PEDOGENESIS AND VEGETATION TRENDS IN

THE ELEFULVIC AND ELDEFULVIC ZONES

OF THE NORTH - EAST BEN OHAU RANGE,

NEW ZEALAND.

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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.   Harbeck 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 evapo-
transpiration. 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 estim-
ated 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 zones 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 α 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 predominate 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 (Pa + Pf) 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)

ELDEFULVIC

CLINI-ELDEFULVIC   FULVI-ELDECLINIC

ii)

ELDEPODIC

CLINI-ELDEPODIC   PODI-ELDECLINIC
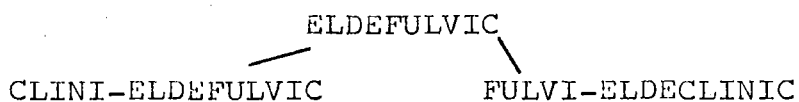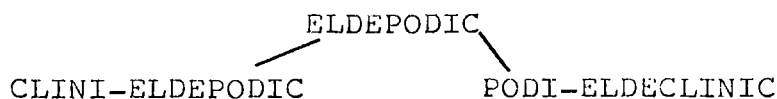
On the Old Man Range of Central Otago McCraw (1962)

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 redeposi-
tion 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 susceptability 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 stoni-
ness 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 zona-
tion 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, oligioclase, 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 Aranuian 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 home-steads 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 $1^{o}C$ or $2^{o}C$ 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 shows 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 subsericea 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:

i) 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:

   i) 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 $\pm$ 1.5% and
that for humidity $\pm$ 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, $\pm$ 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 eva-
poration.

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 record-
ing air temperature and humidity.   One mechanic-
al 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-pen 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 pedo-
       genic 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

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) an "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 vegeta-
tion 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

ELEFULVIC

MADENTI–FULVIC   CLINI–FULVIC   FULVIC
                                                   (ENLEACHED PHASE)
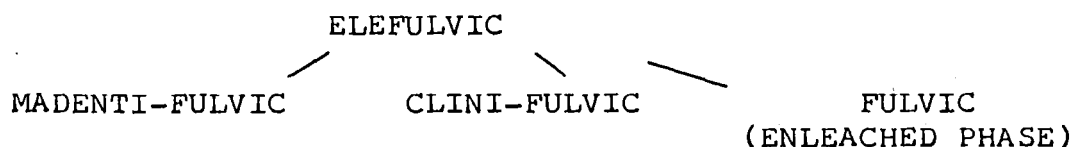
The prefixes, which have been used to form inter-
grades are all terms adapted from Taylor and Pohlen's
concepts.   In one case only have two terms been used
which are not included in their classification: namely,
eutrophic and dystrophic, both terms used frequently in
pedological literature referring 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 associa-
tion, 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 $20^{\circ}C$;

b. K saturation at $20^{\circ}C$;

c. K saturation heated to $350^{\circ}C$;

d. K saturation heated to $550^{\circ}C$.

The saturated soil samples were mounted on porous plates approximately 3 cm^2 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 Gunn, 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 per-cent 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 pre-dominance 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 distribu-
tion of the younger Ferintosh moraines and the distribu-
tion 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 (Chiono-
chloa 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 moranic 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 attri-

butable 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 topo-
graphy 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 ($<$ 2mm).
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 differen-
tiate 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 Ferintosh 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 evolu-
tion 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 through-
out 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 distribu-
tion 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 relation-
   ship 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 relation-
ships 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 snow-

pack 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 distri-
bution of the snowpack (Figure 15). It
will be seen that although snow fell to low
levels in 1969 a combination of low precipi-
tation 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
$18^{\circ}C$ occurred during January and February as
opposed to $15^{\circ}C$ and $13^{\circ}C$ 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, sub-
surface 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 $8.1^{\circ}C$
    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 catch-
    ment. 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 evapotranspira-
tion 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 evapotrans-
piration.   It will be noted that at ground

surface on the 1,560 m (S.E.) site precipitation
was 3.1 greater than potential evapotranspira-
tion whilst on the north aspect it was approxi-
mately 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 destruc-
tion 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 <u>the difference in actual vapour pressure and</u>

        <u>the maximum vapour pressure at the prevailing</u>

        <u>temperature</u>.   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 precipita-

        tion 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 evapo-
transpiration 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 $0^{\circ}C$
and zero humidity photosynthesis is zero.   Photo-
synthesis 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
$25^{\circ}C$ 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'   =   growth index

            h   =   the duration of day in hours

            H   =   the humidity coefficient of the month

            T   =   the temperature ^{O}C.

The growth index 'A' is very low for temperatures below $4^{O}C$ and increases gradually above this temperature. Maximum growth occurs at a humidity coefficient of 0.3 and a temperature of $20^{O}C$.

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 $10^\circ C$ 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:

$$H1 \quad = \quad e^{ct1} + e^{ct2} + 2e^{ct3}$$

where   H1   =   humolytic index

         t1   =   temperature, $^\circ C$, for the warmest month

         t2   =   temperature, $^\circ C$, for the coldest month

         t3   =   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:

$$Hg \quad = \quad \frac{150\sqrt{A}}{H1}$$

where   Hg   =   humogenic index

         A   =   growth index

         H1   =   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

$Hl = (7.4) + (0.9) + 2(2.9) = 14.1$

$$Hg = \frac{150\sqrt{A}}{Hl}$$

$$= \frac{150\sqrt{0.34}}{14.1} = 6.20$$

	Hg	Hl	Hg/Hl
∴	6.20	14.1	0.439

b. North aspect, 1,200 m site

$Hl = (5.7) + (1.0) + 2(2.1) = 10.9$

$$Hg = \frac{150\sqrt{A}}{Hl}$$

$$= \frac{150\sqrt{0.22}}{10.9} = 6.45$$

	Hg	Hl	Hg/Hl
∴	6.45	10.9	0.591

c. South aspect, 1,200 m site

$Hl = (4.9) + (0.7) + 2(1.9) = 9.4$

$$Hg = \frac{150\sqrt{A}}{Hl}$$

$$= \frac{150\sqrt{0.18}}{9.4} = 6.76$$

	Hg	Hl	Hg/Hl
∴	6.76	9.4	0.719

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

$Hl = (4.0) + (0.6) + 2(1.5) = 7.6$

$$Hg = \frac{150\sqrt{A}}{Hl}$$

$$= \frac{150\sqrt{0.14}}{7.6} = 7.38$$

	Hg	Hl	Hg/Hl
∴	7.38	7.6	0.971

In Figure 23 the humogenic, humolytic index
has been plotted against altitude to indi-
cate 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 transfor-
mations 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 co-
       efficient 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 environ-
ment under which soil formation has taken place.   The
classification has followed Kübiena (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 undecom-
     posed 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.

iii) Argillicol: colloids dominate fabric.

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, Kübiena, 1953)

Plate 12B — Profile reference: MB2

Horizon: A   Depth: 0 - 2 cm

Vegetation: <u>Marsippospermum gracile</u>

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 <u>Celmisia</u> 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 (<u>Dracophyllum</u>, <u>Coprosma</u>, 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, Kübiena).

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 unde-
composed 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_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.

Remarks: A certain similarity with mull-like moder of the alpine sod braunerde (Kubiena, 1953, 1969).

Plate 13D   -   Profile reference: TW9

Horizon: B_1 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 (Kubiena)

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, Kubiena) 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 Kübiena, 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 forma-
tion 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 accu-
mulation 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 disgnostic 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 ($<$ 2mm) dominated by silts and sands. As there is often an abundance of water available in this environ-ment 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 resorted 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 represent-
ing 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. Cryo-
   turbic 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 vegeta-
tion which in turn is controlled by the micro-
topography.   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 defla-
tion 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:

Horizon	Depth (cm)	Description	Diagnostic Horizon
O_1	0 - 5	Undecomposed root mat))	
O_2	5 - 14	Black (5yr 2/1 peaty loam))	
O_g	14 - 31	Dark brown (10yr 4/3)) peaty silt loam spot) gley))	lodic O
(u)O[2]	31 - 34	Black (5yr 2/1) stony) peaty loam)	

[1] Refers to top 5 cm of soil.

[2] An horizon buried in situ through cryoturbic
processes.

Horizon	Depth (cm)	Description	Diagnostic Horizon
(u)G	34 – 41	Light grey (5y 7/1) silt loam	gley
(u)B	41 – 51	Light olive brown (2.5 yr 5/6) stony silt loam	Incipient B [1]

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:

Horizon	Depth (cm)	Description	Diagnostic Horizons
A_1	0 – 8	(5y 5/2) olive loamy sand	)
(u) A	8 – 25	(5y 5/3) olive, stony loam sand	) Humic A)

[1] Possible relic feature.

Horizon	Depth (cm)	Description	Diagnostic Horizons
(u) B	25 - 28	(5yr 5/8) yellowish red) stony sand)	Incipient B
C	28 - 48	(2.5y 5/4) light olive) brown stony loamy sand)	Lithic C

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:

Horizon	Depth (cm)	Description	Diagnostic Horizons
A	0 - 1	Moder	Raw A
C	1 - 6	Solifluct	Lithic

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 chiono-philous plants. Humogenic-humolytic _____ 0.78 - 0.90 winter and spring temperatures $0^{o}C$. 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:

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

Dominant processes:

    Strong organic régime. Active flushing and alluvia-
tion 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 $0^{o}C$ - $3^{o}C$. 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:

Horizon	Depth (cm)	Description	Diagnostic Horizons
A	0 - 2	Brown (7.5yr 3.2) stony sandy loam	Raw A
C	2 - 10	Rock fragments	Lithic C

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:

(O), A, C soils.

Profile:

Horizon	Depth (cm)	Description	Diagnostic Horizons
A	0 - 25	Greyish brown (2.5yr 5/2) sand	Raw A
GC	25 - 100	Pale olive (5yr 6/3) loamy sand	Regic C
uB	100 - 120	Yellowish brown (10yr 5/6) sand	Buried soil
uC_1	120+	Glacio-fluvial outwash	

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 $0^{o}C$ - $1^{o}C$ 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:

O, (A), C soils.

Profile:

Horizon	Depth (cm)	Description	Diagnostic Horizons
O_1	0 - 3	Amorphous peat	Platic O
C_1	3 - 4	Yellowish brown (10yr 5/4) loamy sand	
O_2	4 - 7	Very dark brown (10yr 2/2) peaty loam	Dominantly
C_2	7 - 10	Yellowish brown (10yr 5/4) silty loam	regic with platic
O_3	10 - 12	Very dark brown (10yr 2/2) peaty loam	layers
C_3	12 - 17	Yellowish brown (10yr 5/4) loam sand	
O_4	17 - 19	Very dark brown (10yr 2/2) peaty loam	
C	19+	Water table overlying out-wash gravels	Lithic

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
$1^{\circ}C$ - $2^{\circ}C$.   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 ele-
platic (eutric phase) refers to organic soil with relati-
vely 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:

    O, GC soils.

Profile:

Horizon	Depth (cm)	Description	Diagnostic Horizon
O	0 – 15	Amorphous peaty	Platic O
G	15 – 30	Light grey to grey (5yr 6/1) sand	)
			) Gley
uO	30 – 35	Dark reddish brown (5yr 3/2) Anmoor peat	)
			)
uG	35 – 54	Grey 5y 5/1) gritty silt loam	)
C_1	54+	Colluvial gravels	Lithic C

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 influ-
ence 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 consider-
ably 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 altera-
tion 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:

Horizon	Depth (cm)	Description	Diagnostic Horizon
A	0 - 15	Dark yellowish brown (10yr 4/4) loamy sand	Umbric A
B_1	15 - 22	Yellowish brown (10yr 5/6) stony loamy sand	))) Cambic B
B_2	22 - 37	Yellowish brown (10yr 5/8) stony sand	)))
C_1	37+	Fragmented schist	Lithic C

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:

Horizon	Depth (cm)	Description	Diagnostic Horizon
O	0 - 4	Dark brown (10yr 3/3) peaty loam	Moroid O
A	4 - 11	Dark grey (10yr 4/1) silt loam	Umbric A
B	11 - 31	Brownish yellow (10yr 6/6) stony silt loam	Cambic B

Horizon	Depth (cm)	Description	Diagnostic Horizon
C_1	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 $1.0^{\circ}C - 3.0^{\circ}C$. 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:

Horizon	Depth (cm)	Description	Diagnostic Horizon
A	0 - 10	Dark greyish brown (10yr 4/2) gritty sandy loam	Umbric A
uA/B	10 - 20	Yellowish brown (10yr 5/4) stony sandy loam	Cambic B (with frag-mented layers)
uB/C	20 - 35	Yellowish brown (10yr 5/4) stony sand	Lithic C

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 inter-grade).

In the summer these soils may fall below field capacity. Humogenic-humolytic index about 0.75 with a mean annual temperature approximately $3.5^{\circ}C$ - $4.0^{\circ}C$. 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 <u>Chionochloa</u> <u>rigida</u> with some shrubs.

6(d). Madenti-elefulvic (see Plate 26, Chemical and

      Physical Analyses, Table 50 and 51)

General specifications:

    A, G, B, C soils.

Profile:

Horizon	Depth (cm)	Description	Diagnostic Horizon
A	0 - 4	Very dark brown (10yr 2/2) peaty loam	Moder silicate
G	4 - 39	Light grey to grey (5yr 6/1) silt loam	Gley G
B	39 - 64	Brown to dark brown (7.5yr 4/4) stony sand	Cambic B
C_1	64+	Outwash gravels	Lithic C

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 $1^{\circ}C$. 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
elefulvic (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 $3.5^{\circ}C$ - $4.0^{\circ}C$ 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 $4.0^{\circ}C$
(5 cm below surface) mean annual temperature as the divi-
sion between the elefulvic 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 elefulvic 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.

i) 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.)

<u>General specifications</u>:

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

<u>Profile</u>:

Horizon	Depth (cm)	Description	Diagnostic Horizon
O	0 - 6	Brown to dark brown (10yr 4/3)	Moroid O
A	6 - 16	Dark greyish brown (10yr 4/2) silt loam	Umbric A
B_1	16 - 31	Yellowish brown (10yr 5/8) silt loam	Cambic B
B_2	31 - 91	Brownish yellow (10yr 6/8) silt loam	
B_3	91 - 101	Brown (7.5yr 3/2) stony silt loam	
C	101+	Schist fragments from colluvium and solifluct	Lithic C

<u>Dominant processes</u>:

    Strong organic régime, with mottling and seasonal
gleying in the B_2 horizon.

<u>Environment</u>:

    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 steepland 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-eldefulvic (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.

Profile:

Horizon	Depth (cm)	Description	Diagnostic Horizon
A_1	0 - 15	Dark grey (10yr 4/1) silt loam	) Umbric A) (with frag-) mented layer)
uA_1	15 - 19	Dark yellow brown (10yr 4/4) stony silt loam	)))
uA_3	19 - 41	Yellow brown (10yr 5/4) gritty loamy sand	)))
uB	41 - 71	Brownish yellow (10yr 6/1) stony loamy sand	Cambic B
C_1	71+	Schist and argillite fragments	Lithic C

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 $5.5^{\circ}C - 6.0^{\circ}C$, with a humogenic-humolytic index about 0.50. Altitude: $\triangleq$ 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:

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

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 eldefulvic 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 compli-
cated. 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. = $\frac{1}{14,256}$. 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 transi-
      tion 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
alpine [1] soils which were associated with well developed
0 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.

3. Summary of distribution of soil classes.

   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 develop-
      ing.

  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 snow-
melt 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 environ-
ment 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 : $S = f(cl, 0, r, p, t)$, 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 $S = f\ (T, M)\ 0, r, p, t$

where $T\ =\ $ temperature

                       $M\ =\ $ 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 frame-
work 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 mechnical 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

earth. (< 2 mm) in soil.   Figure 29 shows the distribu-
tion 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 madenti-
podi-eldefulvic (10 - 20%) and clini-eldefulvic
soils (5 - 8%), on the Ferintosh 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
(Iodic) 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 altitu-
dinal 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-
eldefulvic (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 under-gone 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 S_1O_2/R_2O_3 ratio from
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 trans-
formations, 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 distri-
bution of the various phosphorus fractions,
(Walker and Adams, 1959) rapid analytical method
was used. Abbreviated forms of the various
fractions have been referred to:

Pf = occluded phosphorus

Po = organic phosphorus

Pa = available phosphorus (Ca-P + Al, Fe-P)

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-
eleclinic 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 rejuvena-
   tion. 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 develop-
   ment.

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 un-
weathered 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.

3. Soil mineralogy of the alto-sequences.

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 mu - 50 mu size range, was
separated from parent material and the clay fractions (0.2 mu -
2 mu) 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 through-
out 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 10Å and therefore suggest the presence of vermiculite. Heating to 550°C with potassium saturation, resulting in an increase in peak height to 14Å probably indicates the presence of primary chlorite.

Several samples when treated with potassium and heated to 550°C shows collapse of the 14Å 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 inter-
grades.

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 pF 2.52 (field
capacity for the upper 30 cm (12"))of solum, the
Australian alpine humus soils are summarised as follows:

   i) Meadow   0.253

  ii) Transitional alpine humus   0.233

 iii) 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 dura-
tion 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 preci-
pitation 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-evapotrans-
piration 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-elefulvic 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 redistri-
bution 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). ^{I}ves suggested that the specific gravity of
apatite (3.10 - 3.35 g/m^3) would preclude it being blown
to higher altitudes (if the source is valley floor), hence
larger quantities of available phosphorus at lower alti-
tudes 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 colluvia-
tion 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 catch-
ment 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 ecolo-
gical 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 <u>Podocarpus</u> <u>hallii</u> (identi-
fied 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 stabi-
lity 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 contro-
versial issue.

In the Twin Stream catchment an isolated stand of
scrub which includes some moribund trees of <u>Podocarpus</u>

hallii 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.   Through-
out 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 (_Ant hoxanthum 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 approxi-
      mately 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 <u>Chiono-</u>
<u>chloa rigida</u> grassland being invaded by adven-
tive 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 <u>Festuca</u> <u>novea-zelandiae</u>
becomes less frequent. The adventive species, such as
brown top (<u>Agrostis</u> <u>tenuis</u> and <u>Anthoxanthum</u> <u>odoratum</u>)
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 successi-

vely 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 signi-

ficance 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 <u>Chionochloa</u> <u>rigida</u> and <u>Agrostis</u> <u>tenuis</u>

    10% of <u>Celmisia</u> <u>densiflora</u>

    25% of <u>Trifolium</u> <u>repens</u>.

The intermediate surface K2, shows higher ratings for

shrubs and <u>Chionochloa</u> <u>rigida</u> but lower ratings for

<u>Trifolium</u> <u>repens</u>. The oldest K3 ground surface has

high values of shrubs, <u>Dracophyllum</u> <u>uniflorum</u> and

<u>Gaultheria</u> <u>crassa</u>. 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 satu-

ration 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 vegeta-
tion takes place.   This change is in response to micro-
climatic 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 Draco-
phyllum 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 combina-
tion 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 com-
ponents 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 latitu-
dinal 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 inter-
glacial 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 grass-
lands were limited in distribution.

i) _Chionochloa rigida_, _Poa colensoi_ dystrophic
grassland

Connor (1964) described the floristic composi-
tion of similar grasslands in the Mackenzie

vegetation survey. He referred to them as alpine <u>Chionochloa</u> <u>rigida</u>/<u>Poa</u> <u>colensoi</u> grasslands. They were differentiated from the lower grasslands on the basis of a higher rating of <u>Poa</u> <u>colensoi</u>.

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 <u>Festuca</u> <u>novae-zelandiae</u> was absent from the plant list. The high constancy of <u>Poa</u> <u>colensoi</u> was probably indicative of the influence of overgrazing, as found by Connor (1964) and Burrows (1969).

ii) <u>Chionochloa</u> <u>rigida</u> 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 <u>Festuca</u> <u>novae-zelandiae</u> and a lower frequency of <u>Celmisia</u> <u>lyallii</u>.

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 noda
of alpine grasslands are limited in number, they can
be divided floristically and pedologically into three
groups:

i) <u>Poa</u> <u>colensoi</u> 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 <u>Hebe</u>, <u>Gaultheria</u>, <u>Dracophyllum</u> genera associated with the other grasslands. <u>Chionochloa</u> <u>rigida</u> and <u>Chionochloa</u> <u>macra</u> are both absent from this nodum, and although <u>Notodanthonia</u> <u>setifolia</u> 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 seti-
folia*.   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 Catch-

ment, 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 grass-

land (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 <u>Celmisia</u> <u>lyallii</u>. Although this plant maintains its dominant status within the seral grasslands, on the colder aspects <u>Chionochloa</u> <u>macra</u> and <u>Poa</u> <u>colensoi</u> occur in greater numbers. <u>Celmisia</u> <u>lyallii</u> 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. <u>Celmisia</u> <u>lyallii</u> 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 <u>Chionochloa</u> <u>rigida</u> and <u>Chionochloa</u> <u>macra</u> fluctuates considerably from a co-dominant status to a few scattered plants. <u>Aciphylla</u> <u>similis</u> 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 noda,

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 de-

graded grasslands is greatly reduced in numbers

compared with either the eutrophic and dystrophic grasslands.

3. Noda associated with hydrous soils.

The plants that form the individual stands will all tolerate prolonged snow cover, and are therefore chionophilous (Gjaervoll, 1965). Some of these plant communities have been described further south in the alpine zone of Central Otago by Mark and Bliss (1970). In the snowbank 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	Phyllachne colensoi
Carex pyrenaica v. cephalotes	Poa colensoi
Celmisia haastii	Plantago lanigera
Claytonia australasica	Raoulia grandiflora
Coprosma pumila	

In Canterbury (Burrows, 1967) referred to Chionochloa oreophila as a snowbank association, with a number of sub-dominant plants which included Poa colensoi, Anisotome imbricata, Marsippospermum gracile and Celmisia sessiliflora. 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) <u>Marsippospermum gracile</u>, <u>Celmisia haastii</u> nodum

In this catchment this community is fragmented.

For example, <u>Marsippospermum gracile</u>, 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 <u>Celmisia haastii</u>, <u>Chionochloa oreo-</u>

<u>phila</u> and <u>Celmisia hectori</u> (see Plates 39, 40

and 41).   Further north in the Sealy Range

however, <u>Marsippospermum gracile</u> forms dense

continuous communities, particularly well

developed on shallow gleyed organic soils which

are flushed by snowmelt.

<u>Celmisia haastii</u> is widespread on soils ranging

from the elefulvic soils to the fulvi-elegelic

soils.   On such sites it is usually associated

with <u>Poa colensoi</u> and <u>Marsippospermum gracile</u>.

iii) <u>Celmisia hectori</u> 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 develop-
ment.

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 poor-
ly represented by species. In some of the late
snow bed hollows on the recent Dun Fiunary
surface three genera, one hepatic and two mosses
are typical; Gymnomitrium, Andreaea and Poly-
trichum 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 coloni-
sation. 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 repre-
sents the clini-eldefulvic 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 asso-
ciated with the eleclinic soils in a rejuvenating régime
with nutrient cycling from flushing and further amend-
ments 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 pave-
ments.   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 profound-ly 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 consi-dered: micro-climate, forms of organic matter, soil formation and soil nutrients.

1. Micro-climate

The role of micro-climate with relation to pedo-genesis 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 accu-mulate 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 snow-
pack 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 relation-
ship 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 snow-
bank 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 receeding 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, <u>Celmisia haastii</u> and <u>Chionochloa oreophila</u>.

The organic matter formed by bryophytes such as <u>Philonotis</u> 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 plati-eleluvic soils characterised by shallow humified peat with a thick mat of <u>Oreobolus</u>. 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-eleclinic, eleluvic and madenti-elefulvic soils, show very similar trends to those seen in the succession of hydrophytic communities. Thus the early plant noda of <u>Celmisia hectori</u>, <u>Marsippospermum gracile</u>, <u>Celmisia haastii</u> 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-eleclinic soil in which plant succession is at a

well developed stage and is in the transition between
Marsippospermum _gracile_, _Celmisia_ _haastii_, and _Chiono-_
chloa _oreophila_ noda.   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 reduc-
tion 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 lithi-
skel (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-
eleclinic, 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 _Marsippospermum gracile_ is not typified by raw humus.
A strong relationship between plants, soils and micro-
topographic control can be witnessed on the fulvi- and
lodi- elegelic soils.   The zonation of plants in rela-
tion·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 cryotur-
bic 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 stabili-
sed 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 counter-
part 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, particu-
larly 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 stablised 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 signif-

icant 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
takes 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 per-
cent 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 madenti-
elefulvic 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, character-
ised by the fulvic soils this process tends to be ale-
viated 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 clini-
elefulvic 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 develop-
ment 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 <u>Chionochloa</u> <u>rigida</u>, 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 hierachial
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 inter-
relationships 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 classi-
fication. 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 lime-
stone 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 A_2 horizon overlying parent material. Such soils could
be compared to Kubiena's moder ranker, or in the cases
where A_2 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, A_2
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_2 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 $8^{\circ}C$ 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 O horizon which was saturated during part of the summer and a mean summer temperature of less than $6^{\circ}C$ were regarded as a cryic soil. In Table 69 the cryaquents are saturated during part of the summer months and with the O 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 entisoils 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 $8^{\circ}C$ 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 $5^{o}C$ 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 taxono-
mic 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 semi-
terrestrial 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 calcar-
eous 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 environ-
mental 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 signific-
antly 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:

	Barratt	Kubiena	Organic Form
i)	Ligno-parenchymal humiskel	Acid raw humus	Acid mor
ii)	Humiskel-lithiskel with some humicol	Silicate moder	Moder
iii)	A complex of ligno-paren-chymal humiskel with platy humicol	Raw humus with dystrophic peat	Lodic peat
iv)	Humicol-lithiskel complex with some mullicol	Mull-like-moder	Mull
v)		Anmoor	Acid organic peaty material

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: Lodi-elegelic

                                                          Fulvi-elegelic

ii) Eleclinic soils   Intergrade : Humi-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 Ferintosh 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 mu - 2 mu) indicate a low degree
of weathering with a high content of interlayered
material suggesting replacement of the basic
cations in the micaceous 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 hydro-
lysed 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 collu-
viation 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 infil-
tration 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:

Diagnostic horizons

Horizon	Hydrous soils	Hygrous soils
O	Lodic, platic, moroid	Not developed
A	Humic, umbric, gley	Humic, umbric
B	Cambic and gley alluvial layers common	Cambic, fragmented layers

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 noda with one fragmented nodum are associated with the hygromorphic soils, these may be listed as follows:

    i) _Chionochloa_ _oreophila_, nodum

   ii) _Marsippospermum_ _gracile_, _Celmisia_ _haastii_, nodum

  iii) _Celmisia_ _hectori_, nodum

   iv) Fragmented noda of bryophytes and vascular hydro-
       phytes.

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 effective-
ness 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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