis during 1969-1971.
Sampling was mainly carried out on the north and south aspects of Scots and in Pyramid Basin. The period between samples varied depending upon the time of the year, monthly intervals during early winter and every week during the summer and autumn.

ix) A snow survey was maintained along the snow-courses in Pyramid Basin from 1966-1971 (For snow survey methods, see Archer, 1971). A further small area of about 0.25 hectare was chosen for intensive work on snow conditions in relation to soil moisture and the zonation of soils and plant communities. In this case, a small area was gridded with metal poles in a locality where snow accumulated to a considerable depth during winter and spring. Measurements were made of both net accumulation and ablation.

C. FIELD PROCEDURE

A survey revealed that the distribution of soils and the vegetation pattern were very strongly influenced by aspect and altitude. Within these overall differences the soils exhibited a high degree of variability and the soil auger was of little value hence it became necessary to resort to the digging of soil pits at frequent intervals for soil typing.
D. AIR PHOTOGRAPHS

Vertical air photographs at a scale of 360 m = 2.5 cm were used in establishing both the geographical limits of the surfaces and also the extent of the geomorphic units. The various criteria used for identifying surface features included:

- texture,
- shadow,
- shape and size,

these factors have been described by Clarke (1961).

E. SLOPE ANALYSIS

In mountainous terrain, particularly areas which have been heavily glaciated compound slopes range from undulating to precipitous. In terrain associated with rolling relief such as moraine topography Ruhe's (1969) concept of slope has been adapted (Figure 5).

In precipitous terrain which has a wide altitudinal range Dalrymple et al (1968) slope concept is used (Figure 6).

Taylor and Pohlen's (1962) descriptions of compound slopes have been followed and are included in Appendix I.

F. DRAINAGE

Drainage classes were also adapted from Taylor and Pohlen, with some slight modification to class concept. These classes referred to soil drainage classes according to the rate from which water is removed from the soil (see Appendix II).
G. PROFILE DESCRIPTIONS

Descriptions and notations of profiles closely follow Taylor and Pohlen with some modifications to certain aspects of the profile. These are summarised below:

i) Soil thickness -
- Very shallow: 0 - 5 cm
- Shallow: 6 - 30 cm
- Moderately deep: 31 - 60 cm
- Deep: 61 - 100 cm
- Very deep: > 100 cm

ii) Colour (according to Munsell colour charts) - Generally colours are given for a moist soil. In some cases, however, particularly with intergrade classes, dry colours give a clearer indication of colour differentiation for distinguishing horizon transitions.

iii) Stoniness - The three classes of stoniness are inadequate for this study hence a fourth class has been taken from Ives (1970) to describe extremely stony conditions > 60%.

iv) Roots and organic matter - The degree of development of the O and A horizons is a very important feature in the soils of this study as an indication of the morphology and pedogenic tendencies of the soil. The description of the rooting zone follows Clarke (1961) whose root classes give a good indication of the form of rooting zone. These classes are
as follows:

Quantity -

Abundant 100 per sq 30 cm of profile face
Frequent 100 - 20 per sq 30 cm of profile face
Few 20 - 4 per sq 30 cm of profile face
Rare 3 - 1 per sq 30 cm of profile face

Size:

Large 10 mm
Medium 10 - 5 mm
Small 5 - 1 mm
Fine < 1 mm

The descriptions are also followed by the nature of plant and its rooting structure. Micromorphologic description of organic form of soils were done from thin sections according to Barratt (1971). These methods will be described in a later section. In the field however Kubiena's (1953) terminology was used.

H. PHYTOSOCIOLOGICAL METHODS AND TERMINOLOGY

Vegetation studies were carried out in accordance with the concepts of the Zurich-Montpellier School with certain modifications adapted by Poore (1955). Field procedure involved the recognition and selection of a floristically homogenous area of vegetation (the stand) as relevé (Braun-Blanquet, 1932) which had a relatively uniform environment. The average size of the stand varied in accordance with the floristic diversity and
habitat. However, throughout the study it was found that 4 sq m was the minimal area (this included all the species forming the community) that covered over 90% of the survey. The vegetation study involved two phases, the analysis and the synthesis phases:

i) Analysis - when a stand has been selected the area boundaries were approximated on the ground and the plants were enumerated on a 10 point Domin scale:

1. One or two individuals
2. Sparsely distributed
3. Frequent but lower cover ( < 1/20)
4. Cover 1/20 - 1/5
5. Cover 1/5 - 1/4
6. Cover 1/4 - 1/3
7. Cover 1/3 - 1/2
8. Cover 1/2 - 3/4
9. Cover 3/4 - 9/10
10. Cover almost complete.

Cover is regarded as the vegetation cover as projected onto the ground surface. All the plant species in the prescribed area were then listed and enumerated as above. Each stand was then recorded according to Reference Number, Area, Altitude, Aspect, Slope and Percent Bare Ground.

ii) Synthesis phase - Over 60 stands were analysed in this study, of these 50 were selected which
had sufficient floristic homogeneity to be grouped into several plant communities. As the vegetation was extremely variable and generally poor floristically, the plant communities were grouped into a series of "Noda". The term nodum was defined by Poore (1965) on "abstract unit of vegetation of uncertain status". Thus on a gradient of continuous variation reference points could be located where plant communities showed some form of homogeneity. At the present level of floristic organisation these points of reference became noda. As the area was spatially limited and the plant communities highly fragmented, no attempt was made to map the boundaries of the communities. The vegetation boundaries are, therefore, based upon soil type boundaries which coincide with the actual noda of the particular vegetation type.

I. TAXONOMIC SOILS UNITS AND THEIR CLASSIFICATION

The main problem in describing and classifying soils of this area is that little previous work has been carried out on the pedogenesis of mountain soils, particularly in the regions of high precipitation. Also some of the findings of this study do not agree with a number of concepts relating to soil forming processes influencing steepland soils.
Taxonomic soil units have been based upon Taylor and Pohlen's technical genetic classification. Initially the soils have been classified to Category III according to the three main categories:

i) Category I - Basal Form

ii) Category II - Main Energy Status

iii) Category III - Main Class which coincides with the great soil groups.

The three final categories are based upon factors of genetic significance:

iv) Category IV - refers to illuviation, gleying, concretions and pan formations.

v) Category V - enleaching status.

vi) Category VI - parent material.

The breakdown of the main soils groups into Category III has been based on pedogenesis which is in accordance with Taylor and Pohlen's concepts. Where soils in Category III have some characteristics of other basal forms (i.e. Category I) they are classified as intergrades. The correlation of soil profiles recorded in the field have been grouped according to similarity based on the following criteria -

basal form, kind and sequence of diagnostic horizons, parent material, physiography, drainage, horizon morphology, base status, form of organic matter, gleying, illuviation and the régime under which the soil was formed.
Category III, its intergrades and phases thus form the main soils. An example of this has been illustrated below:

**CATEGORY III**

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ELEFULVIC
\------\       \------\
MADENTI-FULVIC     CLINI-FULVIC      FULVIC
                        (ENLEACHED PHASE)
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The prefixes, which have been used to form intergrades are all terms adapted from Taylor and Pohlen's concepts. In one case only have two terms been used which are not included in their classification: Namely, eutrophic and dystrophic, both terms used frequently in pedological literature referring to high and low nutrient status respectively.

**J. MAPPING UNITS**

The soils are very variable and have been grouped on map as soil associations, or soil landscape units. There may be more than one taxonomic class in an association, and therefore it is the members that are classified and not the association (see map, Vol. II).

The distortion due to photograph of terrain being taken with a high range of altitude, the soil boundaries have had to be plotted from the photograph.

**K. LABORATORY PROCEDURE**

Methods of physical and chemical analyses have been included in Appendix III.
1. Mineralogy

Clays were separated from selected samples to assess the degree of weathering of crystalline primary minerals and the formation of secondary clay minerals.

i) Preparation of samples - Soils were treated with hydrogen peroxide to destroy the organic matter. The samples were then deferrated using citrate dithionite. Separation of the clay, silt and sand fractions were carried out by centrifuging.

ii) Examination of samples - Samples of the various size fractions were treated as follows:
   a. Mg saturation with glycerol solvation at 20°C;
   b. K saturation at 20°C;
   c. K saturation heated to 350°C;
   d. K saturation heated to 550°C.

The saturated soil samples were mounted on porous plates approximately 3 cm² and dried before installation into the X-ray diffraction unit. The instrument used was a Phillips P.W. 1310 diffraction unit with an all vacuum tube, iron anode operating at divergence, receiving scatter slits at 1° and 0.1° and 0.01° respectively with an Mn filter.

2. Thin sections

The soils in this study had a very wide range of different forms of organic matter at varying stages of
development and decomposition. In order to understand and separate the various forms of organic matter thin sections were prepared and examined under a microscope.

i) Preparation of samples - Samples were air dried, impregnated with cold setting plastic resin, ground into thin sections (0.03 - 0.05 mm thick) and examined under a petrological microscope at between 44 - 200 magnification.

ii) Examination of material - The organic and mineral components were visually estimated according to Folk (1951). Colour was described using the Munsell scale viewed from a section in plain polarised light at a magnification of x 44 with a blue filter. The methods and terminology were according to Barratt (1965, 1971) and Kubiena (1953).

3. Soil monoliths

Monoliths were taken from soil profiles using standard techniques of adhesive material of vynal resin in an acetone solvent.
CHAPTER IV

THE PHYSICAL ENVIRONMENT OF TWIN STREAM CATCHMENT

A. CHARACTERISTICS OF THE CATCHMENT

The catchment is a transverse valley drained by the Twin Stream which rises in the North-East Ben Ohau Range. The stream is largely supplied by glacial and snowmelt water with peak discharge occurring during the early summer. In common with other regions of the Southern Alps there is widespread evidence of former glaciation manifested by ice eroded surfaces, and material associated with glacial deposition. A panoramic view of the area is indicated in Plate 4.

Physiographically the area is extremely complex and consists basically of a series of eroded recumbent folds (Lillie and Gunm, 1964), which have subsequently been modified by glacial erosion into three major cirques, Twin Stream Headwaters (see Plate 1), Twin Basin, Mount Mary Basin and a number of subsidiary cirques one of which has been named Pyramid Basin. Mount Mary Basin is really a small subsidiary catchment with its own small drainage system independent of the main catchment. The air photograph (Plate 1) of the area, which was taken in March 1968, is not representative of normal snow cover at this time of year, as large quantities of seasonal snow were still retained following the unprecedented November snowfall in November 1967. In reality perennial snow and ice cover a small part of the
catchment and are restricted to a number of cirque glaciers above the headwaters and in the uppermost parts of the Twin and Mount Mary Basins.

A topographic analysis of the catchment can be demonstrated by calculating the range of altitudes of the area. In Figure 7, this frequency has been calculated, using a square centimetre grid from a base line of 800 metres which is the altitude of the low level fans and terraces. The map used to extract the heights was one prepared by the Department of Lands and Survey at a scale of 1/15840. Figure 7 was compiled with the range of heights along the horizontal axis and the percent frequency along the vertical axis. Analysis of this figure shows that over 30% of the terrain is between 850 - 1,220 m. This represents part of the montane and upper subalpine zone. The range of altitude between 1,220 m and 2,140 m includes all the morainic surfaces of the three last glacial advances. The summit ridges of the highest part of the catchment are formed by surfaces at altitudes ranging from 2,140 m to 2,440 m.

An analysis of the total ground surface over which this study took place, shows that (Table 7) there is a considerable contrast between the cold and warm aspects, with nearly twice as much terrain occurring on the south and east aspects as compared to the north and west.

B. GEOLOGY

Some brief mention of the petrography of the rocks was made in the literature review (Lillie and Gunn, 1964).
Although the catchment consists broadly of greywacke, there is petrological diversification which will have some relationship to the relative rates of physical weathering of parent materials. In the eastern part of the catchment sedimentary deposits (Glentanner gravels) of lower Pleistocene age outcrop below the high structural benches. Large areas of these rocks have been overlain with moraine and glacial outwash deposits. In the main central block of the catchment, which includes Twin Basin, Mount Mary Basin and Pyramid Basin, low-rank metamorphic rocks of the chlorite sub-zone II occur, composed of fine-grained non-foliated schist, (Grindly et al, 1959). These rocks have been upthrusted against the sedimentary rocks along a north-south axis, in the mid-catchment. West of the basins in the headwaters of the Twin Stream undifferentiated greywackes occur. Texturally these rocks are coarse arkosic sandstones and contain a predominance of quartz and K-feldspar. Throughout both the schist and greywackes, frequent bands of argillite are found.

C. GEOMORPHOLOGY

1. Chronosequence of moraines

When the geographical limitations of the study were posed in the chapter devoted to methods, it was stated that the Ferintosh deposits on the lowest surface formed the altitudinal base-line of the study. As this surface has overridden some of the deposits of the older Birch
Hill surface a brief description of the latter is warranted in order to comprehend the form and distribution of the younger Ferintosh moraines and the distribution of the different surfaces. A simplified geomorphic map has been prepared (Figure 8).

i) The Birch Hill surface

The deposits forming this surface are the thickest and most extensive. McGregor considered that there were two sets of moraine, Birch Hill I, and a younger set, Birch Hill II which had the most massive moraines (see Plate 5). The altitudinal range of this surface is between 700 - 1,200 m. The moraines are well vegetated principally by snow-tussock (Chionochloa rigida). In Plate 5 one can see that the moraines of Birch Hill have been breached by former melt waters. In some places the moraine has been covered by subsequent fan deposits (Plate 5) emanated from Twin Basin.

ii) Ferintosh surface

This surface is well represented in Twin Basin, Mount Mary Basin and Pyramid Basin, forming the lower moranic deposits at the base of the three basins. The Ferintosh surface in the main Twin Stream Valley is not represented as it was probably destroyed by later glacial advances. In the Twin Basin the extensive southern aspect has been severely influenced
by cirque glaciers, and the Ferintosh moraines have been pushed to lower altitudes than in the other basins. Former ice fluctuations can be seen in the double moraine loop on the eastern side of the morainic terminus (Plate 6). The breached terminus drops to an altitude of 1,158 m. On the E.S.E. aspect of Pyramid Basin a massive moraine lobe has been formed (see Plate 7). The terminus is at an altitude of approximately 1,310 m. The sides of the moraine are steep and show little modification.

The deposits forming this surface on Mount Mary Basin are not so extensive as the former two, probably because cirque glaciers were not so vigorous on the warmer N.E. aspect. The termini of these deposits are found at an altitude of 1,219 m (see Plate 8).

iii) Jacks Stream surface

Remnants of morainic material deposited during Jacks Stream advance are well represented in Pyramid and Mount Mary Basins. In the Twins Basin, however, later glacial advances were very active and some of this surface has been subsequently overridden with ice. Some scattered deposits probably of Jacks Stream age are represented as moraines and outwash, sometimes containing former sites of kettle-holes. The range in altitude of this surface varies from
1,500 - 1,750 m. In Pyramid Basin, Jacks Stream surface, (Plate 9) consists of a series of small morainic lobes at an altitude ranging from 1,430 - 1,550 m which had probably been formed by small cirque glaciers thrusting from the S.E. wall of the basin. The regolith of the basin is highly permeable hence there is little evidence of surface modification attributable to flowing water. Deposits associated with Jacks Stream ice advance in the Mount Mary Basin, except for one locality, are difficult to correlate with the Jacks Stream formation because of an extensive ice eroded rock wall which separates the upper and lower basins (see Plate 10). Morainic loops probably associated with the Jacks Stream formation are found in the southern and northern ends of the basin at altitudes ranging from 1,700 - 1,750 m.

iv) Dun Fiunary

The youngest deposits, which consist largely of unweathered unvegetated moraine, are found throughout the catchment. The most extensive are those in the Twin Stream headwaters where valley glaciation has been the most active. These deposits cover a wide altitudinal range from about 1,350 m to over 1,800 m where recent deposits occur from glaciers which are at present in recession (see Plate 11). Similar
deposits are found in the other basins at altitudes ranging from 1,700 m to 1,900 m. Recent moraine deposits in Twin Basin are at present damming a small lake which forms a perennial supply of water to lower parts of the basin.

The age of the moraine surfaces has been tentatively considered by McGregor as Dun Fiunary and has been included in Table 6.

2. Geomorphic units

In order to avoid lengthy descriptions, the geomorphic units have been represented in diagrammatic form for the Twin Stream headwaters, Twin Basin, and Mount Mary Basin (Figures 9, 10 and 11). Pyramid Basin has not been included as it shows the least diversity of the various forms. The significant factors concerning these superficial deposits so far as soil forming processes are concerned, is that they determine the local topography and are the source of soil parent material. The distribution of this material bears some relationship to the various age surfaces which have been represented in Figures 9 - 11. The form and distribution of the geomorphic units have been summarised below:

i) Moraines

The various form of moraine termini indicate the extent of previous glacial advances over the last few thousand years. On the three
surfaces the particle sizes are very variable, ranging from large blocks to a high content of \(<\) 2 mm diameter. From 12 samples more than 60% (by volume) consisted of fines (\(<\) 2 mm). The plates that illustrate the moraines show that they are associated with a high degree of symmetry. On the up-slope side within the actual moraine lobe or loop the fabric before deposition was ice cored. Large quantities of fine particles were subsequently transported in suspension by melt waters, to the moraine fronts thus leaving the moraine fabric as large angular blocks which today form block fields contained within the walls of present day moraine. A cross section of this can be seen in Figure 10 at an altitude of 1,580 m at the junction of Jacks Stream surface.

ii) Glacio-fluvial deposits

These are associated with the outer parts of the moraines where the meltwaters have been the chief agency in the resorting and redistribution of till fabric. Such deposits are usually found on the foot and toe of the moranic slopes in the form of fans or aprons of partially sorted sediment, generally with a very high proportion of fines (\(<\) 2 mm). On the older Ferintosh surface it is difficult to differentiate between moranic and outwash deposits because of the vegetated cover. However, on
the younger Jacks Stream and Dun Fiunary surfaces extensive outwash deposits are found. Closely associated with outwash are lacustrine sediments deposited in kettle holes or small depressions where water has been ponded for a considerable time. These are characterised by a high proportion of fine sand and silt.

iii) Blockfields

These are usually found within a moraine loop, or isolated against a lateral moraine. The blocks can be exceptionally large, sometimes several metres across, and there is a general absence of fine material. In this area their origin is probably the result of being deposited from a melted ice core. Blockfields occur throughout the area. They are not so evident on the older Perintosh surface because of the colonisation by vegetation. The most extensive areas of this unit occur in close proximity to the recently deglaciated areas throughout the upper catchment, on the Dun Fiunary recent surfaces.

iv) Scree

These have originated through colluvial processes but today are stable and show some degree of colonisation by vegetation, either in a pioneer form of lichen or by higher forms of plants. The largest areas of scree are found in close proximity to the blockfields, and show a marked
degree of stability particularly on the shaded south and eastern aspects.

v) Colluvial deposits

These are graded into scree. They form the most extensive deposits attributed to colluvial processes (see Figures 9, 10 and 11). This term has been used to cover all material that shows some degree of inherent instability in response to gravity. Although this material is found on a wide range of sites the areas of inherent instability are generally found on the northern and western aspect. Accumulations of unstable rock fragments with a wide range of particle size grade from the eroding soils to form extensive sheets of coarser rock debris interspersed with soil pedestals. In Figure 12 an idealised diagram of the genesis of colluvial deposits indicates the wide range of material that occurs in such environments, with the evolution of the finer deposits in close proximity to the soil column grading down to the older eroded surfaces where most of the fine particles have been lost. It is in environments such as these where many of the present day concepts of New Zealand steepland soils have evolved in relation to wasting and rejuvenation processes.

vi) Stone pavements

These are found distributed along the flat to undulating ridges which form the dividing
lines between the basins. In some instances ice eroded pavements may have a capping of rock fragments. The stone pavements are invariably influenced by freeze-thaw processes, which are manifested by movement of stones and in extreme cases patterned grounds in the form of irregular polygons and stone stripes. Patterned ground in this area although widely distributed throughout a broad altitudinal range is not expressed in highly developed forms. The most common type occurs as irregular stone stripes frequently associated with colluvial deposits on sloping topography.

vii) Solifluction deposits

The most massive form of solifluction deposits attributed to cryoturbatic processes (freeze-thaw) are solifluction terraces. Two forms occur, the so-called stone-bank (Antevs, 1932) and turf bank as turf garlands (Tricart, 1970). Of the two forms the turf banked terraces are the most frequent and widely distributed. However, examples of stone banked terraces occur on Jacks Stream surface in Pyramid Basin. Colonisation by vegetation has been difficult because of the extreme coarseness of material forming the terrace.

Small poorly developed turf banked terraces are found on transition of slopes between Ferintosh and Jacks Stream surfaces.
D. CLIMATE

The variation of mountain climate is largely dependent upon aspect and altitude, and although it is obvious that north aspects are warmer and drier than southern ones it is important to determine by how much and to what extent do these factors influence the natural systems. In order therefore to characterise the climate throughout the study area the two elements of climate concentrated upon were temperature and moisture.

1. Temperature

Mean annual temperatures recorded during 1969-1972 within an altitudinal range from 850 m to 1,450 m have been indicated in Figure 13. These temperatures which were recorded on the E.S.E. aspect have a significant linear correlation, \( P < 0.05 \) with an environmental lapse rate (decrease in temperature with increase of altitude) of \( 2^\circ C \) per 300 m. This rate is higher than that suggested by Kidson's (1931) \( (2.7^\circ F \) per 1,000 ft) and is probably because of the cold air draining down slope and the lack of insolation on these shaded aspects. Garnier (1958) suggested that the lapse rates vary with both altitude and season and tend to be greater at higher altitudes.

A comparison between mean annual temperatures and Thornthwaites (1948) thermal efficiency index \( i = \frac{T-32}{4} \), (Table 8) shows a difference in temperature of \( 1.6^\circ C \) on the north and south aspects at 1,250 m. As Thornthwaite regarded the index of 16 as the transition between alpine
and subalpine zones this value will occur between the i values of 13.29, and 18.87 and will approximate at an altitude of 1,250 m.

This contrast in temperature on north and south aspects is further indicated in Table 9, of diurnal temperatures observed by Archer (1969). These temperatures were recorded 30 cm above ground surface on the two opposing aspects. If these temperatures are reduced to the winter and summer solstices and the equinoxial periods, a significant difference in the diurnal range exists between the two sites. These differences may be summarised as follows:

i) Throughout all seasons the mean diurnal temperature range is greatest on the north aspect.

ii) The greatest contrast in temperature range, between aspects occurs in the winter months, June and September. This indicates a vigorous freeze-thaw cycle.

iii) The lowest daily temperature range at ground surface on the south aspect is in September, because of the ground insulation from snow cover.

2. Precipitation

i) Rainfall

An analysis of rainfall appears in the section on evapotranspiration. However, at an altitude of 850 m over a four year period 1967-1970, an average of 1,780 mm was recorded.
Monitoring rainfall in mountainous terrain has many difficulties because of differential turbulence. Results of the altitudinal distribution of rainfall over a short period of time, December 1970 to May 1971, from two sites, the field station (850 m) and Pyramid Basin (1,840 m) are shown in Table 10. During this period 357 mm was recorded at 850 m and 689 mm at 1,480 m. Thus 93% more rain fell at the higher site.

ii) Seasonal snowfall

An early survey of the region showed that snow influenced many areas for over half the year and would probably have a strong effect upon such factors as the contribution of snowmelt to soil moisture and the surface and sub-surface temperatures. Snow studies were therefore considered from two main angles, the distribution and duration of the seasonal snowpack, and the period over which accumulation and ablation (melt, sublimation, evaporation) occurred.

a. Effect of distribution of snowpack on climate

To enable the evaluation of the relationship between temperature and snowpack, mean daily temperatures above freezing were calculated for air temperatures from instruments located in Pyramid Basin at
an altitude of 1,480 m during 1969-1971, and Figure 14 summarizes these relationships as follows:

(i) Winter temperatures are relatively high. Temperature was at freezing point only in 1971 during July and August.

(ii) As temperatures are above freezing for most of the time ablation of the snowpack will be relatively rapid.

(iii) A combination of low precipitation and high temperatures will naturally result in a lean snow year.

The trends of temperature and precipitation are substantiated in the altitudinal distribution of the snowpack (Figure 15). It will be seen that although snow fell to low levels in 1969 a combination of low precipitation and mild temperatures resulted in a short snow season at 1,480 m, as compared with the other years.

The altitudinal distribution of snow is indicated in snow water equivalents (Figure 16). Water equivalents have a positive linear regression, \( p < 0.05 \) with altitude. The rate of increase and annual variation are shown as follows:

- 1969: 6.6 cm w.e./100 m
- 1970: 9.2 cm w.e./100 m
- 1971: 15.0 cm w.e./100 m
b. Accumulation and ablation

Tables 11 and 12 summarise net accumulation and ablation with regards to the number of days at various altitudes when either net accumulation or net ablation were recorded, the water equivalent and the daily rates of increase and decrease with increasing altitude. These tables indicate that Ben Ohau area is characterised by:

(i) A gradual accumulation period followed by rapid ablation.

(ii) Some variations in snow season with a lean snow year in 1969, and a more protracted one in 1971.

(iii) Parts of the eastern aspect are under snow cover for 30% - 50% of the year.

3. Freeze-thaw cycles

Although the relationship between mean annual temperatures and altitude has been considered, they only express a small fraction of the influence of temperatures upon pedogenesis. Freeze-thaw cycles have been compiled from three localities, with E.S.E. and S.E. aspects at altitudes ranging from 850 - 1,550 m (Table 13) during 1971. These records were made above the surface of the snow, and as deep snow was recorded at the 1,550 m station, recording heights fluctuated between 30 - 180 cm.

Table 13 may be summarised as follows:
i) Ice days increase with altitude

ii) A relatively severe frost climate at 1,550 m station with about 30% of the year frost free.

iii) 1971 was a mild summer and this is reflected in frost free periods at the 850 m station in January - March

iv) The greatest contrast in seasonality, (difference between winter and summer freeze-thaw cycles) is at the 1,550 m station.

4. Wind

In order to obtain information on the influence of wind in the catchment anemometers were sited at two localities, 850 m and 1,480 m. It subsequently proved that the 850 m site was severely affected by a narrow valley which constricted wind thereby increasing velocity. Hence the comparison in altitude of wind force is a negative one. However, Figure 17 and Table 14 give some indication of the force and direction of winds in the area:

i) The highest velocities occurred during the spring equinox.

ii) The different velocities recorded during the two summers suggest a marked variation in windiness from one year to the next.

iii) The high incidence of N.W. winds, which are relatively warm and consistent, particularly in 1972 suggest that this climatic variable has a strong influence upon evapotranspiration.
5. Soil temperatures

i) Seasonal changes of temperature

In Figure 18 the trends of mean daily temperatures are shown at two soil depths, 30 cm and 90 cm, over a two year period at an altitude of 850 m. The mean values at the two depths compare favourably with those recorded by Morris (1965), at Camp Stream and those of Cass by Greenland (1971). However, the fall in temperature in March of the 30 cm depth relative to 90 cm depth occurs two months earlier than that recorded by Greenland and is probably because these temperatures were typical of a more easterly aspect as compared with the Cass records which were taken on a N.E. aspect.

ii) Aspect

The trends in soil temperature at various depths is influenced by snow cover. For example, in Figure 19 mean monthly temperatures are indicated by isotherms ranging in depth from ground surface to -10 cm depth. The distribution of the isotherms on the two opposing aspects, 1250 S, and 1250 N show an extended cold period on the south aspect with sub-zero temperatures during the three coldest months, June to August. On the north aspect the more intense insolation reduces the cold period to one month, namely July when sub-zero temperatures existed throughout
the vertical range of the profile. The ground surface heating throughout the year, particularly in summer is greater on the northern aspect. On the north aspect mean daily temperatures of 18°C occurred during January and February as opposed to 15°C and 13°C on the south aspect. The temperature régime of one of the coldest sites is indicated at 1,550 m on a S.E. aspect, (Figure 19). Snow lies until December, subsurface temperatures are below freezing for over six months of the year.

The comparison of the seasonal trends between aspects has been shown in Table 15 tends to stress the range of temperatures which will influence pedogenesis within a range of aspects.

iii) Freeze-thaw cycles

A considerable amount of material has been produced devoted to studies concerning mass movement of soils incurred through freeze-thaw processes (Gradwell, 1954, 1955, 1957; Owen, 1967; Haywood, 1969; Greenland, 1969; Soons and Greenland, 1970). Various authorities concur that soil creep is a complex process associated with freeze-thaw phenomena, available moisture, drying and wetting cycles and colluviation, etc. In order therefore to complete the pattern of soil temperatures freeze-thaw cycles have been calculated from available data to give some indication as to the degree of variation of
freeze-thaw phenomena, particularly as related to aspect. Freeze-thaw cycles were compiled from three sites, two from colder south and east aspects and one from a warmer north-east aspect. The results may be summarised as follows (Figure 20):

a. Ice days, (temperature at freezing or below during 24 hour period) the 1,550 m (S.E.) site has the highest percentage of ice days. The other two sites have lower values.

b. Frost free period - 28% of year was frost free at the 1,550 m (S.E.) site. The other sites have higher values.

c. Frost alternate (freeze-thaw) during 24 hour period at the 1,550 m (S.E.) site are slightly higher than the other sites.

Records of freeze-thaw cycles at -10 cm depth of soil at an altitude of 1,590 m have been compiled by Mark and Bliss (1970) on the Old Man Range of Central Otago. The most significant difference between the two study areas is that above ground surface in Central Otago over 20 percent of frost alternate days were recorded which is well in excess of those recorded in the Ben Ohau Range. This suggests that the frost climate in Central Otago is more conducive for the formation of frost patterned ground, which
has been supported by evidence from Mark and Bliss.

6. Water budget

i) Above ground surface

In an attempt to assess some of the features of moisture relationships which would influence soil forming factors four years of record (Table 16) were used to compile water budget on basis of Thornthwaite's rational classification. During this period the mean annual temperature was 8.1°C and the mean annual precipitation was 1,785 mm at an altitude of 850 m. The water budget therefore applies to the lower part of the catchment. According to Table 16 and Figure 21 potential evapotranspiration and water surplus values indicate that during eleven months of the year there is an abundance of moisture, and no moisture stress within the biological systems. Although the water budget in January indicates a moisture need (P.E. in excess of precipitation) according to Thornthwaite the soil water surplus carried over from the previous month would be available to plants. From such a moisture régime one would assume that the high country yellow-brown earth soils in this area would be above field capacity throughout the year. However, before one considers soil moisture status critically through experimentation, it would be well to compare the empirically based
moisture index of Table 16 with values recorded over a short period of time from actual measurements. During the four year period from which records were used to compile Table 16, precipitation and evaporation over fifteen months (October 1968 - December 1969) were also recorded. These records which have been summarised in Table 17 were taken from Archer and Collett (1971). Although precipitation was relatively high and constant, evaporation was in excess of precipitation during four months of this period. This would suggest that in some of the coarser textured soils of low water holding capacity on the northern aspects moisture constants could fall below field capacity at certain times of the year in surface horizons.

ii) Aspect

In order to ascertain the order of evapotranspiration on different aspects of the higher altitudes a number of Piche atmometers were located on several aspects. Evaporation was recorded daily and also hourly over specified time periods. The measurements were then converted to raised tank evaporimeters by a factor of 0.64 and then to potential evapotranspiration using Penman's factor of 0.55. Table 18 summarises the results throughout the sites in terms of a ratio of precipitation to potential evapotranspiration. It will be noted that at ground
surface on the 1,560 m (S.E.) site precipitation was 3.1 greater than potential evapotranspiration whilst on the north aspect it was approximately equal. At one metre above ground surface a moisture deficit is recorded. This could be related to the greater turbulence above the surface. Geiger (1965, page 273) noted the differential effects of wave motion close to ground surface that effected evaporation from both vegetative and soil surfaces.

More intensive measurements were made over an hourly period during warm northerly weather in January 1971. These measurements were again converted to potential evapotranspiration values. Figure 22 demonstrates the marked contrast in potential evapotranspiration between aspects. Thus at both the 1 m height and ground surface the P.E. is the greater on the north aspect than on the south and east aspects. It should be noted that the 1,520 m S.E. site had a P.E. which is associated with little daily variation ranging from 0.21 mm to 0.39 mm as opposed to the daily range on the northern sites which are two to three times greater (Figure 22).

7. The energy status of the soil

The major problem limiting studies of soil energy is in most cases total lack of both biological and physical parameters associated with soil development.
With this problem in mind, one can visualize that soil as part of the natural system can be studied from two levels. In the first instance soil formation can be studied with regard to exchange of substance between the soil and other components of the natural environment and the transformation of substances in the soil. Secondly, soil formation can be studied with regards to the input and output of energy.

Volobuyev (1961) presented the energy balance of soil formation as follows:

\[ Q = W_1 + W_2 + b_1 + b_2 + e_1 + e_2 + g + v \]

where \( Q \) = amount of incoming energy

\( W_1 \) = amount of energy spent in physical destruction of parent rocks

\( W_2 \) = amount of energy spent in chemical decomposition of parent rocks

\( b_1 \) = energy spent in biological transformation reactions of organic and mineral substances

\( b_2 \) = energy accumulated in organic substances

\( e_1 \) = energy spent in evaporation from the surface of soil and plants

\( e_2 \) = energy spent in transpiration

\( g \) = energy lost in mechanical migration of salts and soil particles in soil

\( v \) = energy spent in the heat exchange in the soil atmosphere.

In this study the data are not available to quantify input and output of energy of the various factors in Volobuyev's equation. Records, however, exist which will
enable one to establish a number of rational indices which indicate the probable magnitude of the various processes operating within the system. These indices tend to relate to the $b_1$, $b_2$ and $g$ factors of the Volobuyev equation as they refer to growth, soil organic matter decomposition, soil organic matter content and leaching. These indices were compiled from methods which were originated by Papadakis (1961).

i) Water balance

An essential component in the formulation of Papadakis's biological and pedological indices was the calculation of a humidity coefficient. The methods used by Papadakis were based on monthly precipitation values, and saturation deficits. The saturation deficit can be defined as the difference in actual vapour pressure and the maximum vapour pressure at the prevailing temperature. It is a useful factor as it assesses the capacity of air for additional moisture retention. It has been frequently used for ecological purposes in considering the moisture status of the atmosphere (Meyer, 1962; Jenny, 1941; Prescott, 1938, 1949). In the four tables presented, Tables 19 to 22, humidity coefficients have been calculated from precipitation and saturation deficit based over a period of four years (1968-1972). During this period the most consistent precipitation records were
obtained from the 850 m S.E. aspect station. At the 1,200 m north and south sites it was difficult to obtain reliable precipitation records due to excessive exposure to high winds. The highest site (1,550 m S.E.) recorded over 50% of the total precipitation as snow. Due to the high rates of ablation between sampling periods, net accumulation therefore only records a fraction of the total precipitation. Hence precipitation records shown in Table 22 have been estimated and are only approximate.

Water need serves as a basis for the estimation of water for irrigation and approximates to the evaporation of water from a free water surface at soil level. Water need is compiled by multiplying saturation deficit by 20. The humidity coefficient is the quotient precipitation/water need. Water in excess of potential evapotranspiration would be recorded as water stored. Papadakis calculated this water budget for agricultural soils, hence although he assumed that stored water cannot be negative and cannot exceed 100 mm (4 inches), in the mountain soil of this study, water storage could be much less in the skellic soils and considerably more in the organic soils. Papadakis regarded normal leaching rainfall as an index of drainage, but soil leaching depended on the maximum leaching in a series of years, and was therefore based
on the summation of monthly values of rainfall x 2 evapotranspiration.

Saturation deficits become increasingly smaller with increase in altitude, whilst the humidity coefficients become increasingly greater; lower saturation deficits are also recorded on the south aspects as opposed to the north aspects. Similarly with a steep rise in precipitation with altitude, there will also be an increase of the maximum leaching rainfall.

ii) Growth index

Accumulation of plant organic matter is closely related to temperature and humidity. At 0°C and zero humidity photosynthesis is zero. Photosynthesis increases with the rise of both temperature and humidity. However, above a certain point further increases in these factors leads to a reduction in photosynthesis. In contrast respiration increases continuously with the rise in temperature and is only affected by very low humidities. Consequently, the optimum temperature for growth hardly increases beyond 25°C and is often lower under conditions of low humidity.

Papadakis formulated a growth index which is related to temperature, humidity and day length:

\[ A' = \frac{h}{12} \frac{8H^2T^2}{(1 + 4H^2)(20^2 + T^2) + 10^{-6}(1 + 2H)T^6} \]
where

\[ 'A' = \text{growth index} \]
\[ h = \text{the duration of day in hours} \]
\[ H = \text{the humidity coefficient of the month} \]
\[ T = \text{the temperature } ^\circ\text{C}. \]

The growth index \( 'A' \) is very low for temperatures below 4\(^\circ\)C and increases gradually above this temperature. Maximum growth occurs at a humidity coefficient of 0.3 and a temperature of 20\(^\circ\)C.

The four Tables 23 to 26 indicate the growth index for each of the four stations. The two columns \( A \) (provisory) and \( h/12 \) are obtained from tables included in Appendix IV. \( 'A' \) is the product of \( A \) (provisory) and \( h/12 \). As one would expect the growth index is least at the highest altitude by as much as 0.18 compared with the lowest station. On the northern aspect the index is greater by 0.02 compared with the index on the southern aspect.

iii) Humolytic and humogenic indices

Volobuyev's equation which referred to the two factors, \( b_1 \) and \( b_2 \) relating to the biological transformations in the soil although difficult to quantify in the field can be equated with empirical indices based on temperature and moisture. These indices although approximate do indicate the degree of biological interactions that are operating spatially throughout complex terrain which characterises mountain soils.
Jenny (1941) considered that soil organic matter decreased 2 to 3 times for every rise of 10°C in the mean annual temperature. Papadakis regarded the relationship between organic matter decay and temperature as exponential. On this basis he calculated a humolytic index (climatic index of soil organic matter decay) based on the following formula:

$$H_1 = e^{ct_1} + e^{ct_2} + 2e^{ct_3}$$

where

- $H_1 =$ humolytic index
- $t_1 =$ temperature, °C, for the warmest month
- $t_2 =$ temperature, °C, for the coldest month
- $t_3 =$ mean annual temperature.

The tables of $e^{ct}$ values have been included in Appendix IV.

In contrast to the humolytic index, Papadakis compiled a climatic index of soil organic matter content (Humogenic Index). This he calculated by dividing the square root of the climatic growth index by the humolytic index:

$$\frac{\sqrt{150A}}{H_1}$$

where

- $H_g =$ humogenic index
- $A =$ growth index
- $H_1 =$ humolytic index

On the basis of the humidity coefficients and growth index that have been presented in Tables 23 to 26, the humogenic/humolytic indices were calculated for the same sites, from Papadakis's formula.
a. S.E. aspect, 850 m site

\[ H_l = (7.4) + (0.9) + 2(2.9) = 14.1 \]

\[
\begin{align*}
H_g &= \frac{150\sqrt{A}}{H_l} \\
&= \frac{150 \sqrt{0.34}}{14.1} = 6.20
\end{align*}
\]

\[
\begin{array}{ccc}
H_g & H_l & H_g/H_l \\
6.20 & 14.1 & 0.439
\end{array}
\]

b. North aspect, 1,200 m site

\[ H_l = (5.7) + (1.0) + 2(2.1) = 10.9 \]

\[
\begin{align*}
H_g &= \frac{150\sqrt{A}}{H_l} \\
&= \frac{150 \sqrt{0.22}}{10.9} = 6.45
\end{align*}
\]

\[
\begin{array}{ccc}
H_g & H_l & H_g/H_l \\
6.45 & 10.9 & 0.591
\end{array}
\]

c. South aspect, 1,200 m site

\[ H_l = (4.9) + (0.7) + 2(1.9) = 9.4 \]

\[
\begin{align*}
H_g &= \frac{150\sqrt{A}}{H_l} \\
&= \frac{150 \sqrt{0.18}}{9.4} = 6.76
\end{align*}
\]

\[
\begin{array}{ccc}
H_g & H_l & H_g/H_l \\
6.76 & 9.4 & 0.719
\end{array}
\]

d. S.E. aspect, 1,550 m site

\[ H_l = (4.0) + (0.6) + 2(1.5) = 7.6 \]

\[
\begin{align*}
H_g &= \frac{150\sqrt{A}}{H_l} \\
&= \frac{150 \sqrt{0.14}}{7.6} = 7.38
\end{align*}
\]

\[
\begin{array}{ccc}
H_g & H_l & H_g/H_l \\
7.38 & 7.6 & 0.971
\end{array}
\]
In Figure 23 the humogenic, humolytic index has been plotted against altitude to indicate the contrast between the index on the north and south aspects. From 850 m to 1,200 m on the north aspect the index increases by 0.152, whilst on the south aspect the index is nearly doubled to 0.280. This suggests that the biological transformations within the energy systems are strongly affected by the interaction between aspect and altitude, hence the influence of altitude upon the energy status of the soils may be offset by aspect differences.

iv) Summary of energy status of the soil

a. Within the prescribed altitudinal limits, there is an increase in the humidity coefficient and normal leaching index with altitude.

b. These indices are higher on the southern than on the northern aspects.

c. There is a strong interaction between aspect and altitude with growth index.

d. There is an increase of the humogenic/humolytic index with altitude, which
suggests that mineralization and organic matter turnover will be slower at higher altitudes and on colder south and east aspects.
CHAPTER V
SOIL CLASSIFICATION

A. CRITERIA FOR CLASSIFICATION

The classification of mountain soils in New Zealand is beset with problems from the outset due primarily to the sparsity of both environmental and pedological data. The high degree of variability and the very strong influences of environment upon the soils require the stipulation of a number of criteria which indicates the type of process under which soils have developed and are being influenced during the present day.

The New Zealand Technical Classification (Taylor and Pohlen, 1962) is based on a series of qualitative soil parameters from which the general basal form concept has evolved. Subdivision which occurs at a high level is not solely determined upon morphological criteria but rather upon soil forming factors which are related to an energy régime. This classification has been influenced by a number of concepts which have originated from early studies of steepland mountain soils in the drier sub-humid to humid regions of the eastern coastal ranges. These may be summarised as follows:

i) Steepland soils in general were regarded as unstable and were subjected mainly to a drift régime with periodic rejuvenation through colluvial processes.

ii) The influence of moisture in soil genesis of steepland soils was not considered.
iii) The soils of the alpine zone were regarded as skeletal, having little profile differentiation.

iv) The term gelic was briefly referred to, and regarded as a subdivision of the skelic soils. They were defined as formed on a surface bare of insulating vegetation. Frost lift ensured that the finer particles would be redistributed and dispersed by wind action.

The soils in this project have been broadly classified according to Table 27. Three basal forms (Category I) are recognised and are further subdivided. In Category II the skeliform and organiform soils occur mainly in the alpine zone and therefore have the ele prefix. The fulviform soils have a wider altitudinal distribution and occur in both the subalpine (elde, prefix) and alpine zone. Because of the diversity of the soil forming factors there is some degree of variability in each class of the soils forming Category III. Sub-classes of some of the soils forming Category III can be clearly defined morphologically, physically and chemically. Spacially, however, they form a mosaic of continuous variation, the boundaries of which are sometimes poorly defined. Consequently soils represented by modal profiles are frequently small in area. Because of the interaction of soil forming factors intergrades cover larger areas of terrain than do modal groups.

The soils of this study have been classified according to the New Zealand Technical Classification. However, an
attempt has been made to define the categories and classes on the basis of morphological criteria using diagnostic horizons and other pedologic criteria. This enables the soils to be described in objective pedological terms. The causative relationship of soil forming factors to soil morphology can thus be considered as a separate, though related exercise in soil genesis.

B. CLASSIFICATION OF ORGANIC MATTER

Particular attention has been given to the organic matter component of the soil profile, as in the high altitude soils the organic horizon is an important diagnostic factor in differentiating between groups of soils, and intergrades. The nature of the organic matter is also a good indicator of the immediate environment under which soil formation has taken place. The classification has followed Kūbihia (1953 and 1969) and Barratt (1965 and 1971). The basis for classification is the degree of decomposition of the organic matter and the extent of its incorporation with mineral particles. In this region soil organic matter has been formed in part from woody material with a high lignin and fibre content, and also from herbaceous matter which has a varying content of woody and fibrous tissues.

Barratt (1971) divided the soil materials into five main classes, two skeletal and three plasmic as follows:

Skeletal materials
i) Humiskel: organic residues that are undecomposed or chemically preserved.

ii) Lithiskel: mineral grains and rock fragments.
Plasmic materials

i) Humicol: strongly humified organic residues of colloidal size.

ii) Mullicol: strongly humified organic residues of colloidal size and clay colloids mixed or associated.


In Plates 12 and 13 the microfabrics of the main forms of organic material forming the organic and A horizons have been illustrated in a series of microphotographs.

Plate 12A - Profile reference: MB6

Horizon: 0  Depth: 0 - 2 cm
Vegetation: Predominantly *Celmisia lyallii*

This is largely of organic material with 1% of surface area angular to subangular fine to medium grains of muscovite. Organic debris covers over 80% of the estimated field, consists mainly of ligno-parenchymal humiskel comprised of fibrous and parenchymal tissue of *Celmisia lyallii* foliage.

Classification: Ligno-parenchymal humiskel.

Remarks: The genus *Celmisia* appears to be resistant to decay and forms an acid moroid 0 horizon.

Organic horizons can contain the characteristic litter, fermentation and humus layers of the moroid organic material. (Acid raw humus, Kubienska, 1953)
Plate 12B - Profile reference: MB2

Horizon: A  Depth: 0 – 2 cm

Vegetation: Marsippospermum gracile

Highly porous material with over 20% (area) medium sized angular to subangular mica grains. Organic components consist of a humiskel of highly fragmented undecomposed ligno-parenchymal tissue with some isolated areas of decomposed organic material and a few faecal pellets.

Classification: Humiskel-lithiskel complex with some humicol.

 Remarks: Plant material was relatively easy to decompose. The soil is younger and the organic matter less acid, than Celmisia material. No formation of litter layer. Frequently referred to as silicate moder (Kübiena, 1953).

The next three microphotographs refer to a shallow peat profile characteristic of soils formed under a high moisture régime on extreme south aspects.

Plate 12C - Profile reference: TW19

Horizon: 0  Depth: 0 – 2 cm

Vegetation: Prostrate shrub (Dracophyllum, Coprosma, etc) and grasses.

1-5% (area) angular to subangular grains of fresh micaceous material, with over 90% (area) of predominantly undecomposed coarse fragments of ligno-parenchymal tissue.
Classification: Ligno-parenchymal humiskel
(Raw humus, Kūbiiena).

Plate 13A - Profile reference: TW19
Horizon: 0 Depth: 10 cm

Between 20% - 30% (area) of micaceous material of partially weathered subangular to angular grains. Organic material consists of decomposed organic material forming a diffused humicol with a few faecal pellets and some widely scattered fragments of undecomposed plant residues.

Classification: Humicol-lithiskel complex

Plate 13B - Profile reference: TW19
Horizon: 0 Depth: 25 cm

A highly porous mineral skeleton of 10% - 20% (area) angular to subangular grains of micaceous minerals with a < 1% subangular grains of feldspar, with a colloidal groundmass of decomposed organic material with signs of a platy orientation, with some scattered fragments of humiskel.

Classification: Platy humicol
Remarks: This material is typical of amorphous peaty material formed at high altitudes under a high moisture régime on shaded aspects.

Plate 13C - Profile reference: MB11
Horizon: A\textsubscript{1} Depth: 8 cm
Vegetation: Chionochloa rigida grassland.
Mineral skeleton consists of a number of medium sized grains of weathered muscovite situated within a fine ground mass of micaceous minerals and <1% feldspar. A yellowish brown isotropic groundmass of plasmic material consisting of partially decomposed leaf tissue, seed coats and epidermal cells. A few widely scattered faecal pellets.

Classification: The degree of decomposition and the association of mineral and organic matter suggests a humicol-lithiskel complex with some mullicol.


Plate 13D - Profile reference: TW9
Horizon: B₁ Depth: 30 cm
Vegetation: Grasslands with low shrubs

A mineral skeleton of fine to medium sized partially weathered micaceous minerals associated with a colloidal groundmass of well decomposed organic material. Some streaks of amorphous ferric hydroxide and some scattered fragments of humiskel.

Classification: Humicol-mullicol complex with some lithiskel.

Plate 13E - Profile reference: TW20
Horizon: 0 Depth: 3 cm
Vegetation: Bryophyte flush
Mineral skeleton consists of a few widely scattered micaceous grains. A colloidal groundmass of well decomposed algal and higher plant residues with some undecomposed fragmented leaf parenchymal and epidermal tissues and some widely distributed faecal pellets.

Classification: Hanging Anmoor (Kübierna)

The microphotographs in Plates 12 and 13 cover a complete range of the organic forms found within the area of study. These forms can be grouped in a series related to soil moisture decreasing water régime as follows:

1. Semi-terrestrial conditions

These conditions are of frequent occurrence in alpine regions subject to prolonged winter snow cover, followed by seasonal snowmelt during spring and summer. Soils are saturated throughout the year.

i) Hanging anmoor, generally a eutrophic environment related to constant flushing and rejuvenation with fresh mineral material.

ii) Humiskel, with platy humicol, (raw humus, dystrophic peat, Kübierna) characteristic of slow decomposition and accumulation of organic material in the soil. Formed on the colder south aspects under conditions of prolonged winter snow and summer snowmelt.
2. Terrestrial conditions

i) Ligno-parenchymal humiskel (Raw humus, Kübiena) -
Typical of the moister colder soils subject to
lower temperatures and reduced evapotranspira-
tion of the south aspect under the influence
of leaching from snowmelt and rainfall, and a
hydrous moisture régime (soil above field capa-
city throughout the year).

ii) Humiskel, lithiskel complex (Silicate moder,
Kübiena) - Formed on the younger less leached
soils. Contains 'browned' plant fragments,
faunal droppings and a high content of loose
noncoherent mineral particles.

iii) Humicol lithiskel complex with some mullicol
(Mull, Kübiena) - Found typically on soils on
the drier warmer sites where the soils are
free draining and are associated with grassland
and herbaceous vegetation. Organic decomposi-
tion is more complete and a high degree of
incorporation with weathered mineral material.
Soil moisture régime usually hygrous (short
period in which soils are below field capacity).

C. DIAGNOSTIC HORIZONS

In nature soils occur as a continuum in which variations
occur along a gradient of continuous change. The only
way that those changes can be measured is through the soil
horizon. The recognition of basic characteristics, of
the soil horizon in the field is vital as one assumes a covariance of chemical mineralogical and physical properties with morphology that enables one to interpret the changes taking place along the soil continuum. Several systems of soil classification, 7th Approximation (1960); Soil Survey Staff (1967); Food and Agricultural Organisation (1968); Soils of the Tugela Basin (1969) and Fitzpatrick (1971), have focused attention upon the horizon through a number of diagnostic criteria. These criteria consist of a number of profile characteristics which when grouped together facilitate the isolation of a number of horizons with similar properties. The establishment of a number of diagnostic horizons enables one to readily recognise horizons as they intergrade laterally and vertically.

In the study of mountain soils where there is a high degree of variability, a similar approach has been used and a number of delineating factors have been selected in order to isolate several diagnostic horizons and layers to characterise the soil.

1. Peaty organic horizons (semi-terrestrial soil)

All organic accumulations either overlying mineral soil in basins or as buried layers, are dominated by organic matter in some textural forms.

i) Overlies gley or saturated regolith.

ii) Organic matter content 20% with clay content less than 5% of mineral fraction.

iii) Associated with high water table and saturated with water for all or part of the time, or
continuous or periodic flushing by water (on slopes).

iv) Formed from residues of hygrophilic plants, in situ, or from accumulation of organic material with sediments in water (limnic deposits).

The peaty organic horizons can be differentiated into two classes: lodic and platic.

1(a). Lodic

This term has been adapted from Taylor and Pohlen (1962). The term has been derived from lodix a rug or blanket.

i) Organic matter > 20%

ii) Upper part of horizon dominated by undecomposed plant fragments. Plant tissue recognisable in hand.

iii) Some decomposition with depth, material peaty, greasy to feel, black to very dark brown in colour.

iv) Usually formed on gently undulating terrain.

1(b). Platic - Adapted from Taylor and Pohlen (1962)

i) Shallow peaty material found in former sites of kettle-holes and tarns.

ii) Frequently bands or lenses of silt and fine sand with organic material interlayered.
iii) Peaty amorphous material greasy to feel, black to dark brown.

The platic soils have been separated into two phases to denote varying degrees of nutrient enrichment, dystric and eutric.

a. Dystric phase

Dystric term has been derived from the Greek dys, ill, dystrophic, infertile (see Kubiena, 1953, page 294), and can be recognised from the following:

(i) Acid peaty soils associated with the organic material forming the soils of the older colonised lacustrine sediments.

(ii) pH < 5.0 with a base saturation of between 0 - 15%.

(iii) Very dark brown to black. Older humified material greasy to feel.

(iv) Typical of peat formed from Oreobolus and Sphagnum communities.

b. Eutric phase

The term eutric is derived from the Greek eu, good, eutrophic, fertile, and can be recognised from the following:

(i) Typical of flushed sites and springlines across the lower slopes.

(ii) Associated with organic material formed from the moss genus Philonotis and higher plants of Scirpus, Carex and Schoenus species.
(iii) Thick cohesive turf, dark brown with recognisable organic remains overlying gleyed layers.

(iv) Base saturation 15% with a pH >4.5.

(v) Organic material referred to as hanging anmoor (Kubiena, 1953).

2. Organic matter of terrestrial soils

Thin sections of the forms of organic matter have been discussed in previous sections. As diagnostic terms Kubiena's terminology has been adopted.

2(a). Moroid organic horizon

i) Usually characterised by three layers related to varying degrees of decomposition, litter layer, F-layer and often weakly developed H-layer. Increasing humification down the horizon.

ii) Forms a sharp boundary with the mineral soil.

iii) Acid

iv) Causes eluviation of mineral colloids through the formation of acid humus sols.

v) Well aerated, free draining.

3. Diagnostic A horizons

i) Raw A

The concept of the Raw A (Kubiena, 1953) refers to immature A horizons which are generally low in organic material. This horizon is diagnostic
of the immature skelliform soils. They may represent the earliest stages of soil formation in which organic material is in the initial stages of being incorporated into the profile or latter stages of soil development in which extreme cases of erosion have removed a large part of the organic material leaving a residue of coarse mineral fragments intermingling with what is left of the organic material.

a. A discrete mixture of unweathered fragments and mineral matter with partially humified or undecomposed organic material.

b. Does not occur over a cambic horizon, except in the case of composite soils.

c. Low in organic matter (0 - 5%)

d. Texturally coarse with low clay content.

e. Horizons diagnostic of soils which are either associated with scattered pioneer herbs, cushion plants and bryophytes or on older surfaces where soils have been eroded and secondary stages of plant succession have commenced colonisation.

f. Occurs on outwash alluvium, colluvium and moraines.

ii) Humic A horizon

This horizon results from the progressive accumulation and humification of organic matter.
It is associated with an active organic régime such as occurs with the hydromorphic soils in a high moisture régime. Diagnostic characteristics are as follows:

a. It is typical of soils with a well developed organic horizon in which some humification results in the production of silicate moder and formation of humic horizon.

b. Can occur in both O/A/C and O/A/B/C soils. In each case the organic and/or humic A horizons are clearly demarcated overlying either the B or C horizon.

c. Organic matter between 5 - 20%.

d. pH < 5.0

e. Colours usually dark brown to very dark brown.

f. Transition of the O horizon (if present) to the humic A is gradual and can be diffuse.

g. A hand lens aids in identification of humification of the organic material in contrast to total plant remains of the organic and A horizons.

h. Associated particularly with the lodi-elegelic, humi-eleclinic and fulvic intergrades.
iii) Umbric A

This term has been adapted from the 7th Approximation. The genesis of this horizon from the former humic A is one of progressive melanization and is marked by an absence of an organic horizon, and a transition from the moder-silicate humus to a mulloid form. Hence this horizon is typical of the elefulvic and eldefulvic soils which are associated with more mesomorphic conditions.

This horizon can be recognised by the following:

   a. Humus form mulloid, organic material humified and incorporated with mineral matter (melanized).

   b. This horizon frequently found with composite soils, hence buried, umbric A horizons are common.

   c. Horizons are greater in depth by 1/3 of total profile.

   d. Base saturation < 50%

   e. Colour values 5.5

4. Diagnostic B horizons

The diagnostic B horizons may also be arranged in order of progressive development commencing with the thin immature horizon which mark the transition from the skelliform to the fulviform soils to the more high differentiated B horizons associated with typical fulviform soils.
i) Incipient (1) (B)

The diagnostic characters are as follows:

a. The fabric of original parent material still evident being unweathered and low in colloidal material.

b. B horizon 1/3 of solum.

c. Maximum thickness 10 cm.

d. Where > 5% mottles, the horizon is designated as mottled incipient (B).

ii) Cambic B (derived from the Latin cambiare)

The term has been adopted from the 7th Approximation. This horizon tends to be diagnostic of the mesomorphic soils typical of the elefulvic and eldefulvic group. The chief diagnostic criteria are as follows:

a. A crumb or fine nut structure.

b. Alterations reflected by stronger chroma and redder hues than the underlying horizon.

c. Thickness > 10 cm.

d. Greater proportion of colloidal and fine particles compared to the incipient (B) horizon.

e. Friable, no cementation or induration.

(1) If lithi contact occurs close to solum in a strong leaching environment, a deposition of iron hydroxide and organic material may be found. This can be distinguished mainly by colour, with hue ranging from 10YR - 5YR, values<5 and chroma>4.
f. Little evidence of illuviation.

g. Where $>5\%$ mottles occur referred to as a mottled cambic B.

5. Diagnostic gleyic horizons

Gleying is an important process in mountain soils, and is frequently a feature associated with the hydrous soils. This horizon is diagnostic of the madentic soils and intergrades and can be recognised as follows:

i) Colour light grey to grey.

ii) Red to red brown mottles may be present.

iii) High proportion of silts and fine sands in fine fractions.

iv) Associated with a high moisture régime.

v) Water conditions saturated throughout year.

6. Diagnostic C horizons

This horizon which forms the basic material from which the soils are formed is largely characterised by a fabric containing a wide range of particle sizes varying from coarse angular fragments to a fine fraction ($<2\text{mm}$) dominated by silts and sands. As there is often an abundance of water available in this environment resorting of this diverse material will occur to form a distinct horizon which can be differentiated mainly on the basis of texture:

i) Lithic C

a. Dominantly coarse textured horizon of unsorted material with a very wide range of particle sizes.
b. Colours similar to parent materials.

c. Lack of chemical weathering, mineral grains clean and lack colloidal or oxide coatings.

d. Associated with morainic, glacio-fluvial and colluvial deposits.

ii) Regic C

a. Finer textured horizon formed of sands and silts of resort ed material.

b. Localised areas of fine outwash material, where the deposition from suspension of the fine particles has taken place from melt waters.

7. Other diagnostic criteria

i) Fragmental layers

These layers occur within the solum. They are not true horizons but represent periodic deposition or removal of material. They are important to recognise as they are indicative of periods of former instability. They are recognised through:

a. A coarse texture stone line which may occur either in the A or B horizon.

b. Coarser than horizon above or below.

ii) Alluvial layers

These are also quite distinct layers formed in the solum. Unlike the former fragmental layers however they are fine textured representing material deposited in suspension from melt
waters. The layers are recognised as:

a. Distinct bands of mineral material frequently alternating with organic layers.

b. Layers may occur overlying buried soils.

iii) Pedoturbic features

This feature is diagnostic of the gelic soils and has been considered in chapter dealing with the physical environment.

a. Mixing of organic material in depth through freezing and thawing,

and/or

b. physical sorting of mineral skeleton, as in patterned ground.

(Complete soil profile description - See Appendix V.)

D. SOILS

1. Elegelic soils

In the montane, subalpine and alpine zones, frost is an extremely important micro-climatic element which has a profound effect upon soil forming processes. However, in the context of this classification the term gelic is used only for soils whose morphology shows features which can be attributed to cryoturbic influences. Because they are skelic they have few pedological features. The diagnostic features which define these soils and sites are as follows:

i) Pedoturbic features are always present. Cryoturbic movements have resulted in a mixing of both mineral and organic matter, in situ, not
only at the surface but also at considerable depth.

ii) Stone orientation - Coarse angular stones are frequently aligned in the direction of former movement when the terraces were active.

iii) Site - Close relationship to physiography - In this area type localities are solifluction terraces, close to perennial snowline. In such a situation pedogenic processes have been strongly influenced by the zonation of vegetation which in turn is controlled by the microtopography. Thus because of the greater plant development on the risers of the solifluct terraces the soil organic matter is highest there.

Intergrades: Lodi-elegelic
Fulvi-elegelic

1(a). Elegelic soils (see Plate 14A)

Elegelic soils are skeletal soils with minimal horizon development. However, with the progressive development of an organic horizon the original elegelic soil is transformed into intergrades which, although they have the prerequisites of the gelic category, have also well developed organic horizons.

General specification:

A mineral soil low in organic matter, stony
coarse textured. Some form of stone orientation has taken place under the influence of cryoturbic processes. Elegelic soils include primary skeletal soils, or are of secondary origin where formed on remnants of severely eroded soils.

Profile:

Thin humus, < 1.0 cm, lying directly upon coarse textured lithic C horizon. The surface shows sorting due to cryoturbation.

Diagnostic horizons etc:

Raw A, overlying a lithic C. Pedoturbic features are associated with textural sorting.

Dominant processes:

A strong drift régime; mixing of the fine material through cryoturbation; loss of fine material through deflation and colluviation. Very slow accumulation of organic matter.

Environment:

These soils are associated with a lack of insulation. Although they can be a growth index of 0.22 (see Table 24) establishment of plant cover is restricted by freeze-thaw phenomena. It is not the mean daily temperature which is the critical factor delimiting these soils but the high daily temperature range which varies between 8°C to 11°C in the winter and summer months respectively which results in surface instability. These soils occur over a wide altitudinal range from subalpine to alpine 1,200 - 1,800 m.
Physiography:

Generally flat to undulating surfaces occurring on a wide range of slopes and varying from the summit to colluvial foot slope (see Figure 6).

Moisture régime (1):

Field capacity not recorded but probably <15%.

Plant cover:

*Dracophyllum pronum* with small herbs.

1(b). Lodi-elegelic soils (see Plate 14 - Chemical and Physical Analyses in Tables 29 and 30).

General specification:

An organic soil (>20% organic matter) in which organic matter has been mixed to some depth through cryoturbic processes.

Profile:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>0&lt;sub&gt;1&lt;/sub&gt;</td>
<td>0 - 5</td>
<td>Undecomposed root mat</td>
<td></td>
</tr>
<tr>
<td>0&lt;sub&gt;2&lt;/sub&gt;</td>
<td>5 - 14</td>
<td>Black (5yr 2/1 peaty loam)</td>
<td></td>
</tr>
<tr>
<td>0&lt;sub&gt;g&lt;/sub&gt;</td>
<td>14 - 31</td>
<td>Dark brown (10yr 4/3) peaty silt loam spot gley</td>
<td>lodic 0</td>
</tr>
<tr>
<td>(u)0&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>31 - 34</td>
<td>Black (5yr 2/1) stony peaty loam</td>
<td></td>
</tr>
</tbody>
</table>

(1) Refers to top 5 cm of soil.

(2) An horizon buried *in situ* through cryoturbic processes.
Dominant processes:

Strong organic régime, with high moisture and gleying.
Mixing by cryoturbic processes.

Environment:

In this catchment found on the coldest aspects in the vicinity of late snowbanks. Altitude 1,500 - 1,800 m. A humogenic humolytic index of 0.971. Mean annual temperature 1°C.

Physiography:

Characteristic of solifluction lobes and hummocks, frequently on the toe slopes below moraines. Aspect: S., S.E.

Moisture régime:

Field capacity 77%, wilting point 40%.

Plant cover:

Chionochloa oreophila with Marsippospermum gracile.

1(c). Fulvi-elegelic soil (see Plate 15 - Chemical and Physical Analysis in Tables 31 and 32)

General specification:

A, (B), C soils with some buried and mixing by cryoturbic processes.

Profile:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizons</th>
</tr>
</thead>
<tbody>
<tr>
<td>(u)G</td>
<td>34 - 41</td>
<td>Light grey (5y 7/1) silt loam gley</td>
<td></td>
</tr>
<tr>
<td>(u)B</td>
<td>41 - 51</td>
<td>Light olive brown (2.5 yr 5/6) Incipient stony silt loam</td>
<td></td>
</tr>
</tbody>
</table>

(1) Possible relic feature.
<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Horizons</th>
</tr>
</thead>
<tbody>
<tr>
<td>(u) B</td>
<td>25 – 28</td>
<td>(5yr 5/8) yellowish red stony sand</td>
<td>Incipient B</td>
</tr>
<tr>
<td>C</td>
<td>28 – 48</td>
<td>(2.5y 5/4) light olive brown stony loamy sand</td>
<td>Lithic C</td>
</tr>
</tbody>
</table>

**Dominant processes:**

An accumulating organic régime with mixing through cryoturbic process; high moisture régime, flushing may slightly offset acidification.

**Environment:**

Humogenic - humolytic index .75 – .90, altitudinal range of 1,500 – 1,800 m, a persistent snow cover (5 – 6 months) and mean temperature of about 1°C.

**Physiography:**

Solifluction lobes, and frost hummocks, usually on undulating terrain on flat ridges or mid and toe of slopes.

**Moisture régime:**

Field capacity 60%, wilting point 30%.

**Plant cover:**

*Chionochloa oreophila* with prostrate shrubs.

2. Eleclinic soils

Although these soils are skeliform and are exposed to severe frost at the higher altitudes they are usually insulated by snowcover and are not subjected to severe alternating freeze-thaw conditions.
They are thus separated from the former soils because little disturbances from cryoturbic processes.

Intergrade: Humi-eleclinic

2(a). Eleclinic soils (see Plate 16, Chemical Analyses in Table 33)

**General specifications:**

(A) C soils.

**Profile:**

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizons</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 - 1</td>
<td>Moder</td>
<td>Raw A</td>
</tr>
<tr>
<td>C</td>
<td>1 - 6</td>
<td>Solifluct</td>
<td>Lithic</td>
</tr>
</tbody>
</table>

**Dominant processes:**

Rejuvenating with flushing and incorporation of new material through colluviation and from snowmelt.

**Environment:**

These soils are protected from exposure to wind and low surface temperatures by prolonged snowcover. Such soils in close proximity to the perennial snow form the immediate material from primary colonisation by chionoophilous plants. Humogenic-humolytic index: 0.78 - 0.90 winter and spring temperatures 0°C. Altitude: 1,800 - 1,900 m.

**Physiography:**

Fans and colluvial toe slopes formed by morainic outwash sediments.

**Moisture régime:**

Field capacity = 15%; wilting point 4%.
Plant cover:

Spps. of Epilobium, Agrostis subulata, Poa novae-zelandiae and Raoulia youngii and some mosses and hepatics.

Where colonisation from Celmisia hectori has taken place a dark brown to black (10yr 3/3-2/1) silicate moder has formed 2 - 5 cm in depth.

2(b). Humi-eleclinic soils (see Plates 17 and 18 - Chemical and Physical Analyses, Tables 34 - 35).

General specifications:

O, A and C soils.

Profile:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizons</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 - 12</td>
<td>Dark brown (10yr 4/2) peaty loam</td>
<td>Lodic O</td>
</tr>
<tr>
<td>A</td>
<td>12 - 25</td>
<td>Dark yellowish brown (10yr 4/4) fine sandy loam</td>
<td>Humic A</td>
</tr>
<tr>
<td>C</td>
<td>25 -</td>
<td>Fragmented rock</td>
<td>Lithic C</td>
</tr>
</tbody>
</table>

Dominant processes:

Strong organic régime. Active flushing and alluviation particularly from snowmelt.

Environment:

Insulation from snow cover ensures an equable winter soil temperature which remains at just below freezing throughout winter. These soils will have a humogenic-humolytic index ranging from 0.76 - 0.97. This will generally vary according to aspect, the lower index being associated with the North and West aspects. Mean temperature range 0°C - 3°C. Altitude: 1,500 - 1,800 m.
Physiography:

These soils occur on a wide range of terrain from precipitous fall faces (see Figure 6) to undulating physiography below the moraines.

Moisture régime:

Field capacity 65%, wilting point 30%.

Plant cover:

Prostrate shrubs and cushion plants.

3. Elelithic soils

The dividing line between this group and the elegelic soils is very fine. However, this group has been included as there are large areas of these soils which although having some surface sorting due to freeze thaw actions surface material is not incorporated to any depth. Essentially forming in situ through physical weathering.

(See Plate 19, Chemical and Physical Analyses - Tables 36 and 37)

General specifications:

(A), C soils.

Profile:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizons</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 – 2</td>
<td>Brown (7.5yr 3.2) stony sandy loam</td>
<td>Raw A</td>
</tr>
<tr>
<td>C</td>
<td>2 – 10</td>
<td>Rock fragments</td>
<td>Lithic C</td>
</tr>
</tbody>
</table>

Dominant processes:

Removal of fine particles by wind and colluviation.

Surface freeze thaw process.
Environment:
Exposed to high winds; little insulation from snow cover during winter owing to removal of the snow by wind. These soils are usually disturbed on ridges and warm aspects and will therefore receive high rates of direct insolation. Mean summer temperatures may be 12°C, with marked diurnal fluctuations. Altitude: 1,200 – 1,900 m.

Physiography:
Flat to undulating terrain. These soils usually exposed to the warmer N.E. and N. aspects.

Moisture régime:
Moisture. No measurements recorded but soils have probably low storage values.

Plant cover:
Stunted and sparse wide range of individual plants. Dracophyllum pronum is frequent with some Celmisia lyallii and Poa colensoi.

4. Eleluvic soils

The term luvic has been adapted from Taylor and Pohlen to denote soils that can be recognised by internal evidence of layering. It is not an ideal term as it conflicts with the F.A.O. (1968) usage for soils with illuvial accumulation. B horizon, i.e. with argillic horizons. Luvic soils are often associated with buried soils which have been formerly covered by sediments deposited as outwash from the moraine and colluvial deposits.
Intergrade: Plati-eleluvic

4(a). Eleluvic (see Plate 20 and Chemical and Physical Analyses in Tables 38 and 39)

General specifications:
(0), A, C soils.

Profile:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizons</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 - 25</td>
<td>Greyish brown (2.5yr 5/2) sand</td>
<td>Raw A</td>
</tr>
<tr>
<td>GC</td>
<td>25 - 100</td>
<td>Pale olive (5yr 6/3) loamy sand</td>
<td>Regic C</td>
</tr>
<tr>
<td>uB</td>
<td>100 - 120</td>
<td>Yellowish brown (10yr 5/6) sand</td>
<td>Buried soil</td>
</tr>
<tr>
<td>uC₁</td>
<td>120+</td>
<td>Glacio-fluvial outwash</td>
<td></td>
</tr>
</tbody>
</table>

Dominant processes:
Rejuvenating régime from unweathered alluvial material and flushing from snowmelt.

Environment:
These soils usually have snowcover over six months of the year. Although soils are cold with a growth index of between 0.18 - 0.14, the soil temperatures remain at a constant 0°C - 1°C throughout the snow period. Altitude: 1,700 - 1,800 m.

Physiography:
Associated with glaciofluvial outwash fans on gently undulating terrain. These soils are typical of young surfaces at altitudes ranging from 1,700 - 1,800 m.

Moisture constants:
Moisture constants not recorded, but an estimate of
storage capacity would regard them as having a field capacity of 50 - 60% and wilting point of 10 - 20%.

Plant cover:

Poa colensoi with Marsippospermum gracile and Celmisia haastii.

4(b). Plati-eleluvic (see Plate 21 and Chemical and Physical Analyses, Tables 40 and 41)

General Specifications:

0, (A), C soils.

Profile:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizons</th>
</tr>
</thead>
<tbody>
<tr>
<td>0_1</td>
<td>0 - 3</td>
<td>Amorphous peat</td>
<td>Platic 0</td>
</tr>
<tr>
<td>C_1</td>
<td>3 - 4</td>
<td>Yellowish brown (10yr 5/4)) loamy sand</td>
<td></td>
</tr>
<tr>
<td>O_2</td>
<td>4 - 7</td>
<td>Very dark brown (10yr 2/2) peaty loam</td>
<td>Dominantly regic with platic layers</td>
</tr>
<tr>
<td>C_2</td>
<td>7 - 10</td>
<td>Yellowish brown (10yr 5/4)) silty loam</td>
<td></td>
</tr>
<tr>
<td>O_3</td>
<td>10 - 12</td>
<td>Very dark brown (10yr 2/2) peaty loam</td>
<td></td>
</tr>
<tr>
<td>C_3</td>
<td>12 - 17</td>
<td>Yellowish brown (10yr 5/4)) loam sand</td>
<td></td>
</tr>
<tr>
<td>O_4</td>
<td>17 - 19</td>
<td>Very dark brown (10yr 2/2) peaty loam</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>19+</td>
<td>Water table overlying outwash gravels</td>
<td>Lithic</td>
</tr>
</tbody>
</table>

Dominant processes:

Strong organic régime. Dystric conditions by progressive acidification through leaching of nutrients. Humus forms platy humicol (Barratt) or dystrophic Anmoor (Kubiena). Conditions are typical of shallow soligenous
peats. At lower altitudes similar situations result in formation of topogenous bogs.

Environment:

These soils are covered from 4 - 6 months of the year by snow. It is only during an abnormally dry summer that these soils are not saturated. Humogenic-humolytic index, 0.78 - 0.97. Mean annual temperatures 1°C - 2°C. Altitude: 1,500 - 1,600 m.

Physiography:

Small basins typical of tarns.

Moisture constants:

Not recorded but estimated field capacity, about 70% with wilting point 35% - 40%.

Plant cover:

Oreobolus dominant with hydrophytic plants.

5. Eleplatic soils

In the alpine zone organic soils are usually shallow when compared with those of lower subalpine and montane zones. In most instances they occur as intergrades but in some isolated localities they are distinctive and warrant the term platic even though they are thinner than would be allowed by soil survey manual. These soils can be divided on the basis of nutrient status into two phases, the eutric or dystric phases. Thus the eleplatic (eutric phase) refers to organic soil with relatively high base saturation and eleplatic (dystric phase)
similar soils of lower base saturation which are not found in this catchment.

5(a). Eleplatic (eutric phase) (see Plate 22, Chemical and Physical Analyses - Tables 42 and 43)

**General specifications:**

0, GC soils.

**Profile:**

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 - 15</td>
<td>Amorphous peaty</td>
<td>Platic 0</td>
</tr>
<tr>
<td>G</td>
<td>15 - 30</td>
<td>Light grey to grey (5yr 6/1) sand</td>
<td>Gley</td>
</tr>
<tr>
<td>uO</td>
<td>30 - 35</td>
<td>Dark reddish brown (5yr 3/2) Anmoor peat</td>
<td></td>
</tr>
<tr>
<td>uG</td>
<td>35 - 54</td>
<td>Grey 5y 5/1 gritty silt loam</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>54+</td>
<td>Colluvial gravels</td>
<td>Lithic C</td>
</tr>
</tbody>
</table>

**Dominant processes:**

The organic horizon well developed. Periodic accumulation of organic material by burial. Strong gleying occurs below the surface. Organic matter 5 - 15% with base saturation > 30%.

**Environment:**

Strongly flushing, along springlines and meltwater channels. Humogenic-humolytic index, 0.72 - 0.90.

Mean temperatures, 2°C - 3°C. Altitude: 1,200 - 1,800 m.

**Physiography:**

Lower slopes, especially along the toes of slope.
Moisture constants:
Not measured, but estimated field capacity, 70% with wilting point 35% - 40%.

Plant cover:
Bryophytes and higher forms of hygrophytes.

6. Elefulvic soils

Unlike the skelliform soils this class has well developed B horizons. They may be associated with diagnostic Moroid O horizons, umbric A and cambic B horizons. Under conditions of impeded drainage gleyic horizons are usually present. In a region which has a marked moisture gradient and a broad altitudinal range these soils have a high degree of variability. The influence of soil moisture from one site to another can have a profound effect upon soil forming processes. Many of these soils particularly those found on the south aspect are close to the limit of their range as fulvic soils (yellow-brown earths), and have some affinities with incipient features of podzols. These soils are referred to as a strongly enleached phase of the elefulvic group. In other circumstances where gleying is a dominant process a madenti-elefulvic intergrade is formed. On the north and east aspects the elefulvic soils have been severely influenced by erosion and deposition which have considerably modified the modal forms to form composite soils having varying degrees of eroded and buried horizons. Such soils are referred to as clini-elefulvic intergrades:
i) Elefulvic

ii) Elefulvic (strongly enleached phase)

Intergrades:

iii) Clini-elefulvic

iv) Madenti-elefulvic

6(a). Elefulvic soils (see Plate 23, Chemical and Physical Analyses, Tables 44 and 45)

General specifications:

This class shows little outwards appearance of alteration through a drift régime or rejuvenation through flushing and therefore has well developed profile at least for this environment. Base saturation is low ranging from 2.5% - 11.0%. Sesquioxide values indicate some translocation of iron oxide (see strongly enleached phase below).

Profile:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 - 15</td>
<td>Dark yellowish brown (10yr 4/4) loamy sand</td>
<td>Umbric A</td>
</tr>
<tr>
<td>B₁</td>
<td>15 - 22</td>
<td>Yellowish brown (10yr 5/6) stony loamy sand</td>
<td>Cambic B</td>
</tr>
<tr>
<td>B₂</td>
<td>22 - 37</td>
<td>Yellowish brown (10yr 5/8) stony sand</td>
<td></td>
</tr>
<tr>
<td>C₁</td>
<td>37+</td>
<td>Fragmented schist</td>
<td>Lithic C</td>
</tr>
</tbody>
</table>

Dominant processes:

Generally non-accumulating, possible deflation of the A horizon in exposed situation.
Environment:
Influenced by snow from three to four months of the year. Soils are usually above field capacity throughout the year. Mean annual temperatures approximately 3.5° - 4.0°C. The humogenic-humolytic index ranges between 0.75 - 0.76. Altitude: 1,400 - 1,700 m.

Physiography:
Wide range of slope locations, varying from upper mid-slopes to toes of slope.

Moisture constants:
Field capacity, 50%, wilting point 25%.

Plant cover:
*Celmisia lyallii* with *Dracophyllum pronum* and *Poa colensoi*.

6(b). Elefulvic (strongly enleached phase) (see Plate 24, Chemical and Physical Analyses, Tables 46 and 47)

General specifications:
Although having similar properties to the modal form, these soils are more highly leached. Some indication of this is shown by increase of sesquioxides in the B horizon. In the field they also have a well formed organic horizon with a discrete boundary with the A horizon.

Profile:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 - 4</td>
<td>Dark brown (10yr 3/3) peaty loam</td>
<td>Moroid O</td>
</tr>
<tr>
<td>A</td>
<td>4 - 11</td>
<td>Dark grey (10yr 4/1) silt loam</td>
<td>Umbric A</td>
</tr>
<tr>
<td>B</td>
<td>11 - 31</td>
<td>Brownish yellow (10yr 6/6) stony silt loam</td>
<td>Cambic B</td>
</tr>
</tbody>
</table>
Horizon  | Depth (cm) | Description       | Diagnostic Horizon
---       | ---        | ---                | ---
C₁       | 31+        | Schist gravel solifluct detritus | Lithic C

Dominant processes:
A strong organic régime. A permeable soil surface with acid humus eluviation indicated by increase with depth of both the iron oxides and alumina.

Environment:
These soils are strongly influenced by snowmelt during summer, and four to five months snowcover in winter. Soils are above field capacity throughout the year. Humogenic-humolytic index will be approximately 0.78 with a mean annual temperature about 1.0°C - 3.0°C.
Altitude: 1,500 - 1,600 m.

Physiography:
Gently undulating terrain.

Moisture constants:
Field capacity 65% - 70% and a wilting point 35% - 40%.

Plant cover:
*Celmisia lyallii* with *Dracophyllum pronum*.

6(c). Clini-elefulvic (see Plate 25, Chemical and Physical analyses, Tables 48 and 49).

General specifications:
A, B, C soils.
### Profile:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 - 10</td>
<td>Dark greyish brown (10yr 4/2) gritty sandy loam</td>
<td>Umbric A</td>
</tr>
<tr>
<td>uA/B</td>
<td>10 - 20</td>
<td>Yellowish brown (10yr 5/4) stony sandy loam</td>
<td>Cambic B (with fragmented layers)</td>
</tr>
<tr>
<td>uB/C</td>
<td>20 - 35</td>
<td>Yellowish brown (10yr 5/4) stony sand</td>
<td>Lithic C</td>
</tr>
</tbody>
</table>

### Dominant processes:

These are largely composite soils having been influenced by periodic erosion and deposition.

### Environment:

These soils are typical of the warmer drier north and west aspects. Snow cover is never prolonged on these soils. The surface has little insulation from snow in the winter, or vegetative cover and therefore susceptible to mixing in the upper part due to freeze flow processes. (Pedoturbic process only sufficient to form gelic intergrade).

In the summer these soils may fall below field capacity. Humogenic-humolytic index about 0.75 with a mean annual temperature approximately 3.5°C - 4.0°C. Altitude: 1,400 - 1,700 m.

### Physiography:

Eroded steepland soils usually found on the crests and mid-slopes. Deeper composite profiles often located along the toes of slopes. Aspect north and west.

### Moisture constants:

Field capacity about 50% and wilting point about 20%.
Plant cover:

Dominantly *Chionochloa rigida* with some shrubs.

6(d). Madenti-elefulvic (see Plate 26, Chemical and Physical Analyses, Table 50 and 51)

General specifications:


Profile:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 - 4</td>
<td>Very dark brown (10yr 2/2) peaty loam</td>
<td>Moder silt-cate</td>
</tr>
<tr>
<td>G</td>
<td>4 - 39</td>
<td>Light grey to grey (5yr 6/1) silt loam</td>
<td>Gley G</td>
</tr>
<tr>
<td>B</td>
<td>39 - 64</td>
<td>Brown to dark brown (7.5yr 4/4) stony sand</td>
<td>Cambic B</td>
</tr>
<tr>
<td>C&lt;sub&gt;1&lt;/sub&gt;</td>
<td>64+</td>
<td>Outwash gravels</td>
<td>Lithic C</td>
</tr>
</tbody>
</table>

Dominant processes:

Strong organic régime. The gleying is attributed to impeded drainage combined with an abundance of moisture from precipitation and snowmelt.

Environment:

Cold wet soils influenced by snow cover during the winter and snowmelt in summer. Mean annual temperature about 1°C. Humogenic-humolytic index 0.75 - 0.80.

Altitude: 1,600 - 1,700 m.

Physiography: Hollows and depressions. Usually found on south aspect.

Moisture constants:

Field capacity, 70% with a wilting point ranging from 40% - 45%.
Plant cover:

*Chionochloa oreophila.*

7. Eldefulvic soils

In a region where there is an absence of timberline there is a lack of a clear demarcation between the A and B horizons and the transition takes place over a vertical range of about 100 - 200 m. The ecotone between the elufulvic (alpine) and the eldefulvic (subalpine) zones is associated with increasing thickness of profiles and clearly differentiated horizons. This boundary tends to coincide with a mean annual soil temperature (5 cm below surface) of 3.5°C - 4.0°C and a humogenic-humolytic index of about 0.75. This boundary will therefore tend to be lower on the colder aspects and higher on the warmer ones.

Although profile differentiation has been taken into account, an arbitrary line has been selected of 4.0°C (5 cm below surface) mean annual temperature as the division between the elufulvic and eldefulvic zones.

The study of the eldefulvic soils was limited to the steepland terrain of the catchment. On the south aspect, as in the elufulvic soils, the eldefulvic soils were at the upper limit of their moisture range, and they therefore tended to be highly leached or gleyed. On the north aspect however they were under the influence of a strong drift régime and had a wide range of composite profiles.

1) Eldefulvic (strongly enleached phase)
Intergrades:

ii) Clini-eldefulvic

iii) Madenti-podi-eldefulvic

7(a). Eldefulvic (see Plate 27 – Chemical and Physical analyses, Tables 52 and 53.)

General specifications:

These soils are not typical of the modal form as they have a strong organic régime with a well developed organic horizon and are also more highly leached.

Profile:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>0 - 6</td>
<td>Brown to dark brown (10yr 4/3)</td>
<td>Moroid O</td>
</tr>
<tr>
<td>A</td>
<td>6 - 16</td>
<td>Dark greyish brown (10yr 4/2) silt loam</td>
<td>Umbric A</td>
</tr>
<tr>
<td>B1</td>
<td>16 - 31</td>
<td>Yellowish brown (10yr 5/8) silt loam</td>
<td>Cambic B</td>
</tr>
<tr>
<td>B2</td>
<td>31 - 91</td>
<td>Brownish yellow (10yr 6/8) silt loam</td>
<td></td>
</tr>
<tr>
<td>B3</td>
<td>91 - 101</td>
<td>Brown (7.5yr 3/2) stony silt loam</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>101+</td>
<td>Schist fragments from colluvium and solifluct</td>
<td>Lithic C</td>
</tr>
</tbody>
</table>

Dominant processes:

Strong organic régime, with mottling and seasonal gleying in the B2 horizon.

Environment:

A high moisture régime, with a winter snowcover of four to five months and snowmelt during spring and early summer. Soils above field capacity, throughout year.
Mean annual temperature 4°C and a humogenic-humolytic index of 0.60 - 0.65. Altitude: 1,402 m.

Physiography:

Mid-slope and toe of slope in steepleand terrain.

Moisture constants:

Field capacity 74% and wilting point 42%.

Plant cover:

*Celmisia lyallii* with some *Poa colensoi* and *Draco-phyllum pronum*.

7(b). Clini-elfulvic (see Plates 28 and 29, Chemical and Physical analyses, Tables 54 and 55)

General specifications:

On A, B, C soils which have been modified by periodic erosion and deposition.

<table>
<thead>
<tr>
<th>Profile:</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizon</th>
<th>Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0 - 15</td>
<td>Dark grey (10yr 4/1) silt loam</td>
<td>Umbric A</td>
<td>(with fragmented layer)</td>
</tr>
<tr>
<td>uA1</td>
<td>15 - 19</td>
<td>Dark yellow brown (10yr 4/4) stony silt loam</td>
<td>)</td>
<td>)</td>
</tr>
<tr>
<td>uA3</td>
<td>19 - 41</td>
<td>Yellow brown (10yr 5/4) gritty loamy sand</td>
<td>)</td>
<td>)</td>
</tr>
<tr>
<td>UB</td>
<td>41 - 71</td>
<td>Brownish yellow (10yr 6/1) stony loamy sand</td>
<td>Cambic B</td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>71+</td>
<td>Schist and argillite fragments</td>
<td>Lithic C</td>
<td></td>
</tr>
</tbody>
</table>

Dominant processes:

An active drift régime, with periodic erosion and deposition of new material. Buried horizons with
organic material and coarse fragmented stonelines are common.

Environment:

These soils are not exposed to prolonged snowcover. They receive high rates of insulation and the desiccating effects of the N.W. winds. These soils can fall below field capacity. Mean annual temperature 5.5°C - 6.0°C, with a humogenic-humolytic index about 0.50. Altitude: 1,250 m.

Physiography:

Eroded soils usually occur on the crest and mid-slopes. Composite soils are frequent along backslopes and toes of slopes.

Moisture constants:

These soils are naturally the most variable, and moisture constants will depend upon the degree of erosion and deposition. The range of field capacity is about 40% - 50% with wilting points ranging from 15% - 35%.

Plant cover:

Chionochloa rigida, with Celmisia lyallii and Poa colensoi.

7(c). Madenti-podi-eldefulvic (see Chemical and Physical Analyses, Tables 56 and 57)

General specifications:

A, G, B, C soils. These soils are gleyed and strongly enleached.
Profile:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
<th>Diagnostic Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 - 20</td>
<td>Dark grey (10yr 4/1) silt loam</td>
<td>Umbric A</td>
</tr>
<tr>
<td>G</td>
<td>20 - 32</td>
<td>Grey (H6/) silt loam</td>
<td>Gley G</td>
</tr>
<tr>
<td>B_1</td>
<td>32 - 38</td>
<td>Yellowish red (5yr 4/8) silt loam</td>
<td>Cambic B</td>
</tr>
<tr>
<td>B_2</td>
<td>38 - 58</td>
<td>Yellowish red (5yr 5/8) stony sandy loam</td>
<td></td>
</tr>
<tr>
<td>B_3</td>
<td>58 - 70</td>
<td>Strong-brown (7.5yr 5/6) loamy sand</td>
<td></td>
</tr>
<tr>
<td>C_1</td>
<td>70+</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dominant processes:

Vigorous organic régime. Abundant moisture moving through soil from snowmelt and high precipitation, moderate to strong leaching with mottling and gleying.

Environment:

Similar environment to the strongly enleached eld-fulvic soil. Main difference is that it is more strongly gleyed and leached. The high moisture status from snowmelt in summer insures that soils are perennially gleyed. Altitude: ~1,097 m.

Physiography:

Steepland to undulating moraine. Usually located on mid and toe slopes.

Moisture constants:

Not recorded but field capacity estimated at between 70% - 75% and wilting point about 40% - 45%.

Plant cover:

Dominantly Chionochloa rigida.
E. DISTRIBUTION OF THE SOILS (soil profile reference Nos., Appendix VI).

The two main environmental factors determining the distribution of the soils are temperature and moisture. On the basis of moisture the soils can be considered from two points of view, hygrous soils (Taylor and Pohlen, 1962) which can fall below field capacity for a limited period of time and hydrous soils (which include the organic and gleyed soils) are above field capacity throughout the year. The hygrous soils include the clinic soils which are located on the drier north and west aspects.

The distribution of the hydrous soils is more complicated. On the warmer aspects they occur at higher altitudes in close proximity to the seasonal snowmelt zone, or in small localities where drainage is impeded. The hydrous soils however reach optimum development along the whole altitudinal range of the colder south aspects. The moisture relationship of these soils will be discussed in a section at the end of the next chapter.

The soil categories and their associations have been mapped (see Vol.II) at a scale of R.F. = 1/14,256. Type localities have been further indicated in Figure 24 which shows a scatter of soil classes across an altitudinal range of the various alto-sequences separately. Each point represents a locality where a pit was dug, the soil described and samples taken for analysis. Some soils are exclusive to a particular basin, for example, the lodi-elegelic soil which is found in the extreme south aspect of Twin Basin.
1. Altitudinal zonation of the main classes.

i) The lateral transition between the skelic and fulvic soils is gradual.

ii) Below 1,700 m soils are more or less continuous, above this they form a discontinuous mosaic with bare rock.

iii) Soil development occurs above 1,900 m.

iv) A number of localities at high altitudes have soils with well developed profiles, these may be relic soils which have survived on refugia and have escaped recent glacial erosion.

v) The transition between the elefulvic and eldefulvic zones is a continuum. Altitudinally the transition has been placed at 1,400 – 1,500 m which coincides with a mean annual temperature of about 4°C or a humogenic-humolytic index of approximately 0.75.

2. Horizon differentiation.

Mature soil development is manifested by a well developed B horizon. Kubiena (1953) referred to zonal (1) alpine soils which were associated with well developed O and A horizons. The ratio of A to B horizons varied from 3:1. Such soils were termed "alpine humus soils" by Jenny (1948).

The ratio of A to B horizons of a wide altitudinal range of soils from Twin and Pyramid Basins is indicated in Table 58. Generally the soils in the elefulvic zone have thinner B horizons but distinct organic and A monoliths of characteristic alpine soils are illustrated in Plates 30 – 33.
horizons. These differences can be summarised as follows:

i) Profiles which have the highest OA/B ratio within altitudes ranging from 1,400 - 1,800 m are soils on the cold aspect and reflect the greater accumulation of organic matter.

ii) In the Twin Basin the soils range from high OA/B ratio for organic soils at higher altitudes, e.g. 3.6, and 5.8 to ratios ranging from 0.25 to 2.8 at altitudes below 1,500 m.

iii) The elefulvic (strongly enleached phase) soil which approximates to the zonal soil in the per-humid alpine zone has an A/B ratio of 1.


i) Lodi-elegelic soils
   This intergrade has a very limited distribution and occurs only on the south aspect of the Twin Basin. Altitudinal range: 1,500 - 1,800 m.
   It is found on isolated rock outcrops which may have formed refugia from recent glacial erosion where relic soils were able to continue developing.

ii) Fulvi-elegelic soils
   Although lacking in the development of the organic horizon as compared with the lodic intergrade it is closely related to the former soil in morphology. It is widely distributed at higher altitudes,
1,600 – 1,800 m, throughout the four basins and is influenced by a strong flushing régime from snowmelt.

iii) Eleclinic and humi-eleclinic soils

Also occur at higher altitudes, 1,800 – 1,900 m. Some of humi-eleclinic soils are probably relic soils found particularly in isolated localities along ridges where a protective cover of snow ensures equable temperatures in winter and snowmelt prevents drying out in summer.

iv) Elelithic soils

In this study area they are primary skeletal soils which occur chiefly on exposed summits of ridges – altitudinal range: 1,200 – 1,900 m.

v) Eleluvic, luvi-eleplatic and eleplatic soils

These soils are found in an accumulating environment on fresh sediment deposited from meltwaters. They tend to occur on the upper Jacks Stream surface below the main melting zone of the perennial snowline – altitudinal range: 1,500 – 1,800 m.

vi) Elefulvic soils

These soils occur chiefly on the lower and upper surface of the Jacks Stream formation. The modal form does not occur in the Twin Stream Basin. The class is found mainly in Pyramid Basin and the Twin Stream headwaters and a few scattered localities on the darker aspect of Mary Basin.
a. Strongly enleached phase occurs on the colder aspects of the Twin Basin.

b. The madenti-elefulvic intergrade soil on the warmer aspects, e.g. Mary Basin is under strong topographic control being located in depressions with poor drainage. In the Twin Basin this intergrade occurs on both steepland sites and in some basins.

c. The clini-elefulvic intergrade is confined to the warmer north and west aspects. They have a very limited occurrence on a few isolated localities with a north-east aspect in Twin Basin. However in Mary Basin where the warmer drier aspects are more frequent this intergrade is widespread on the upper and lower Jacks Stream surface.

d. The eldefulvic soils and their intergrades occur on similar sites but lower altitudes to their elefulvic counterparts. These soils occur on the Ferintosh surface and lower parts of the Jacks Stream surfaces. The madenti-podi-intergrade soils are isolated to the colder south aspects in contrast to the clinic intergrade soils which are confined to warmer northern and western aspects.
CHAPTER VI
PEDOGENESIS

A. MONOSEQUENCES AND POLYSEQUENCES IN RELATION TO PEDOGENESIS.

A strong influence of temperature and moisture upon the energy status and distribution of the soils suggests the dominating control of these two variables as soil forming factors. Thus on the cold aspects one finds gleyed and strongly enleached soils and on the warmer aspects, fulvic soils even though they are formed from similar aged parent material. The relative importance of mono, and polysequence studies on mountain soils depends largely upon the locality of the soils under study. For example, mountain soils are usually associated with a high degree of site variability, therefore soil sequences when studied on a large area will usually be compounded of several soil forming factors, in this case, temperature and moisture. Jenny (1941, 1958) who regarded soil formation as a functional relationship of climate, organisms, topography, parent material and time, expressed in the equation: \( S = f(c_l, 0, r, p, t) \), regarded polysequences as helpful for purposes of system arrangement and soil sequence classification, but they did not match the scientific value of monosequences. Such a sequence where moisture and temperature were dominant factors in soil formation could be expressed in Jenny's
equation as  \[ S = f(T, M, O, r, p, t) \]
where  
\[ T = \text{temperature} \]
\[ M = \text{moisture} \]

So far as this study is concerned the nearest approach to a monosequence in Jenny's terms is the sequence of hydromorphic soils associated with the colder southern and eastern aspects. These soils have suffered less disruption through erosion, and pedogenesis has tended to be autochthonous. Such a sequence forms the basis of a model of a chrono-sequence, since time is the variable factor with the other factors being more or less constant. On the warmer drier sites associated with the north and west aspects, a high degree of variability of parent material due to erosion and deposition phases exists and soils are better described as polysequences, in essence chrono-litho sequences.

Because mountain soils are characterised by complexity, the mono- and poly-sequence approach forms a logical framework in which these soils can be studied and it is with these concepts in mind that one can begin to study these sequences in relation to age, aspect and altitude.

It has frequently been either stated or implied in this study that the dominant controlling influence upon pedogenesis is the interaction between aspect and altitude. This can be substantiated by the fact that the soils on the colder aspects have some hydromorphic features, such as gleying, whilst the soils on the warmer aspect are considerably drier and hence more mesomorphic in type.
Although it is difficult to isolate aspect and altitude the lower end members of the altitudinal sequence in the Twin, Mary and Pyramid Basins do demonstrate the influence of aspect on soil forming processes. At higher altitudes increased precipitation and lower temperatures tend to offset the impact of aspect and the soils reflect increasing moisture, lower temperatures and hydromorphic characteristics.

B. THE ALTITUDINAL SEQUENCE OF THE SOILS ON THE COLD AND WARM ASPECTS.

The three main alto-sequences of soils have been presented in Figures 25 - 27. Those include:

i) Twin Basin with an altitudinal range of 1,097 - 1,870 m (Figure 25).

ii) Twin Stream Headwaters with an altitudinal range of 1,310 - 1,767 m (Figure 26).

iii) Mary Basin with an altitudinal range of 1,246 - 1,975 m (Figure 27).

Each one of these sequences commences at the higher altitudes on the Dun Fiunary surface close to the perennial snowline and then falls down to the lower Jacks Stream and older Ferintosh surface.

1. Parent material.

The results of mechanical fractions made on these soils are indicated in Figures 28 and 29. In Figure 28 the results have been shown as the percentage of fine
123

earth. (< 2 mm) in soil. Figure 29 shows the distribution of the fine earth fraction, in depth of each profile. The results can be compared from two points of view: aspect and time.

i) Aspect

Figure 28 shows a significant difference in the percentage of fine earth according to aspect. For example, the soils of the dark aspect have approximately 90% fine earth compared with the sunny aspect soils which range between 60%, 70%. This suggests a more active drift régime on the sunny north aspects compared to the dark south aspects.

Figure 29 indicates a higher silt fraction in the soils on the dark aspect, of the hydrous soils ranging from 25% - 45%, than the opposing north aspect hygrous soils ranging from 10% - 20%.

ii) Time

There is little apparent difference between the fine earth fractions of soils on the different aged surfaces. Within the profiles however an increase in clay occurs at depth in the madentipodi-eldefulvic (10 - 20%) and clini-eldefulvic soils (5 - 8%), on the Perintosh surface as compared to no change with the two younger soils on the Jacks Stream surface. On the upper part
of the Jacks Stream surface there is a slight clay increase at depth in the madenti-elefulvic and eleluvic soils.

2. Chemistry of the soils.

i) Carbon

The trends of carbon for the alto-sequences of Twin and Mary Basins are shown as a function of depth on a volume weight basis, per horizon (Figure 30). These trends can be summarised in terms of aspects and altitudes in relation to the soils.

a. Aspect

In general the soils of the north aspect which include all the clini soils (MB5 and MB10) have lower carbon per profile, 3.91 and 11.38 kg/ha/profile, than the madenti and strongly enleached soils (TW16, TW10 and TW2), 11.79, 8.3 and 16.67 kg/ha/profile. The higher carbon close to the surface of these latter soils reflect upon the more strongly developed organic horizon as opposed to the eroded horizons of the clini soils.

b. Altitude

Because of greater precipitation at the higher altitudes, aspect influences tend to be less distinct. For example, the humi-eleclinic soil (MB18) although on a north aspect has a
stable non-eroded organic horizon.

From the soils presented in Figure 30 there are no significant carbon trends with altitude. However, if one includes the organic soils (lodic) as they occur on the south aspect above 1,800 m and consider the carbon in the organic horizon, as a percent in profile there is a trend of an increased organic horizon within an altitudinal range of between 1,200 - 1,900 m (see Figure 31).

ii) Nitrogen

The nitrogen content of these soils has been illustrated in Figure 32 and naturally shows similar trends as that of carbon content.

a. Aspect

The soils on the colder aspects (TW2, TW14, TW16, TW22) tend to have greater percentage of total nitrogen than the clinic intergrades on the warmer aspects (MB10, MB5).

b. Altitude

Although there appears to be an increase in total percentage of nitrogen over an altitudinal range of between 1,200 - 1,800 m this is not statistically significant.

iii) pH

Along the whole sequence of soils the generally low base status (2 - 10%) is associated with
low pHs with little distinction between alto-sequences (see Figure 33).

iv) Base saturation
In Figure 34 base saturation is generally low. However, although the lowest values are recorded in the madenti-podi eldefulvic (TW2) and the strongly enleached phase of the elefulvic soils (TW14), the north aspect alto-sequence has slightly higher values which suggest the influence of rejuvenation processes. For example, the humi-eleclinic and madenti-elefulvic soils (MB18 and MB6) are rejuvenated from a flushing régime whilst the clinic soils (MB5, MB10) are influenced by a strong drift régime in which new material is incorporated into the soil.

v) Total calcium and magnesium
The higher base saturation in the soils of the north, alto-sequence is substantiated by the higher totals of calcium and magnesium. For example, both the clini-elefulvic (MB5) and clini-elefulvic (MB10) have the highest totals (Figure 35a), with the lowest values being recorded in the strongly enleached elefulvic (TW14) and the madenti-podi eldefulvic (TW2) soils (Figure 35b).

The relatively high content in the eleluvic and eleclinic soils is a reflection upon the fact that they are younger soils rejuvenated by an active flushing or drift régime.
vi) Iron and aluminium

The molecular ratio of iron and aluminum oxides to silica demonstrate rates of translocation within the various soils. These differences can be summarised as follows, see Figure 36:

a. The humi-eleclinic soils (MB18) have no detectable movement.

b. The eleluvic soil (TW22) has a more complex pattern and suggests a composite soil. Thus in the upper 50 cm movement is minimal, but at greater depths a marked fluctuation in the ratio of both iron and alumina indicates either some depositional process, weathering or translocation of sesquioxides. The accumulation of sesquioxides at the 100 cm depth takes place in a B horizon that has subsequently been buried by glacio-fluvial sediments. This particular site is a good example of a composite soil which has undergone rejuvenation through the addition of sediment.

c. The clini-eledefulvic soil (MB10) has little relative movement of sesquioxides. This is to be expected due to the incorporation and mixing of new material from a drift régime.

d. The elefulvic (strongly enleached phase) (TW14) has a shift of sesquioxide as indicated by the
decrease of molecular $\text{SO}_2/\text{RO}_3$ ratio from $\frac{1}{2} \frac{2}{3}$

the A horizon. A similar shift is also

recorded in the madenti-podi-eldefulvic (TW2) soils.

vii) Phosphate retention

Phosphate retention is a good measure of the accumulation of sesquioxides because of the greatly increased ionic bonding sites for phosphate ions (Wells and Saunders, 1960). Hence these phosphate retention trends follow a similar pattern to the former sesquioxide trends, see Figure 37.

a. The younger eleluvic and humi-eleclinic soils (TW22, MB18) have the least retention of phosphate.

b. The clini-elefulvic (MB5) and clini-eldefulvic (MB10) soils indicate some increase down the profile: 30 - 40%, 40 - 65% respectively.

c. The more highly leached soils, represented by the elefulvic (strongly enleached phase) (TW14) and the madenti-podi-eldefulvic have higher values ranging from 50 - 70% and 25 - 90% respectively.

viii) Phosphorus transformations

As an index of soil development related to soil forming factors phosphorus transformations are probably the most useful key to trace pedogenic tendencies. In order to summarise these transformations, Williams and Walker's (1969) diagram
(Figure 38) has been included. These transformations are summarised as follows:

a. Sole source of inorganic phosphate at zero time assumed to be apatite.

b. Colonisation of soil results in a build-up of organic phosphate, which will eventually decline.

c. Through time the original inorganic (calcium) phosphate is transformed into organic, non-occluded and occluded forms.

In the study of chronosequences by Godfrey and Rieken (1954) Bauwin and Tyner (1957) and Walker (1965), phosphorus transformations were used as an index for the relative age of soils. Walker reported similar results when studying the effects of climate and parent material on soil development. With increased precipitation the available phosphorus decreases. He further suggested that nitrogen accumulation will cease in the ecosystem when all the acid extractable phosphorus, (Ca-P) and iron and aluminium surface-bound phosphorus (Fe, Al-P), are converted to organic phosphorus and insoluble occluded forms of iron and aluminium bound phosphorus. At this stage the only source of phosphorus is from mineralisation of organic phosphorus.
viii)(a) Phosphorus transformations on the alto-sequence of Mary Basin.

In order to obtain some concept of the distribution of the various phosphorus fractions, (Walker and Adams, 1959) rapid analytical method was used. Abbreviated forms of the various fractions have been referred to:

\[ \begin{align*}
\text{Pf} &= \text{occluded phosphorus} \\
\text{Po} &= \text{organic phosphorus} \\
\text{Pa} &= \text{available phosphorus (Ca-P + Al, Fe-P)}
\end{align*} \]

Each fraction is expressed as a percentage of total phosphorus in Figure 39 and may be summarised as follows:

a. The sequence is characterised by peaks and troughs.

b. The variation in the Pa pattern at higher altitudes is due to the intensity of the flushing and organic régimes. Hence the skeliform soils (MB1 and MB2) have a higher percentage of Pa than the older relic humi-eleclenic soil (MB18). Pa values are lower in the clini-elefulvic (MB5) and madenti-intergrade (MB6) soils with an increase in the subalpine zone in the clini-eldefulvic intergrade (MB10) soils.

A more detailed analysis (Table 59), in which the available phosphorus has been separated into
acid extractable forms (Ca-P) and surface bound aluminium and iron phosphorus (Al, Fe-P). The general trends may be isolated as follows:

c. Although the humi-eleclinic soil (MB18) has a small percentage of available inorganic phosphorus to total phosphorus, it has some Ca-P which suggests some forms of rejuvenation. Al, Fe-P is also relatively high.

d. Both the clini-elefulvic (MB5) and madenti-elefulvic intergrades (MB6) have lost the Ca-P fraction.

e. The available inorganic forms (Ca-P + Al Fe-P) are highest in the clini-eldefulvic intergrade (MB10, MB14).

f. Apart from the humi-eleclinic soil (MB18), which is probably a relic soil, there is an increase of organic and total phosphorus down the sequence with increasing profile development.

viii)(b) Phosphorus transformations on the alto-sequence of Twin Basin

As with the former Mary Basin alto-sequence, the trends of the percentage of various phosphorus fractions are indicated in Figure 40. These trends can be summarised as follows:

a. The Pa fraction, as a percentage of total,
has a distinct trend, with markedly greater amounts at higher altitudes. The lower values of Pa refer to the fulvi and lodi-elegelic soils, which are probably old relic soils, in which the Pa has been transformed.

b. Pf has no definite trends.

c. Relatively high values of Po is found in the elefulvic and elefulvic intergrades and ele-gelic soils.

Detailed analysis of the phosphorus fractions in Table 60 confirm the trends in Figure 40 as follows:

d. Relatively high Ca-P values in the eleclinic and eleluvic soils.

e. Ca-P concentrations in successive horizons of eleluvic soil suggest inclusions of fresh unweathered material as might be expected.

f. A marked decrease of Ca-P with decrease in altitude.

g. High concentrations of P-org in the elefulvic (strongly enleached phase) and the madenti-elefulvic intergrade in the upper horizons.


Although both these sequences of soils showed some chemical divergence some doubts arose as to whether they would show any mineralogical differentiation because of
the relatively short time span between the youngest and the oldest soils. From this point of view, therefore, only the soils from the two oldest surfaces, Jacks Stream and the Ferintosh surfaces were examined. Two size fractions were studied. Silt 5 μm - 50 μm size range, was separated from parent material and the clay fractions (0.2 μm - 2 μm) from the A and B horizons of soils found on the two formations in Pyramid, Twin and Mary Basins. X-ray diffraction patterns of the silt fraction indicate that over 70% contains primary quartz and feldspar, followed by 18% mica and 10% chlorite (Table 61). Chemical evidence supports the fact that leaching of the hydrous soils is greater than that of the hygrous soils. However, X-ray diffraction patterns suggests that the rate and degree of weathering are of the same order on both formations throughout the three basins. In the clay fraction very small quantities of feldspar have been detected (see Table 62). This suggests that most of the feldspar has been hydrolysed to amorphous hydrous oxides of alumina and silica. The high content of hydrous oxides has been supported by high phosphate retention values and also by the Fieldes and Perrott (1966) sodium fluoride test. Although this latter test was used to distinguish allophane, it has been found to be non-specific (Brydon and Day, 1970) and can be used only as a measure of "reactive" hydroxy alumina.

X-ray diffraction patterns show no differentiation between the two different aged surfaces. The degree of weathering of the micaceous minerals is about the same with a large content of interlayered material in both
horizons. Samples saturated with potassium and glycerol show X-ray peaks which have collapsed to 10\(\AA\) and therefore suggest the presence of vermiculite. Heating to 550\(^{\circ}\)C with potassium saturation, resulting in an increase in peak height to 14\(\AA\) probably indicates the presence of primary chlorite.

Several samples when treated with potassium and heated to 550\(^{\circ}\)C shows collapse of the 14\(\AA\) which became gradually flatter and broader, thereby suggesting replacement of the potassium ion by alumina and the formation of pedogenic chlorite. Fieldes (1962) referred to this as vermiculite 1. Table 62 summarises the general trend and degree of weathering of the micaceous minerals.

4. Diagnostic horizons

The relationship of diagnostic horizons to soil forming processes on the altitudinal sequences has been simplified in Figure 41, and can be summarised as follows:

i) Semi-terrestrial soils:

a. The raw A is diagnostic of initial stages of solum formation and the beginnings of the accumulation of organic matter.

b. The lodic and platic horizons are indicative of high moisture status, the lodic horizon is associated with the organic soils formed on slopes independent of basin topography. The platic form is associated with shallow basin peats.
c. The incipient B horizon is associated with the skeletal soils. In this study they are specific to the lodic and fulvi-elegelic soils.

ii) Terrestrial soils

These are rarely supersaturated and never inundated by water. Subsequent development of the raw A over the skelic form leads to:

a. The development of the A, C soils characterised by the humic A and sometimes an incipient B horizon.

b. Subsequent development seems to be dependent upon moisture, thus under a hydrous régime (above field capacity throughout the year) the soils are associated with a strong organic régime, progressive leaching which is conducive to the formation of a moroid organic horizon, with an umbric A and a cambic B horizon.

c. The soils influenced by a hygrous régime (below field capacity for one month of the year) are characterised by a strong drift régime. The organic régime is weaker and the diagnostic A horizon is umbric with a cambic B horizon usually associated with fragmental layers.

C. SOIL MOISTURE CHARACTERISTICS

In the chapter on the physical environment a number of parameters relating to moisture emerged which had a
direct bearing upon soil moisture. These may be summarised as follows:

i) There was an increase both in rainfall and snow water equivalents with altitude.

ii) Potential evapotranspiration was greater on northern aspects than on southern aspects.

iii) South aspects were associated with prolonged periods of snowmelt which was largely absent, particularly at lower altitudes on the warmer aspects.

In Figures 42a – e, moisture retention curves have been plotted for a range of soils. The moisture storage values have been summarised in Table 63. These may be listed as follows:

i) The clini-eldefulvic soils have the lowest storage capacity.

ii) The madenti-eldefulvic soils with the well developed organic horizons have approximately twice the storage capacity of the clinic intergrades.

iii) Similarly the organic soils at higher altitudes have high storage values and reflect the well developed lodic and humic organic horizons.

Moisture storage values measured by Macdonald (1961) and Molloy (1964) were made in a Kaikoura Steepland soil and an alto-sequence of high country yellow brown earths respectively. Their measurements were of a similar
order to the clinic soils in this study. Molloy's data showed that with decreasing altitude there was an increase in water storage. This trend will certainly be consistent with the clini-elefulvic soils on the northern and western aspects of this study area, where storage capacity has probably been reduced at higher altitudes because of the removal of the fine particles by colluviation and wind.

There is a paucity of data on the hydrology of alpine humus soils in New Zealand, however, Costin et al (1964) have produced data on these soils from the Australian Alps which may be compared with those in this study.

For example, on a volume basis of pH 2.52 (field capacity for the upper 30 cm (12") of solum, the Australian alpine humus soils are summarised as follows:

1) Meadow 0.253
2) Transitional alpine humus 0.233
3) Alpine humus 0.475

Costin regarded the alpine humus soil as the climax soil for this zone, hence this value will compare favourably with the elefulvic soil which approximates to the climax soil in this region.

In order to assess the moisture régime of these soils in relation to precipitation, two studies were made.

1. Soil moisture in relation to seasonal snowmelt.

Figure 43 represents the soils moisture trend at 10 cm soil depth (gravimetrically determined) of three
soils and the duration of seasonal snow. The following points emerge:

i) The fulvi-elegelic and elefulvic soils have the longest duration of snow cover.

ii) Both soils are above field capacity, the fulvi-elegelic throughout the year, the elefulvic until February when moisture fall below field capacity for two weeks.

iii) The clini-elefulvic soil has the shortest duration of snow cover and is below field capacity for several weeks during the summer months.

2. Soil moisture budget.

The soil moisture budget recorded the precipitation which fell during the spring-summer period. This was in the form of rain, hence the budget does not take into account the moisture in the form of snowmelt that was recorded in the previous study.

The events in Table 64 can be summarised as follows:

i) The locality of the fulvi-elegelic soil (64a) has the lowest potential - evapotranspiration.

ii) In the top 10 cm of soil it has a field capacity of 49 mm which is depleted because of low precipitation during February. In reality however moisture storage of these soils is maintained at field capacity by snowmelt.

iii) The longest records occur on the site of the elefulvic soils (64b). Excess potential-evapotranspiration leads to the soils falling to below
field capacity. However, reference to Figure 43 will again indicate that snowmelt maintains soil moisture at field capacity until mid-February.

iv) The clini-ellefulvic soils (64c) are in a locality with the highest potential evapotranspiration, and there is insufficient snowmelt to maintain the soils at field capacity during the summer months.

It should be noted that these studies took place during the abnormally dry summer of 1970-1971.

D) THE ROLE OF FLUSHING AND COLLUVIATION IN PEDOGENESIS

1. The flushing process

Very little experimental work seems to be available with regards to profile and horizon development for mountain soils. Jenny and Smith (1935) and Thorp et al (1957) attempted to study horizon formation due to movement of ions and colloids through columns. However, Kurtz and Milsted (1973) suggested the movement of dissolved and colloidal substances through the profile by percolating waters were a major factor in soil development.

It is suggested in this study area that the main aspect of soil hydrology, that has had a major influence in differentiating the soils, has been snowmelt. It seems clear that the soils in this catchment have evolved over the last 300 years under a far higher concentration of snowmelt than is occurring during the present day.
Although the seasonal snowline will have obviously fluctuated during this period of time, there will have been a greater volume of residual perennial snow and ice from the last recorded "little ice age".

The analysis of snowmelt and late spring snow indicate generally a low nutrient status (see Table 65). Compared with the analyses of similar material from northern hemisphere alpine regions, these quantities are very much lower. For example, snow taken from the Greater Caucasus was found to have 5.8 mg/litre of calcium and 1.94 mg/litre of magnesium (Stepanov, 1962). Although quantities in this study are low, a continual addition of these nutrients in meltwaters will greatly enhance the nutrient status of the natural systems which have evolved under inherently dystrophic conditions. This seems to be supported by the fact that the platic (eutric phase) soils are found exclusively in free draining supersaturated conditions of meltwaters, and even though the nutrient status of meltwater is lower than that of late spring snow, these soils record the highest base saturation.

Costin (1952) in his discussion on the alpine humus soils of Australia, states that the snowmelt does not leach the soil, since much is discharged in a dense cover of grass, also the high storage values of these soils will retain much of the moisture. In the study of plant communities of the Scottish Highlands, McVean and Ratcliffe (1962) considered that late snowline favoured leaching, except when accompanied by strong irrigation from rich substrate.
One must not, however, dismiss the great importance of the high storage values of these soils and their role in maintaining a reduced rate of discharge in these high catchments. The high degree of stability of these hydrous soils compared with the unstable drier hygrous soils are proof enough of the indirect role of meltwaters in maintaining a greater stability within the natural systems.

2. Colluviation

The process of colluviation has been greatly stressed in New Zealand pedological literature when referring to steepland soils of the high country yellow brown earth zone. This is largely due to the fact that the soils described were located in the drier eastern coastal ranges. Nonetheless, it is a term that had crept into the literature, and has been accepted as applying to all mountain soils associated with steepland terrain.

So far as the Southern Hemisphere alpine soils are concerned the only authorities to draw attention to the pedological role of water has been Costin (1952, 1955, 1964). Cutler (pers. comm.) also objected to the colluviation process being regarded, without reservation, as the dominant process in controlling pedological tendencies in steepland terrain.

Colluviation seems to be the dominant process in steepland terrain where precipitation is either low or ineffective through high evapotranspiration rates or rapid run-off. The clinic soils which characterise the north and western aspects are associated with erosion
and deposition phases which have resulted in the removal of soil at high altitudes and the redeposition of material at lower altitudes with the formation of composite profiles.

Some of the fine fraction at lower altitudes must be attributed to aeolian processes, but by and large redistribution of material in these soils is the result of gravity. The removal of the fine fraction (< 2 mm) to lower altitudes is accompanied by an increase in the acid extractable phosphorus (Ca-P) and bases. The enrichment of soils in the subalpine zone was also recorded by Molloy (1964) and Ives (1970). Ives suggested that the specific gravity of apatite (3.10 - 3.35 g/m³) would preclude it being blown to higher altitudes (if the source is valley floor), hence larger quantities of available phosphorus at lower altitudes could be attributed to greywacke colluvium.

3. Periodicity

From the brief discussion of the two processes, flushing and colluviation, one will conclude that they are the two dominant processes affecting rejuvenation, or local enrichment operating in the pedogenesis of mountain soils. There is no doubt that both processes can operate in the development of a particular soil or group of soils. However, so far as this study is concerned, flushing is more or less exclusive to the hydrous soils and colluviation to the hygrous soils. Soils which are developing in such a diverse topography associated with mountainous terrain are subject to periodic influences, some of these
influences may be wasting processes, other rejuvenating processes. The periodicity attributed to colluviation has been developed (Butler, 1959) in a framework for the study of such soils. This framework has applied to some of the steepland soils in Canterbury (Molloy, 1962), in an attempt to describe the distribution of present day soils. Briefly, Molloy considered the present day alpine zones to be the major "sloughing" zone and the sub-alpine zone to be the major accreting zone. Although this is a very valid concept for the steepland soils forming the yellow brown earth zone, it is not tenable for the alpine soils in general, especially those of the glaciated alpine regions. It is suggested in Table 66, that two forms of periodicity are operating, one may be regarded as sedimentation, which is related to the flushing process, and the other as erosion and deposition related to colluviation process. Thus, in the glacial zone, periodic rejuvenation occurs when fresh unweathered sediment is deposited from suspension on soils developing in close proximity to the ice fronts. This may be further extended to the circulation of colloidal and chemical constituents through the solum by meltwaters. The extent of rejuvenation depends upon the accumulation of fresh unweathered fines accessible to snow and ice meltwaters. The hydrous soils associated with these supersaturated conditions have well developed (though thin) organic horizons which in themselves improve the storage capacity, reduce the run-off and increase the stability of the soils. The incorporation and mixing
of the organic material throughout the profile frequently occurs in the case of the lodic and fulvi-elegelic soils where overturning of the organic horizon takes place due to the horizontal shearing as a result of cryoturbic processes.

In contrast to this form of periodicity, in the drier periglacial zones, glaciation will be a very minor feature and is highly localised. The major form of rejuvenation will be in the form of the transference of fine material (< 2 mm) in sufficient quantities to be of value to the developing soils. In such a zone, wind becomes a more significant agent in the removal and redistribution of fines combined with colluviation.

In this study area of the Twin Stream Catchment, one is fortunate in having the two forms of periodicity functioning in contrasting localities even if only on a small scale. Thus one can suspect that in similar regions further south, with gradually decreasing temperature and increasing precipitation/evapo-transpiration, there will be a gradient from the humic to the lodic soils. Costin in his discussion on the inter-relationships between Southern Hemisphere alpine humic soils suggests that temperature, precipitation conditions, are not conducive to well developed humic soils in New Zealand, stating that conditions are either too dry and are associated with lithosols or too wet when they are associated with blanket peats. Comparison of the hydrous soils in this study with those described by Costin do envisage a similar range of soils, which have
an organic component which typifies their environment.
A comparison of these soils will be continued further
in a following chapter.
CHAPTER VII
PLANT COMMUNITIES

The general concepts of the synecological approach that have been adapted in this study are stated in the chapter on methodology. Because of the limited catchment area (44 sq km) and the profound environmental gradients associated with the region, some of the plant communities exhibit fragmented forms. The status of each individual community will, however, be considered in a later section of this chapter.

In common with other parts of the high country tussock grasslands, the vegetation in this catchment has been strongly modified by man, and it is the effects of these changes upon the pattern of plant cover that will be considered now.

A. MODIFICATION OF THE VEGETATION: NATURAL AND CULTURAL INFLUENCES

The main sources of evidence of changes that have taken place during the pre-European era are from a series of pollen spectra and a C14 date. The C14 date and stratigraphic evidence suggest the onset of ecological instability occurred approximately 1,200 B.P. A series of soil profiles, which have not been included in this study because of their lower elevation, at an altitude of 1,000 m (Plate 34) indicate a well developed
B horizon immediately overlying glaciofluvial drift. The B horizon is further overlain by 15 cm of A horizon which includes charcoal from *Podocarpus hallii* (identified by B.P.J. Molloy) which has a C14 dating of 1,115 ± 80 years B.P.

The location of the charcoal in the soil profile is indicated in Plate 34 by the lower arrow. The two uppermost arrows denote former ground surfaces which suffered burning and the deposition of eroded material from other surfaces. A summary of the time sequence of events in conjunction with C14 date available in other localities of the South Island, one may say that prior to 1,115 B.P. there was a period of considerable stability when pedogenic tendencies were interrupted by pronounced periodicity. From 1,115 B.P. onwards instability of the soils and ground surfaces are marked by phases of periodic erosion and deposition. The present day phase is indicated (top arrow), by the burial of the uppermost ground surface by lateral movement from above.

The time sequence of events concurs with Molloy's (1964) date for a number of widespread localities in similar situations. He suggests that the onset of instability coincided with Polynesian fires. Whether the commencement of instability in this region was due to climatic change or the Polynesian fires is a controversial issue.

In the Twin Stream catchment an isolated stand of scrub which includes some moribund trees of *Podocarpus*
halii lies adjacent to the soils under discussion. The podocarp charcoal is evidence that the stand could have extended beyond its present day limits to cover a larger area. Both Holloway (1954) and Wardle (1963) have found that podocarp in general has not regenerated upon its former ground. Holloway attributed this to a thirteenth century change with a cooler drier climate when the podocarp forest became unstable. Regardless how speculative the reason is leading to a general period of ecological instability, one must realise that prior to the charcoal date of 1,115 B.P., during the period when uninterrupted soil development took place, these high mountain catchments were influenced by a large volume of perennial snow and ice which released large amounts of water during the seasonal melt. There is evidence that about 3,000 B.P. valley glaciers flowed down to 1,200 m onto the Ferintosh surface. Since 1,115 B.P. (even though one must accept localised ice re-advances) there has been a reduction in the volume of seasonal meltwaters accompanied by a raising of the seasonal snowline. Evidence of the great instability of the vegetation on the drier north and west aspects as opposed to the moister colder aspects does suggest a relationship between stability and moisture. Since 1,115 B.P., the soil profile (Plate 34) shows a series of periodic phases of erosion and deposition which are marked by two organic horizons (arrows). No charcoal was found in either horizon but Molloy (pers. comm.) suggests that the middle organic horizon could be related to 600 B.P. when
more recent charcoals in other localities were evidence of extensive burns which were subsequently followed by erosion and deposition, thus burying the soil on the lower slopes. The uppermost buried horizon is of recent origin and contains living fragments of snow-tussock. This particular cycle can be attributed to the European period of the last seventy years. We have abundant evidence today that the combination of burning and over-grazing enhanced the already unstable conditions, particularly in the drier sites where the ecological balance is extremely critical.

The pollen spectra taken from the horizon in which the charcoal (Table 67, interpreted by N.T. Moar) was found show one anomaly in so far as the *Podocarpus* pollen is concerned. Although this pollen was taken from the same horizon as the *Podocarpus* charcoal, only small percentages of the totals were recorded. Throughout the remaining buried surfaces there is no evidence in the distribution of the pollen to suggest a marked change in the different types of vegetative cover within the catchment. Also surface samples of pollen taken recently represent a similar component of plants (see Table 68). For example, *Phyllocladus* is particularly high in all cases as all the soil samples were taken adjacent to a scrub community. The relatively high rating of the *Gramineae* in the majority of cases suggest that grassland has always been an important, if not dominant, form of vegetative cover.

The vegetation changes that have taken place in
the montane, subalpine grasslands since European occupation have been recorded by numerous authorities: Zotov (1938), Molloy (1962, 1964), Cox and Mead (1963). Connor (1964) regards the short-tussock grasslands of the montane zone as induced by man and therefore of recent origin. In the Twin Stream catchment, some of these changes are not so obvious, but in the montane, subalpine transition Chionochloa rigida grassland has been replaced to some extent by adventive grasses characterised by sweet vernal and brown top (Anthoxanthum odoratum and Agrostis tenuis). The indigenous Festuca novae-zelandiae is also a frequent plant growing with a sub-dominant status in conjunction with the adventive species. From the above evidence it is, therefore, possible to summarise the events and the vegetation changes that took place in the montane, lower subalpine zone in this catchment:

i) Prior to 1,000 B.P. (Jacks Stream surface) a limited area of beech forest (Nothofagus) with isolated localities of shrub communities of Podocarpus hallii and Phyllocladus alpinus.

ii) During this period tall-tussock grassland dominated by Chionochloa rigida with some Compositae was widespread.

iii) A period of instability occurred from approximately 1,000 B.P. and has lasted to the present day.

iv) The instability which is widespread is probably attributed to a gradual decrease in soil moisture,
particularly in summer owing to the recession of perennial and seasonal snow and ice and to the previous periodic burning and over-grazing. This has resulted in the once dominant *Chionochloa rigida* grassland being invaded by adventive species and short-tussock grassland.

B. PRESENT DAY DISTRIBUTION OF PLANTS

Although the soils in the lower altitude of this catchment have not been considered in this study, some mention has been made of the vegetation changes and instability of the soils as they tend to reflect upon possible vegetation trends at higher altitudes and suggest the dynamic situation that has been the norm over the last 1,000 years.

With increasing altitude the *Festuca novea-zelandiae* becomes less frequent. The adventive species, such as brown top (*Agrostis tenuis* and *Anthoxanthum odoratum*) persist into the subalpine zone to altitudes above 1,150 m. Within this zone the distribution and frequency of plants is strongly governed by soil periodicity in the form of erosion and deposition surfaces. This broad zone which extends well into the upper part of the sub-alpine zone is something of a tension zone expressed by a high frequency of periodic erosion and deposition phases. A diagramatic cross section through a number of different aged surfaces (Figure 44) will help to indicate the relationship between the vegetative cover and different ground surfaces. If one adopts Butler's
K cycle concept, one can regard the youngest stable surface as the K1, and the K2 and K3 being the successively older surfaces. The present depositional surface is the Ko surface and is associated with clini-elefulvic soils on the drier warmer aspects in the alpine zone. Vegetation analysis according to the Zurich-Montpellier technique (with modification by Poore), of the different ground surfaces shows a contrast in the distribution and frequency of various plant communities. If the significance and abundance of plant species is translated to percentage cover (Figure 45) it can be seen that the K1 surface is characterised by the following plants:

- 10% of Chionochloa rigida and Agrostis tenuis
- 10% of Celmisia densiflora
- 25% of Trifolium repens.

The intermediate surface K2, shows higher ratings for shrubs and Chionochloa rigida but lower ratings for Trifolium repens. The oldest K3 ground surface has high values of shrubs, Dracophyllum uniflorum and Gaultheria crassa. The different ages and changes in the plant communities can be correlated with the soil chemistry to a depth of 5 cm. Thus on the oldest subalpine K3 surface (Figure 46) the pH and base saturation are low, with high values being recorded on the K1 surface. It should be noted that the Ko surface in the alpine zone, clini-elefulvic soils record lower base saturation and pH ratings. This may be due to a more rapid leaching of soil nutrients from
coarse textural soil because of higher precipitation and the removal of the fine soil fractions to lower altitudes. Also the establishment of adventive nitrogen fixation plants into the indigenous grasslands at lower altitudes will tend to ameliorate the low fertility conditions in these soils. In this region the upper limit of white clover is about 1,050 - 1,100 m. Above this, soil temperatures, and generally lower fertility preclude the development of clover. At approximately 1,200 m, a further marked change in the composition of the vegetation takes place. This change is in response to microclimatic edaphic and biotic factors. The first marked change to become noted is the decrease in adventive species, *Agrostis tenuis* and finally *Anthoxanthum odoratum*. This change is further accompanied by an increase in shrubs. Species of *Cyathodes* are confined to the warmer, drier aspects associated with the clinic soils, and species of *Hebe* largely found on the colder aspects associated with the moister soils. Species of *Dracophyllum* are ubiquitous. One plant that occurs with greater frequency with increasing altitude is *Celmisia lyallii*. In the upper part of the subalpine zone it is less abundant, but in the alpine zone it frequently has a high significance/abundance rating on the strongly enleached yellow brown earths (elefulvic soils strongly enleached phase). The widespread occurrence of this plant with high cover values may have been largely induced by the over-grazing of the more palatable species by Himalayan thar which frequent the higher altitudes in
large numbers. Both Cockayne (1928), and Zotov (1938) considered that pure stands of *Celmisia spectabilis* in the tall-tussock grasslands owed their origin to the destruction of the more palatable grasses by a combination of burning and grazing. Throughout these extensive herbfields of *Celmisia lyallii* there are still vestiges of scattered stunted species of *Chionochloa rigida* and *C. macra* which according to Connor (1964) formed climax alpine grasslands prior to European occupation. It seems, therefore, probable that the destruction of the alpine *Chionochloa* grassland in these regions has been very rapid, hence vegetation communities are in a state of flux and in the "Clementsian" sense are in a seral stage.

The higher precipitation that characterises the alpine zone in this region, the vegetation pattern is still influenced by erosion and deposition of the soil. These are, however, confined to the drier north and western aspects, and with increasing altitude the components of the plant communities become less diverse and species small in number.

C. PLANT COMMUNITIES OF THE SUBALPINE-ALPINE TRANSITION AND ALPINE ZONE

In regions which are largely devoid of forest, the vegetational transition from one zone to another is gradual, and forms a broad continuum. Both the latitudinal and altitudinal migrations of plants that have been recorded by Connor (1964, 1965), Wardle (1963) and
Burrows (1969) seems to indicate that the severity of the last pleistocene valley glaciation during Otiran times destroyed sections of the Central Canterbury flora which have since failed to re-establish during later interglacial period. Broad environmental gradients, particularly with relation to moisture, and a long history of human interference have all contributed to the fragmentation of the natural plant communities.

In this study none of these plant communities can be regarded as having association status in the Zurich-Montpellier sense, as the floristic analysis took place over a very limited area. They can, however, in Poore's terms, be regarded as noda showing some degree of floristic homogeneity in a gradient of continuous variation. The various noda have been included in an Appendix VII with a commentary upon the compilation of the Tables.

1. Subalpine grasslands

These grasslands have been established on a floristic and pedological basis. Reference to the floristic Tables (Appendix VII) indicates that the subalpine grasslands, which occur between 1,200 - 1,400 m altitude have been included in the same Tables as the alpine grasslands. This is because the altitudinal base of the study area was in the grassland ecotone and true subalpine grasslands were limited in distribution.

i) Chionochloa rigida, Poa colensoi dystrophic grassland

Connor (1964) described the floristic composition of similar grasslands in the Mackenzie
vegetation survey. He referred to them as alpine *Chionochloa rigida*/*Poa colensoi* grasslands. They were differentiated from the lower grasslands on the basis of a higher rating of *Poa colensoi*.

In this study the various stands which formed the noda had to be divided on the basis of different soils and floristic composition. Thus the dystrophic form of grassland was found on the leached madenti-podi-elefulvic soils. The dystrophic nodum contained a larger number of species than the degraded grasslands and *Festuca novae-zelandiae* was absent from the plant list. The high constancy of *Poa colensoi* was probably indicative of the influence of overgrazing, as found by Connor (1964) and Burrows (1969).

ii) *Chionochloa rigida* degraded grassland

Reference to Table 1, Appendix VII, shows that of the six stands analysed four occur below 1,400 m. This is indicative of the tension zone that occurs on the warm aspects associated with the clinic soils. Floristically these grasslands differ from the alpine degraded grasslands in having a higher frequency of *Festuca novae-zelandiae* and a lower frequency of *Celmisia lyallii*.

As one would expect, the most stable stands were found along the toes of slopes where an
accumulation of fine material and a higher moisture régime were conducive to greater soil accumulation. Evidence of moisture stress has been suggested in the clini-eldefulvic soils during a dry summer when meltwaters have been depleted. The continued instability of the stands forming this nodum is the result of erosion combined with the depletion of fine particles by cryoturbic and aeolian processes.

2. Alpine grasslands

With increasing altitude above 1,400 m *Chionochloa rigida* grassland is largely replaced by *Poa colensoi* and an increasing frequency of *Celmisia lyallii*. Before the grazing pressures from the introduced animals ensued at these higher altitudes, *Chionochloa macra* probably replaced *Chionochloa rigida* on the colder sites. It will be seen from the floristic Tables of the alpine dystrophic grasslands that *Chionochloa rigida* is absent from the higher altitudes but *Chionochloa macra* is found forming what are probably relic communities of once more extensive grassland. *Chionochloa macra* has a wide distribution in drier regions of the tussock grasslands, but in this study area it is probably close to the limit of its tolerance to high moisture levels.

Although the vegetation stands forming the nodum of alpine grasslands are limited in number, they can be divided floristically and pedologically into three groups:
1) Poa colensoi eutrophic grasslands (Plate 35)

It will be seen from the list of stands that apart from one stand appearing in Mary Basin (MB23) this nodum occurs wholly at the head of Twin Stream. This nodum can be differentiated from the other grassland noda on the basis of plant components and habitat factors. The shrubs tend to be prostrate species, as compared with the more upright taller shrubs of the Hebe, Gaultheria, Dracophyllum genera associated with the other grasslands. Chionochloa rigida and Chionochloa macra are both absent from this nodum, and although Notodanthonia setifolia occurs only in two stands situated at the head of Twin Stream, it has a high rating of 6.

The eutrophic grasslands are located below the flushed sites of the hydrous soils and are influenced by the rejuvenated régimes of the recently deglaciated areas.

This plant community, therefore, occurs on the more recent soils where leaching is weak and the base saturation relatively high. Nutrient loss is also offset by a continual addition of fresh material from both flushing and colluvial processes.

This plant community is highly fragmented. Although quantified synecological data are very sparse for the alpine regions, recent records exist that suggest that in the high precipitation zone this form of grassland is characterised
by *Chionochloa pallens* and *Notodanthonia setifolia*. Communities of this former plant, although absent from the locality, are very common in the high precipitation zone further north in the Mount Cook National Park (Archer et al., 1970; Wilson, pers. comm.) are found on rejuvenating soils. *Notodanthonia setifolia* has been regarded as a typical co-dominant of seral grassland which has been encouraged by excessive grazing and in some cases burning. Wraight (1960) referred to this community in the Hokitika River Catchment as a "minor association" which had been induced largely by grazing. He further recorded a widespread distribution of the plant in the Wairau Catchment, whose frequency was largely dependent upon fire. However, recent work in the Mount Cook National Park tends to support the evidence that *Notodanthonia setifolia* is typical of the earlier stages of plant succession where the soils are less leached and where there is an active accumulation of nutrients (Wilson, pers. comm.).

ii) *Poa colensoi*, *Celmisia lyallii* dystrophic grassland (Plate 36)

The term dystrophic has been used to denote grasslands that occur on the older more highly leached soils associated with the elefulvic and podi-elefulvic soils. Plate 36 illustrates a
plant community virtually dominated by *Celmisia lyallii*. Although this plant maintains its dominant status within the seral grasslands, on the colder aspects *Chionochloa macra* and *Poa colensoi* occur in greater numbers. *Celmisia lyallii* even in climax grassland is co-dominant and is widespread throughout both the eutrophic and dystrophic grasslands. It requires high soil moisture but generally free-draining conditions and is also probably a fire tolerant species. Prolonged snow cover is a decided limiting factor. In fact, this plant is probably a good indicator of habitats where the moisture status is being gradually reduced through the reduction of snowmelt by localised recession of perennial snow and ice. *Celmisia lyallii* will not tolerate unstable colluvium and there is abundant evidence of once stable communities now in recession because of the onset of accelerated erosion.

Throughout this catchment the frequency of both *Chionochloa rigida* and *Chionochloa macra* fluctuates considerably from a co-dominant status to a few scattered plants. *Aciphylla similis* is widespread, its abundance has probably been greatly increased by grazing pressures.

iii) The degraded grasslands

Plate 37 shows a typical northern aspect of
degraded grassland. This nodum is largely confined to the composite soils which form the clini-eldefulvic and clini-elefulvic soils. As extensive degraded plant communities exist only in the mid-altitudes of Mary Basin, this limited area did not warrant the separation of the subalpine and alpine grassland forming this group, and the stands have, therefore, been combined. Beyond the study area the degraded grasslands will form two separate nodas, alpine and subalpine. However, even within this limited area it is quite possible to visualise the trends that are taking place.

It has already been stated that there is some loss of soil from the alpine zone which has accumulated in a series of deposition phase at lower altitudes on the Ferintosh ground surface. It is therefore along the toes of slopes and mid-slopes where a combination of accumulated debris and seepage of water from the upper slopes are more conducive for the development of Chionochloa rigida grassland. It can be seen from the various stands that form this nodum, the rating of Chionochloa rigida is high between 1,200 - 1,400 m but at higher altitudes it is replaced by Poa colensoi and Celmisia lyallii. A comparison of the three forms of grassland will show that the flora of the degraded grasslands is greatly reduced in numbers.
compared with either the eutrophic and dystrophic
grasslands.


The plants that form the individual stands will all
tolerate prolonged snow cover, and are therefore chiono-
philous (Gjaervoll, 1965). Some of these plant communi-
ties have been described further south in the alpine zone
of Central Otago by Mark and Bliss (1970). In the snow-
bank community, Mark and Bliss record 15 higher plant
species that occur in the above noda in this catchment,
these are:

Abrotanella caespitosa  Drapetes lyallii
Agrostis subulata       Luzula pumila
Caltha obtusa           Ourisia caespitosa
Carex lachenalii
Carex pyrenaica         Phyllachne colensoi
v. cephalotes
Celmisia haastii
Claytonia australasica
Coprosma pumila

In Canterbury (Burrows, 1967) referred to Chiono-
chloa oreophila as a snowbank association, with a
number of sub-dominant plants which included Poa colensoi,
Anisotome imbricata, Marsippospermum gracile and Celmisia
deflora. He further noted that Chionochloa oreophila
occurred on a number of soils ranging from "lithosols to
gleyed podzols".
The plant communities associated with the hydrous soils have a similar range of habitats as all the plants concerned show a high tolerance to moisture. However, the floristic composition and the community structure of some of these groups of plants seems to indicate that along a gradient of continuous variation some of these communities are sufficiently homogenous to have nodal status.

i) Chionochloa oreophila nodum

The main structural feature of this community is that it forms very compact turf with a dense continuous cover of Chionochloa oreophila (Plate 38). Other species occurring in the community are widely scattered and therefore have low significance and abundance ratings. These plants include Celmisia haastii, Poa colensoi, Carex pyrenaica var. cephalotes and Marsippospermum gracile. Of these species Poa colensoi has such a wide ecological amplitude that it can be regarded as an indifferent plant occurring widely in other noda. The other plants are, however, exclusive to hydrous soils.

In this region, the depth of solum can very considerably depend upon the stage of development in the linear succession of the community. Fragmented communities occur on the fulvi-elegelic soils, but the nodum is more typical on the
madenti-elefulvic soils. Some degree of
gleying in the soil is a feature commonly
associated with this nodum.

ii) Marsippospermum gracile, Celmisia haastii nodum
In this catchment this community is fragmented.
For example, Marsippospermum gracile, which is
a plant preferring hydrous soils, does not form
widespread continuous communities in this
region. It occurs as scattered groups on the
recent gleyed soils with other groups of plants,
particularly Celmisia haastii, Chionochloa oreo-
phila and Celmisia hectori (see Plates 39, 40
and 41). Further north in the Sealy Range
however, Marsippospermum gracile forms dense
continuous communities, particularly well
developed on shallow gleyed organic soils which
are flushed by snowmelt.

Celmisia haastii is widespread on soils ranging
from the elefulvic soils to the fulvi-elegelic
soils. On such sites it is usually associated
with Poa colensoi and Marsippospermum gracile.

iii) Celmisia hectori nodum
As the floristic Tables indicate, this nodum
is characterised by very few species (Plate 40).
The community is not widespread but occurs in
rupicolous habitats characterised by the ele-
clinic soils which are situated in a strongly
flushed environment. This plant is important
in the early stages of plant succession, and will produce a considerable amount of organic material in the early stages of soil development.

iv) Fragmented noda of bryophytes and vascular hydrophytes

In the Twin Stream catchment these noda are highly fragmented and localised. The bryophyte noda, unlike many of the noda occurring in the alpine zone in the Northern Hemisphere are poorly represented by species. In some of the late snow bed hollows on the recent Dun Fiunar surface three genera, one hepatic and two mosses are typical; Gymnomitrium, Andreaea and Polytrichum respectively. Both the eleplatic (eutric phase) and plati-eleluvic soils contain a well developed cover of bryophytes and higher form of plants. The plati-eleluvic soils which are highly localised and are confined to lacustrine sediments on the floors of small tarns. Oreobolus pectinatus with Claytonia australasica tends to dominate the later stages of colonisation. The flush habitats associated with the ele-platic soil contain a greater variety of plant species which tend to be mat forming. For example, Abrotanella caespitosa, Stackhousia minima, Plantago uniflora. Both Scirpus aucklandicus and Schoenus pauciflorus are two important co-dominants in these situations.
In the very early stages of succession, the moss *Philonotis australis* is associated with the flushed sites of the eleplatic soils.

4. Unclassified rupicolous noda

This nodum has been included to list the plants associated with rupicolous habitats. They fall into three broad groups. The community in stand TW1 represents the cli-ni-elfefulvic soils that occur in the lower part of the subalpine zone. The second stand (MB13) is characterised by a group of plants that are typical of precipitous outcrops which are influenced by meltwater during the summer months and the third stand is associated with the stone pavements. Plants are scattered because of the rocky nature of the terrain. Colonisation of accumulations of mineral and organic material is associated with the elelclinic soils in a rejuvenating régime with nutrient cycling from flushing and further amendments to the system by the inclusion of freshly weathered material.

In contrast to these habitats are the wasting régimes characterised by the elelithic soils of the stone pavements. Plant life is sparse and confined to a few isolated communities usually dominated by *Dracophyllum pronum*.

D. ENVIRONMENTAL FACTORS RELATING TO PLANT SUCCESSION

The mutual dependence of soil formation and plant communities is clearly demonstrated, and changes in one
system will always result in changes within the other system. When one begins to consider plant succession in this region one must consider the two main aspects of successional changes, the linear autogenic form and the allogenic successions. In the first case the linear autogenic succession refers to a series of gradual changes commencing with a cryptogram colonising stage of the primary surface by plants leading to greater numbers and high cover values of plants associated with later stages of plant succession. The changes that take place throughout each successive stage are intrinsic as the changes are brought about by the plants themselves. Thus autogenic succession can be regarded as changes taking place within a closed system.

Alternatively allogenic succession refers to changes in succession brought about by external influences. In this region external influences are largely biotic, being the result of burning and grazing. The plant communities associated with the hydrous soils have been less profoundly influenced by grazing than the grassland communities on the warmer aspects.

Although considerable changes have taken place to the natural systems within the last 100 years through grazing and in the lower part of the study area, burning, it is still possible to interpret from the existing vegetation the ultimate climax vegetation that would have prevailed through autogenic succession.

In the next section, three of the major facets relating to linear autogenic succession will be considered: micro-climate, forms of organic matter, soil formation and soil nutrients.
1. Micro-climate

The role of micro-climate with relation to pedogenesis has been dealt with at considerable length in previous chapters. The influence of snowmelt as a major controlling factor with regards to soil moisture relationships and soil forming processes indicates that the duration of snowcover tends to govern the limits of several alpine plant communities and therefore some of the early stages of autogenic succession. It has been shown in Table 11 that the net accumulation period of snowpack in the upper limits of the subalpine zone (1,371 m) and the upper alpine zone (1,645 m) varies considerably from 19 to 83 days in 1969 and to 26 to 136 days in 1971. If the ablation period is included the eastern aspect is under the influence of snowpack for nearly 5 months of the year. However, this does not take into account localities on southern aspects where topographic control is conducive to accumulations of snow which persists for over 6 months of the year. During the years 1970 and 1971, snowpack duration was recorded in one such locality. Average snow depths were then plotted and represented as a series of isopacks in Figure 47. The isopacks show that minimum depths occur in the S.E. corner of the area. Snow depths range from 15 cm to over 200 cm towards the N.W. sector. In general snow began to accumulate in July. Maximum depths were recorded from
September to November when ablation resulted in a rapid depletion of the snow which was finally terminated towards the end of December.

The vertical temperature régime through the snowpack has been recorded in Figure 48. This indicates a brief period in February when mean air temperatures were above 13°C. The decline in temperature was rapid from March onwards and the temperature shows little difference over the vertical range of 180 cm to ground surface. During the summer months there is a lag in temperature below the surface because of the greater surface heating. The temperature becomes more or less equalised with the commencement of the snowpack in the early winter. During the winter months, minimum temperatures are recorded at snow surface. Below the surface, although temperatures are below zero, they remain constant throughout the snow period.

The pattern of vegetation in response to snowcover is quite sharply defined. In Figure 47 the relationship between the snowcover isopacks and distribution of a number of plant noda indicate that chionophilous noda are associated with localities where snowcover persists until December and January. On the edge of the snowbank where the snow disappears by October the locality contains a community of *Dracophyllum pronum* which is again superseded by a relic community of *Chionochloa macra* with *Celmisia lyallii* where snow persists for a few weeks longer.
The inference from this localised study is that plant communities adapted to these conditions have marked seasons in response to well defined periods of warmth and cold. This situation is in complete contrast with the degraded grasslands on the composite yellow-brown earths where seasonal variation is not so marked, but where diurnal temperature ranges, particularly during the winter months, are considerable (Archer, 1969). The alpine and subalpine zones have, therefore, a very wide range of habitats which are characterised by marked contrasts in temperature and moisture régimes.

2. Organic matter

During the initial stages of pioneer colonisation the important contribution that the plants make to the mineral substrate is organic matter. The constructive value of species in terms of consolidation and conservation of fine particles was considered as early as 1919 (see Pavillard, 1919). In Figure 49 a list of species was made on unconsolidated moraines directly below a small receding ice front on the Dun Fiunary surface. In the initial stages the only plants which form localised communities are by bryophytes. Of these plants, the genus Rhacomitrium is the most constructive species in consolidating and collecting fine particles. The higher plants occur as individuals over a wide area and their increment of organic material will be very low. Vegetative cover becomes pronounced at between 1,800 - 1,900 m. One very early plant which
can form extensive mats over several square metres of
ground is *Celmisia hectori*. This plant will not only
be of great value in stabilizing rock debris but will
contribute a relatively large quantity of organic matter
to the mineral substrate. From this early stage larger
numbers of plants participate in the colonising process.
Compared with pioneer colonisation in the alpine zone of
the Northern Hemisphere, the pioneer plants in this
region are adapted to skeletal soils of very low base
status. One other very important feature is that there
is a paucity of nitrogen fixing organisms, hence apart
from nitrogen fixation from lower organisms such as
algae, available nitrogen for these pioneer plants is
very low. Although the diversity of plant communities
is not great as compared with Northern Hemisphere
counterparts, the various communities are still associated
with specific soil organic forms which tends to character-
ise the various noda. This is particularly the case with
communities developed on the hydrous soils.

The classification of soil organic matter has already
been considered with regards to the interpretation of
thin sections following Barratt's and Kubiena's concepts.
In this chapter, however, we are interested in the
contribution of the specific plant noda to the organic
matter component. The hydrous soils are associated with
bryophytes, and hydrophyte noda typical of semi-terres-
trial conditions, with high water-tables and impeded
drainage. The better drained soils are associated with
the noda characterised by *Celmisia hectori*, *Marsippospermum*
gracile, Celmisia haastii and Chionochloa oreophila.

The organic matter formed by bryophytes such as Philonotis and some of the higher forms of hydrophytes is the basin and hanging anmoor which have been described in the European Alpine zone by Kubiena. This spongy mass of roots and partially humified plant residue (Plate 41) is characterised by the platic soils (eutric phase). The continued circulation of water ensures the maintenance of a relatively high base saturation. Plant succession in such localities inevitably results in a gradual accumulation of organic material with progressive leaching and acidification, and the formation of platic soils characterised by shallow humified peat with a thick mat of Oreobolus. The succession of these plant communities is often complex due to frequent inundation and the deposition of sediment burying the former surface. Thus in Plate 42 one can see at least three organic layers in stratified silt and sand.

The plant succession on better drained soils which are formed by the humi-eleclenic, elecluvc and madenti-eleclufic soils, show very similar trends to those seen in the succession of hydrophytic communities. Thus the early plant nodules of Celmisia hectori, Marsippospermum gracile, Celmisia haastii are usually associated with shallow humified organic matter. There is no litter horizon, and very little distinction between the organic and A horizons. This is clearly shown in Plate 43. The Plate shows the shallow organic horizon on the humi-eleclenic soil in which plant succession is at a
well developed stage and is in the transition between *Marsippospermum gracile*, *Celmisia haastii*, and *Chionochloa oreophila* nodum. The later stages of plant succession under saturated soil is indicated in Plate 44, which shows a turf taken from the *Chionochloa oreophila* nodum on the madenti-elefulvic soil. A well developed turf has formed. Below the turf the organic material is incorporated with the mineral constituents to form an A horizon associated with a moder-silicate (humiskel with lithoskel).

These processes on recent alpine soils can be summarised saying that early plant succession is associated with an organic matter which is a polymerized humicol lithiskel complex (Barrett), moder-silicate (Kubiena). Progressive leaching and acidification lead to a reduction in polymerisation and an accumulation of humiskel, lithiskel organic residues (raw humus, Kubiena).

It has already been stated that as a result of grazing pressures, probably from introduced animals such as the Himalayan thar, the natural succession has been modified. It is therefore probable that the largely unpalatable *Celmisia lyallii*, has increased in numbers at the expense of the snow tussocks, *Chionochloa macra* which are found growing in relic stands. With regards to organic matter content and the formation of humus, *Celmisia lyallii* has a foliar structure which is very resistant to decay. Under communities of this plant where the cover is dense, accumulation of organic
residues is greater than decomposition and there is a tendency for the formation of a shallow layer of a raw humus (Kubiena), or a ligno-parenchymal lithiskel (Barratt). Plate 45 shows a monolith of soil taken from a community of *Celmisia lyallii* showing a clearly defined organic horizon. Note that the A horizon upon drying has the tendency to form a blocky structure. This form of organic matter tends to be associated with the strongly enleached elefulvic and madentic soils in the alpine and subalpine transition wherever the *Celmisia lyallii* is highly developed. Contrary to this type of raw humus, the organic material formed from species of snow tussock, fescue and *Poa*, is a well humified mull-like moder (Kubiena), or a humicol-mullicol complex with some lithiskel (Barratt), see Plate 46.

Evidence from these soils of the various types of humus tends to conflict somewhat with views expressed by Costin concerning the nature and distribution of alpine humus soils in New Zealand. He considered that a combination of both topography and micro-climate were not conducive for the development of alpine humus soils in the drier eastern front ranges of the southern alps, and that further south excessive precipitation and low temperatures favour the formation of ombrogenous peats. However, there is a broad belt of alpine terrain on schist and greywacke in the northern and central part of the South Island which have alpine humus soils (humi-elecclinic, and elefulvic, strongly enleached phase), which tend to compare favourably with those described by Costin (1952) in Australia.
3. Plant succession in relation to soil formation and soil nutrients.

The transition from the subalpine and alpine zones is associated with a number of plants which tend to characterise various noda with increasing altitude. Thus, under the present dynamic status of the seral grasslands *Celmisia lyallii* assumes a dominant or co-dominant role at altitudes of about 1,200 m. This plant which characterises the dystrophic grasslands in association with *Poa colensoi* reaches optimum development on the strongly enleached elefulvic and madenti-elefulvic soils ranging in altitude from 1,200 - 1,750 m. On the north and west aspects this nodum becomes degraded and fragmented through accelerated erosion and is typical of the clini-eldefulvic and clini-elefulvic soils. The relationship of the various plant noda with the soils has been illustrated in Figure 50. This shows the distribution of the dystrophic and degraded grasslands throughout the alpine and subalpine zones. Rejuvenation through flushing induces the development of the more enriched eutric type of *Poa colensoi* grassland. At the higher altitudes the discontinuous distribution of soil and plant noda forms a mosaic confined to protected sites where there is a stabilisation of parent material in a strongly flushing régime. Although the plants which characterise the noda are not specific to one soil class, they do tend to be closely integrated with a soil forming process. For example, the *Marsippospermum gracile, Celmisia haastii, Celmisia hectori* noda are
associated with a rejuvenating régime from meltwaters. Also Marsippospernum gracile is not typified by raw humus, A strong relationship between plants, soils and microtopographic control can be witnessed on the fulvi- and lodi- elegelic soils. The zonation of plants in relation to these frost soils has been widely described in the South Island by Billings and Mark (1961), Mark and Bliss (1970), Archer et al (1971).

There is evidence that plant succession in relation to microtopography is strongly influenced by moisture. In this catchment, shallow eroded solifluction terraces exist on exposed slopes and ridges of the Ferintosh surface. Both the treads and footslopes of the risers are strongly influenced by wind erosion and also cryoturbic processes which tend to isolate the finer particles on the surface, from which they are readily removed by colluviation and wind. Plant colonisation in such an unstable substrate as this material is partially stabilised by Dracophyllum pronum. In more stable sites, Chionochloa rigida in conjunction with Dracophyllum pronum are growing on the upper surface of the risers. Similar forms of solifluction terraces on these dry localities have been described by Costin et al (1969) in the Mount Kosciusko area of Australia. The counterpart of Dracophyllum pronum is Epacris petrophila which grows in the protected sites of the shallow risers.

Solifluction lobes formed at higher altitudes on the colder southern aspects are more extensive, particularly in relation to their surface morphology. Swarms
of these features have risers varying in height from between 50 cm - 65 cm, (see Plate 47). The distribution of plants in relation to the topography of the solifluction lobe is shown in Figure 51. The rating of the various plants is according to the significance/abundance on the Domin Scale. From this diagramatic cross-section it is clear that the concentration of plant cover is on the risers with Marsippospermum gracile, Celmisia haastii and Chionochloa oreophila dominating the upper part and Celmisia sessiliflora the foot of the risers. Although the distribution and numbers of plants in this situation compares with that described on other solifluction terraces, it should be stressed that under conditions of high moisture content, colonisation of the tread surface is taking place relatively rapidly, accompanied by the formation of organic matter.

The trends of plant succession and the forms of organic matter in relation to the fulvi and lodi-elegelic soils seems to suggest a progression from the Celmisia hectori, Marsippospermum gracile, Celmisia haastii noda to the nodum characterised by Chionochloa oreophila. Thus under conditions of prolonged snowcover the fulvi-elegelic soils are associated with Marsippospermum gracile, Celmisia haastii nodum, with transitional forms of Chionochloa oreophila communities. The lodi-elegelic soils which are probably relatively old relic soils protected from former glaciations consist of peaty organic material formed from Chionochloa oreophila. The fact that the Chionochloa oreophila is able to resist
competition from other plants is due largely to its
tolerance to prolonged snowcover. In this study the
older more stabilised communities of this plant are
typical of madentic soils. Rejuvenation from flush-
ing will probably have offset progressive acidification
and podzolisation.

In the early stages of plant succession before
progressive leaching has resulted in a marked reduction
of the basic elements in the soil, there are some
significant trends associated with successive plant
communities in relation to chemical transformations.
In Figure 52, the vertical axis is represented by total
percentage of calcium and magnesium in the upper 5 cm
of soil, and the horizontal axis indicates the pH over
the same range of soils. The five communities from the
scattered pioneer habitat of the Chionochloa oreophila
nodum shows a significant linear correlation at $p < 0.05$
in which there is a reduction in pH correlated with a
similar reduction in calcium and magnesium. The various
stages of plant succession are further marked by signifi-
cant increases in organic carbon and phosphorus
transformation. Thus in the primary stage of colonisa-
tion, organic carbon is below 1.0 percent, increasing
to over 10.0 percent in the later stages. Similarly,
organic phosphorus as a percentage of total phosphorus
(Figure 53) has a significant positive linear increase
($p < 0.01$) from 10 percent in the early stage to over
75% under a closed community of Chionochloa oreophila.
These changes are accompanied by transformations in the inorganic phosphorus fraction (Figure 54). The most profound change is the reduction in calcium bound phosphorus (Ca-P). This decrease becomes marked with the progressive stages of colonisation until by the time the 5th stage is reached (Chionochloa oreophila nodum) less than 10 percent of the total remains, phosphorus as Ca-P. There is an inverse relationship between the aluminium and iron bound phosphorus (Al, Fe-P) and the occluded phosphorus (Occ-P). Therefore with an increase in one fraction there is a decrease in the other.

The time scale over which these transformations take place gives considerable scope for speculation. In this study the time scale is approximately 1,500 years, that is from the early stages of pioneer colonisation on the Dun Fiunary surface to the later stages on a lower Jacks Stream surface. This represents a loss of Ca-P from 60 percent of total inorganic phosphorus to 5 percent of the total or in terms of volume weight a loss of over 400 kg/ha per 5 cm of profile. In such a strong leaching environment and an active organic régime which are typical in these alpine regions it is not surprising that the rate of Ca-P transformation is much greater than that recorded by Syers et al (1969) for lower altitude Canterbury soils. Over a time scale of 6,000 years from the younger Selwyn soil to the older Templeton soils he determined a reduction in Ca-P of 715 kg/ha per 40 cm profile. In Figure 54, the inverse relationship between Ca-P and the "surface bound", Al, Fe-P in the
first three plant communities support conclusions reached by Williams (1965) in that during the early stages of soil formation the rate of dissolution of Ca-P exceeds the rate of which "surface bound P" is converted to "occluded P" with the result that the "surface bound P" increases. Further increases in the "surface bound P" is probably favoured in the madentielfulvic soil which is associated with community 5. Such a transformation has been regarded by Syers et al (1969), as a reduction in shift from "surface bound P" to "occluded" form of phosphorus.

Later stages of plant succession which leads to the development of various forms of grassland is associated with progressive leaching and podzolisation. There is, therefore, a tendency in this high precipitation zone, towards dystrophication. On the drier sites, characterised by the fulvic soils this process tends to be alleviated through the incorporation of new material from colluviation and possibly windblown debris. Plant succession will tend to manifest such dynamic conditions that exist with these composite soils. Hence on the upper and mid-slope of terrain associated with the cliniellefulvic soils plant communities will be degraded. On the toes and foot-slopes however, increased moisture and accumulation of eroded material will be conducive to more stable conditions and the progressive development of more stable grassland communities.

In the high precipitation zone of the Southern Alps, the climax community will be some form of dystrophic
grassland dominated by such species as *Chionochloa rigida*, or other species tolerant to dystric conditions. This community will have a high component of forbs whose status will depend upon biotic influences. Zonal soils associated with such climax vegetation will be strongly enleached fulvic soils of varying degrees of development.
CHAPTER VIII

A COMPARATIVE STUDY OF SOIL CLASSIFICATION
OF MOUNTAIN SOILS IN THE TEMPERATE ZONE

The study of mountain soils has tended to be neglected because of their low productivity, inaccessability and intolerance to manipulation. These conditions have, however, not prevented man from exploiting both the grasslands for grazing and the forest for timber to such an extent that the denuding of vegetation and soil in many regions has resulted in an irreversible process of the destruction of vegetative cover and accelerated erosion and hydrologic changes.

Apart from the value for pastoral assets, man has begun to realise that the water resources associated with the alpine regions are vital for domestic supply and the requirements for both irrigation and power generation for continued prosperity. Hence countries that are naturally endowed with large catchment areas of ice and snow are indeed fortunate, and the greater knowledge of such regions will be beneficial to future generations.

In the European alpine regions the value of water resources for power generation were realised several decades ago and these have been extensively developed. However, long before modern industrialisation, the more productive mountain soils supported grazing stock when neolithic communities roamed across Europe and since the social evolution of man they have formed an integral part
in supporting the agricultural populations that eventually settled and became sedentary agricultural communities. It is therefore not surprising that our knowledge of the European alpine ecosystem is more extensive than those of the under populated less fertile mountain regions. Thus any system of European soil classification takes into account the fact that soils have been managed for centuries at a relatively high level of cultural management.

A. EUROPEAN CLASSIFICATION

Systems of soil classification in Europe have tended to be dominated by Kubiena whose influence has been strongly felt not only in Western Europe, but also in the Soviet Union. Kubiena has produced a natural hierarchical soil classification based upon all the data that were available at the time.

Kubiena's three major orders of soil are delimited upon the basis of the soil water status: A, subaqueous soil, B, semi-terrestrial and C, terrestrial soils. Considerable importance has been given to the hydromorphic soils which in many instances have been raised to a zonal status. A significant feature of this classification is the great attention which is given to profile development with the initiation of the incipient A horizon to the formation of the B horizons.

The chief criticism that has been levelled at this system is its subjectivity and lack of quantitative criteria in the classification. Also some soil scientists object to the use of ecological terms to define soil units,
for example, "alpine sod podsol" (Retzer, 1956). However, it must be stressed that this system has evolved on European mountain soils which show a high degree of interrelationships between soil types and plant communities. Changes in soil types are frequently accompanied by changes in a particular component of a plant community.

A comparison between Taylor and Pohlen's classification with Kubiena's concepts is very difficult as the former is strictly based on soil genesis which lacks specific morphological criteria for defining classes.

In Table 69, Kubiena's system of classification has been compared against the system adapted from Taylor and Pohlen in this study. One of the major problems arising from this comparison is that Kubiena regards the rawmark soils as zonal or climatic climax soils whereas the relationships between skeletal soils, zonal and intra-zonal soils were only loosely defined by Taylor and Pohlen. This concept was substituted by the main energy status of the soils in terms of latitude, altitude and by soil moisture which they included in Category II of the classification. This strong emphasis on genetic processes and lack of morphological criteria in defining the soil groups has made the Taylor and Pohlen concepts sometimes difficult to apply in the field, hence importance has been attached to diagnostic horizons in this study.

In New Zealand elelithic soils include two forms of soils:
a) elelithic soils formed on erosion debris from degraded fulviform soils,
b) naturally occurring soils formed in situ.

Kubiena would regard the former soils probably as silicate syrosem or loess syrosem depending upon the parent material upon which they were formed. The latter soils would be regarded as alpine rawmark soils.

In Central European Alps, Kubiena has resorted to a low level of classification to include a wide variety of semi-terrestrial and terrestrial raw soils. These soils have been defined on the basis of parent material and the humus form. In comparing the eleclinic soils with Kubiena's scheme these soils could probably be divided into two parts on the basis of texture. The finer textured soils would have some affinity with the snow basin rutmark. Such soils in European literature have been referred to as "nivaler schneetalchenboden". The coarser textured soils would be closer to the rawmark soil.

Although at this stage our knowledge of New Zealand A/C soils are incomplete, they correlate with certain rankers of Kubiena's scheme of classification. In this study region the humi-eleclinic soils cover a limited area over which sampling sites are minimal and it is probable that they can be further sub-divided on the basis of humus form and profile development. Kubiena has divided these soils on such a basis: e.g. protoranker, moder ranker and dystrophic ranker.

Kubiena does not separate classes of soil relating to frost phenomena. Frost is associated with a wide range of our A/C soils hence minor geomorphic units of solifluction terraces, frost hummocks are typed by him according to underlying soils.
In comparing European alpine soils with those of the Southern Alps one must realise that the comparison is limited by the fact that the European mountain soils have developed over a wide range of parent material which has usually a higher nutrient status. There is thus a wider range of fertility, when comparing extreme eutrophic and dystrophic conditions.

With regards to the rejuvenation of soils in a flushing environment it is worth considering some of the remarks made by McVean and Ratcliffe (1962) referring to this subject on Scottish alpine soils. "In a strong leaching environment base-rich soils are maintained by natural irrigation, with water which is strongly charged with ions removed from the rock and other soils by leaching, or by mechanical instability due to gravity or frost movements."

The distribution of the organic soils in this study are very limited spacially. The platic soils compare favourably in all pedological aspects to the eutric and dystric semi-terrestrial anmoor soils of Europe. The morphology of the organic horizon of the lodi-elegelic soil appears similar to the dystrophic peat ranker. Further south in New Zealand increasing precipitation and lower temperatures could be conducive to more extensive development of lodic conditions which would ultimately assume zonal characteristics.

The classification of steepland soils made by Gibbs (1962) greatly over simplified a complex problem. To assume that all steepland yellow-brown earths and
podzolised yellow brown earths covering broad environmental gradients were largely composite soils influenced by an active drift régime is untenable. When making a comparison of the New Zealand system with the morphological classification of Kubiena one runs into more problems with the complex A, B, C soils than with the skeletal soils. The eldefulvic soils are poorly represented in this region, as they occur in the subalpine, alpine transitional zone. Morphologically the profiles are deeper with better developed B horizons than the alpine braunerde described by Kubiena and they, therefore, tend to fall in between the forest braunerde or oligotrophic braunerde and the alpine braunerde.

The intergrade status of the eldefulvic soils would have been raised to a higher order in terms of Kubiena. Depending upon the development of the B horizon the madenti-elefulvic soil would range between a moder gley to a podzolic-gley soil. The degraded soils cause the greatest problem for comparing with Kubiena's morphological system. These soils are obviously both morphologically and genetically different, as the degraded braunerde refers to a podzolised brown earth.

The strongly enleached elefulvic soil will approximate to the alpine zonal soil in the high precipitation regions. These soils will range from the strongly enleached elefulvic soil, to podic intergrades with an incipient $A_2$ horizon to a well differentiated $A_2$ in the elepodic soils. Such soils can be favourably compared with the degraded
braunderde and alpine sod podzol. These soils whose A, B horizon ratio was in the order of 3:1 were designated by Jenny (1941) as alpine humus soils. Braun-Blanquet and Jenny (1932) demonstrated that the genesis of alpine soils under the existing European alpine climate was subjected to progressive acidification. Hence on limestone parent material early soil development was associated with a rendzina profile with humus accumulations followed by a humus rich alpine humus soil.

The most extensive study of alpine humus soils in the Southern Hemisphere was made by Costin et al (1952) in the Snowy Mountains of Australia. In a later study, Costin (1955) regarded the Australian alpine climate more conducive for the formation of deeper more humified alpine humus soils, compared with Continental Alpine regions. A description of these soils in Australia indicates that the soil profiles are associated with a relatively shallow organic horizon, and a well developed humic A horizon with an A₂ horizon overlying parent material. Such soils could be compared to Kubiena's moder ranker, or in the cases where A₂ horizons are well developed, to podzol rankers. In this study because of the strong flushing steepland environment, and the immaturity of the A/C soils, A₂ horizons are not developed and the closest approximation to these Australian soils would be humi-eleclinic soils, or in the case of the soils influenced by cryoturbation, lodi- or fulvi-elegelic soils.

At the higher latitudes in the northern hemisphere lower temperatures are more conducive for the formation
of zonal peats. McVean and Ratcliffe (1962) found that the most widespread soil type in the Central and Northern Scottish Highlands was the blanket peat. In the North-East Scottish Highlands, Romans et al. (1966) concluded that with increasing altitude, above 1,800 ft, there is a disappearance of the iron pan and a recession of the bright podzolic B horizon which are substituted by a thick A horizon with an attenuated A<sub>2</sub> horizon.

B. NORTH-AMERICAN CLASSIFICATION

A comparison of the United States 7th Approximation (Soil Survey Staff, 1960, 1967) with other systems is difficult due largely to the fact that the system is characterised by its lack of flexibility and also previous studies of alpine soils have tended to use the former 1938 system of classification which was based largely upon Marbutts concepts.

Table 69 indicates that four orders of the 7th Approximation compare, within very broad limits, with the higher groups of the New Zealand system. The entisols which are equivalent to the skeletal soils cover sub-orders psamments and aquents. The psamments have no diagnostic horizons that can be identified and are lower in clay having a fine loam sand or a coarser texture. These soils have been equated with the elelithic, and rawmark soils. Throughout many of the great soil groups the relatively high mean temperatures for cryic soils of less than 8°C for their upper limit includes a very large
section of the high country yellow-brown earths into this group. A later revision of the soil temperature régime in 1973 qualified this in saying that soil with an 0 horizon which was saturated during part of the summer and a mean summer temperature of less than 6°C were regarded as a cryic soil. In Table 69 the cryaquents are saturated during part of the summer months and with the 0 horizon they can be correlated with the humi-eleclinic soil.

Although there will be some doubt as to many of the equivalents of soils at the sub-order level of classification the majority of the entisols in this study area tend to be saturated and show some form of seasonal gleying hence they can be regarded as aquents.

The organic soils which have been designated as platic and lodic intergrades would be equated with the order of histosols. The lower orders which are based upon the degree of decomposition of the organic material contain two sub-orders, folists and fibrists in which the lodic intergrade and the platic soils are comparable. The folists are represented by organic matter which is moderately decomposed, compared with relatively undecomposed fibrists. The great soils groups have been separated on the basis of temperature and the origin of the organic material. In the case of the soils in this study area none of the organic component is formed from Sphagnum. The fact that the mean annual temperature is lower than 8°C qualifies these soils as boro-folists, or boro-fibrists.

The order inceptisol includes the brown-earth group of soils hence show a greater profile differentiation.
They have a well developed A horizon and a cambic B horizon. At the present level of classification it is impossible to correlate these with the elefulvic soils in this study. At the lower orders of the inceptisols, however, there are a number of diagnostic factors which compare favourably, these include:

i) Free draining soil and are not saturated throughout the year.

ii) They have a $5^\circ$C difference between mean summer temperature and mean winter soil temperature. The inceptisols have a higher clay content, (35%) than the elefulvic soils in this study area, hence the exchange complex will be dominated by alumino-silicate clay minerals.

iii) Base saturation $< 50\%$.

The madenti-elefulvic soils are saturated for 6 months and they, therefore, approximate with the aquepts.

Of the elefulvic soils, the clini-intergrades have the lowest organic matter content and lack umbri epipedon. They may therefore be considered to correlate with the ochrepts rather than with either the umbrepts or the aquepts.

The strongly enleached elefulvic soils are not sufficiently podzolised to have the bleached $A_2$ horizon, associated with the more classical podzol. However, a more highly developed sesquioxidic horizon enables the soils to be correlated tentatively with spodosols.
In the alpine zone of the Coastal and Interior Mountains of British Columbia, Sneddon et al (1972) recorded incipient podzols which were more podzolised than those recorded in the Ben Ohau Range. In the Canadian Classification, these soils were regarded as mini-humo-ferric podzols and were compared to the typic-cryorthod of the 7th Approximation.

Retzer used ecological nomenclature to define taxonomic units of a series of alpine soils in the Rocky Mountains of Colorado. The alpine turf soils were compared by Retzer with the ando-humus soils of Jenny (1948) except that the turf soils were more acid and had double the carbon content. With increasing moisture alpine meadow soils occurred, and bog soils under semiterrestrial conditions. In these circumstances the alpine turf soils were probably zonal whilst the other two types were intrazonal. Retzer, however, regarded these soils as representing three great groups.

Nimlos and McConnell (1965) in Montana, U.S.A., studied three soils, one which they regarded similar to Retzer's turf soils, the other soil compared with the bog soils, whilst the third other soil was derived from calcareous parent materials and had rendzina characteristics. The authors considered that the Ptarmigan series (turfsoils) were equivalent to the spodosols, the poorly drained organic soils to the histosols, whilst the soil on calcareous parent material resembled the mollisols.

The generally severe alpine environments, associated with weak chemical weathering, a slow production of
organic material accompanied by weak mineralisation is obviously not conducive for rapid soil development. Such manifestation of the environment results in a high degree of similarity of these soils. They are generally shallow in depth, poorly structured and have limited horizon differentiation. However, although alpine soils are genetically and morphologically similar, there is a complete lack of unified classification. It may be possible that in the future with a greater knowledge of these soils a more rational quantified approach could lead to an overall unified concept.
CHAPTER IX

CONCLUSIONS

The object of this project was to consider the relationship and interaction between physical and environmental parameters upon pedogenesis and plant systems in the alpine and subalpine zone in the Twin Stream Catchment of the N.E. Ben Ohau Range.

A. PHYSICAL ENVIRONMENT

1. Superficial geomorphology

The ground surface is largely controlled by three morainic formations derived from indurated greywacke and low grade schist. These formations may be listed as follows:

i) Ferintosh formation: 2,800 - 3,000 B.P.

ii) Jacks Stream formation: 1,000 B.P.

iii) Dun Fiunary formation: 250 - recent B.P.

The formations have been mapped in detail at a scale of 1/72360.

2. Climate

There was a correlation between altitude and aspect which has a profound effect upon the natural systems. These effects can be summarised as follows:
i) The environmental lapse rate on the E.S.E. aspect is approximately 0.66°C per 100 m.

ii) At an altitude of 1,480 m (alpine zone, lower limit) 689.5 mm of precipitation was recorded as opposed to 357.1 mm at an altitude of 850 m (montane zone) over a five month period (December - May).

iii) Annual records of potential evapotranspiration were less than precipitation and there is thus a water surplus. More detailed hourly and daily measurements during summer, early autumn indicate that P.E. is in excess of precipitation. This was particularly so on the warmer aspects.

iv) North and west aspects are associated with a relatively high diurnal range of temperature throughout the year, which is nearly twice that on the south and eastern aspects. The highest diurnal range of temperature occurs in December and March.

v) Snow covers persisted twice as long in the sub-alpine and alpine zones on the south and east aspects than on the north and west ones.

vi) Seasonal snow was associated with a gradual accumulation period in winter and early spring, followed by rapid ablation in spring and early summer.

vii) A short seasonal snow cover on the warmer aspects is conducive to a vigorous freeze-thaw process.
viii) Seasonal differences in soil temperature are greatest on the south aspect than on the northern aspects.

ix) Soil temperatures (mean monthly) are significantly higher on warm aspects than cold aspects at all altitudes.

3. Energy status of the soils

In order to differentiate the soil energy with regards to the interaction between altitude and aspect, a number of empirical pedogenic indices were calculated, following Papadakis, these included:

i) Humidity coefficients based on precipitation, saturation deficits and temperature.

ii) Growth index based on humidity coefficients and temperature.

iii) Humolytic index based upon the growth index and humidity coefficient. This is used as an index of soil organic matter decomposition.

iv) Humogenic index which was based upon the humolytic index, and is related to the content of soil organic matter.

From these indices it was concluded that there was a reduction in the energy status of the soils, not only with increased altitudes but also on the south and east aspects compared with north and west. This was related to reduction in growth and organic matter decomposition and is reflected as an increase in the carbon nitrogen ratio of soils.
B. SOIL CLASSIFICATION

A classification was made, based on Taylor and Pohlen's technical classification supported with detailed morphological and analytical data. Because of the complexity of the various soil forming factors, soils are very diverse. These soils have been classified to the Category III level of the technical classification.

A soil map was made at a scale of 360 m = 2.5 cm (18 chns = 1 inch). Because of the extreme variability of the soils they have been mapped as complexes and associations as it was impossible to separate individual units at this scale.

1. Microscopic fabric analysis

Organic material was determined by hand and thin sections according to Kubiena and Barratt as follows:

<table>
<thead>
<tr>
<th>Barratt</th>
<th>Kubiena</th>
<th>Organic Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Ligno-parenchymal humiskel</td>
<td>Acid raw humus</td>
<td>Acid mor</td>
</tr>
<tr>
<td>ii) Humiskel-lithiskel with some humicol</td>
<td>Silicate moder</td>
<td>Moder</td>
</tr>
<tr>
<td>iii) A complex of ligno-parenchymal humiskel with platy humicol</td>
<td>Raw humus with Lodic peat dystrophic peat humicol</td>
<td></td>
</tr>
<tr>
<td>iv) Humicol-lithiskel complex with some mullicol</td>
<td>Mull-like-moder Mull</td>
<td>acid organic peaty material</td>
</tr>
<tr>
<td>v)</td>
<td>Anmoor</td>
<td>Acid organic peaty material</td>
</tr>
</tbody>
</table>
2. Diagnostic horizons based upon soil forming properties

In order to recognise the basic characteristics of the soil profile a number of diagnostic horizons have been determined:

i) Diagnostic O horizons: Lodic O
   Platic O (a) Dystric form
   (b) Eutric form
   Moroid O

ii) Diagnostic A horizons: Raw A
    Humic A
    Umbric A

iii) Diagnostic B horizons: Incipient B
     Cambic B

iv) Diagnostic gleyic horizons

v) Diagnostic C horizons: Lithic C
   Regic C

vi) Other diagnostic criteria: Fragmental layers
    Alluvial layers
    Patterned ground

3. Nomenclature of the soil classes and intergrades have been determined as follows:

i) Elegelic soils
   Intergrades: Lodii-elegelic
   Fulvi-elegelic

ii) Eleclinic soils
    Intergrade: Humii-eleclinic

iii) Elelithic soils

iv) Eleluvic soils

v) Eleplatic soils
   Intergrade: Luvi-eleplatic
   Phase: Eutri-eleplatic
vi) Elefulvic soils  
Intergrades: Madenti-elefulvic  
Clini-elefulvic  
Phase: Strongly enleached elefulvic

vii) Eldefulvic soils  
Intergrades: Madenti-podi-eldefulvic  
Clini-eldefulvic  
Phase: Strongly enleached eldefulvic

4. Altitudinal zonation

The transition between elefulvic and eldefulvic zones is a continuum. Altitudinally the transition has been placed at 1,400 - 1,500 m which coincides with a mean annual temperature of about 4°C or a humogenic-humolytic index of approximately 0.75.

C. PEDOGENESIS

1. Environmental control upon soil forming factors

Because of strong environmental control upon soil forming factors, there is a high degree of soil variability. The soils can be arranged into polysequences which show a pedogenic relationship between altitude, physiography, temperature, moisture, parent material and time. On the older Perintosh and Jacks Stream moraine, monosequent trends relating to time as the variable factor, could be observed particularly with soils on the dark faces.

Two alto-sequences of soils were chosen on the basis of aspect to study the changes in soil properties and genesis with altitude and climate.
The south aspect alto-sequence had a hydrous soil moisture régime, in which the soils are above field capacity throughout the year. These soils are associated with:

i) A seasonal microclime with contrasting warm snow free periods and cold snow periods. A humolytic, humogenic ratio varying from 0.700 to 0.970.

ii) Soils are under the influence of snowmelt waters throughout the summer which extends usually into the autumn.

iii) The soils are influenced by a strong organic régime which affects soil properties particularly in relation to leaching and iron eluviation.

iv) Flushing from snowmelt results in rejuvenation through amendments of nutrients and fresh sediment.

v) The soils show iron eluviation with some incipient podzolisation.

vi) Compared to soils on the warmer aspects they are more strongly gleyed, they have greater quantities of fine material (< 2 mm) and older soils are associated with moroid organic forms.

vii) Chemically the soils are:

(a) Low in basic elements.

(b) A reduction of total calcium and magnesium with decreasing altitude accompanied with increased podzolisation.
(c) Phosphorus transformations show a reduction of the "Ca-P" fraction which disappears on the Jacks Stream formation.

(d) These soils have greater concentrations of organic phosphorus than those on the warmer aspects.

(e) "Occluded-P" is high in the young soils derived from glaciofluvial sediments.

viii) Mineralogically X-ray diffractions of the clay fraction (0.2 μ - 2 μ) indicate a low degree of weathering with a high content of interlayered material suggesting replacement of the basic cations in the micaeous minerals by alumina. A high content of amorphous hydrous oxides and high phosphate retention values, (sodium fluoride test) suggest that most of the feldspar has been hydrolysed to amorphous forms.

ix) Hydrologically the soils have high storage values, and slower moisture release curves.

In contrast to this alto-sequence the north aspect soils had hygrous moisture régimes, as they were liable to be field capacity if only for a short period of time during the year. These soils were associated with:

i) A microclimate which had not such a marked difference between the warm and cold season. A humolytic, humogenic index ratio varying from 0.500 to 0.700.

ii) Because of a reduced period of insulation from seasonal snow soils were under a strong freeze-
thaw régime.

iii) Rejuvenation of the soils is mainly from colluviation supplemented by some aeolian deposition.

iv) Seasonally gleyed soils are topographically controlled and are therefore an intrazonal feature.

v) A zone of chemical enrichment occurs on the Ferintosh formation.

vi) Lower phosphate retention values on these soils suggest a lower content of amorphous hydrous oxide than a hydrous sequence.

vii) Hydrologically the soils during a dry summer period are subject to moisture stress. Moisture retention values are generally lower and infiltration rates higher than those of the hydrous sequence.

viii) Diagnostic horizons are indicative of the main pedological differences between the soils with the hydrous and hygrous moisture régimes. They are summarised as follows:

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Hydrous soils</th>
<th>Hygrous soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Lodic, platic, moroid</td>
<td>Not developed</td>
</tr>
<tr>
<td>A</td>
<td>Humic, umbric, gley</td>
<td>Humic, umbric</td>
</tr>
<tr>
<td>B</td>
<td>Cambic and gley</td>
<td>Cambic, fragmented layers</td>
</tr>
<tr>
<td></td>
<td>alluvial layers common</td>
<td></td>
</tr>
</tbody>
</table>
2. Periodicity

The contrast between the soils with the hydrous and hygrous moisture régimes is further reflected in the forms of periodicity. These can be summarised as follows:

i) The hydrous soils tend to be autochthonous in origin having been less disturbed from erosion and deposition phases.

ii) Hydrous soils subject to periodic burial by fresh sediment from glacio-fluvial meltwaters.

iii) Periodic rejuvenation particularly in the gelic soils by mixing of fine and organic material within profile.

iv) Periodic flushing by meltwater insures transference of colloidal and fine fraction material in suspension.

The drier hygrous soils are associated with:

i) Strongly influenced by periodic erosion and deposition phases.

ii) Deposition is usually in the form of colluvial drift in which periodic rejuvenation takes place with the incorporation and mixing of new material.

iii) Deposition of aeolian material.

D. PLANT COMMUNITIES

1. Charcoal, dated 1,150 B.P., at the top of a soil which has a lower stable profile suggests the onset of instability about this time.
2. The instability which is widespread coincides with the reduction of water, particularly in summer, owing to the recession of perennial and seasonal snow.

3. The montane, subalpine zones are associated with three erosion and deposition cycles, which following Butler's concepts have been referred to as K1, K2, K3 ground surfaces starting with the youngest in descending order.

4. The younger K1 surface is characterised by a high rating of *Trifolium repens* whilst the older K3 surface has a high rating of shrubs. The changes in plant communities from the younger to the older surface coincides with a decrease in both pH and base saturation.

5. Analytical and synthetic phases of vegetation rating originated by Zurich-Montpellier, with modifications by Poore, indicate that many of the plant communities are fragmented due probably to broad environmental gradients and a long history of human interference.

6. Two subalpine grassland communities were recognised:
   
   i) *Chionochloa rigida*, *Poa colensoi* dystric grassland;
   
   ii) *Chionochloa rigida*, degraded grassland.

   and three alpine grasslands:

   i) *Poa colensoi*, eutric grassland
   
   ii) *Poa colensoi*, *Celmisia lyallii*, dystric grassland
   
   iii) *Poa colensoi*, *Celmisia lyallii*, degraded grassland.

7. Three nodu with one fragmented nodum are associated with the hygromorphic soils, these may be listed as follows:
1) Chionochloa oreophila, nodum
2) Marsippospermum gracile, Celmisia haastii, nodum
3) Celmisia hectori, nodum
4) Fragmented noda of bryophytes and vascular hydrophytes.

8. Unclassified rupicolous noda.

9. Linear autogenic succession was influenced by grazing in the alpine zone, and both grazing and burning in the subalpine zone. The zonal community would probably consist of Chionochloa rigida, Chionochloa macra grasslands. The present seral alpine grasslands are dominated by Celmisia lyallii and Poa colensoi.

10. On the hygrous soils the vegetative cover is unstable and suffers varying degrees of destruction by accelerated erosion. Rejuvenation on accumulated soils in more stable localities at the mid and toe of the slope has taken place.

11. Plant succession on the hydromorphic soils is related to:

   i) Decrease in the base content
   ii) Increasing podzolisation
   iii) A reduction in acid extractable phosphorus "Ca-P" which amounts to about 60% of the total during 1,500 years.
E. A COMPARISON OF MOUNTAIN SOIL WITH OTHER REGIONS, IN SIMILAR LATITUDES

Other classifications, particularly those of Europe and North America tended to have more clearly defined morphological criteria to designate the various soils than has been developed by the Taylor and Pohlen system in New Zealand.

Although the New Zealand technical classification is genetically orientated, lack of knowledge of environmental processes tends to inhibit the development of this system.

The major difference between the mountain soils in New Zealand and other parts of the world is the dynamic nature of New Zealand soils, particularly when under the influence of processes which tend to reduce the effectiveness of precipitation. Thus there is a considerable contrast between aspects in the transition between humid and perhumid zones which is not well expressed or documented in other parts of the world.

F. RECOMMENDATIONS FOR FUTURE RESEARCH

Taylor and Pohlen's genetic classification was never substantiated with morphological criteria for mountain soils. The recognition and classification of pedological units will be greatly enhanced if a more definitive system is used, based on morphological criteria, chemical, physical and micro-morphological criteria. The establishment of a number of diagnostic horizons for the
individual soil profiles will greatly facilitate correlation and interpretation from the lowest level of classification to the higher grouping at the sub-classification and classification levels.

The key, however, to a greater understanding of the mountain soils of the marginal grasslands in the South Island is a wider comprehension of the processes that control and govern the natural system. As a suggestion for future research two levels of operation are recommended:

i) Research at relatively low-intensity over broad environmental gradients. The approach to this project will be similar to that adopted in this present study, i.e. the acceptance of a well tried system of vegetation study, such as that used by the Zurich-Montpellier School, which can be adapted to the conditions in this country. This vegetation survey should be integrated with field and laboratory studies of the soils at a similar level of intensity that has been used in the present project.

ii) High intensity of work within a small area. This will involve a limited and more intensive study of a particular group or groups of soils in relation to physical and chemical variations. These studies could be incorporated into the influence of various cultural practices, such as fertiliser amendments, animal husbandry, and introduction of plant materials into the natural systems. A facet of these suggested studies, which may prove
scientifically profitable, would be the effect upon the soil in relation to nutrient cycling within a irrigation system.
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