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FRONTPIECE. Oblique aerial photograph of the two photographic study areas. Main divide of southern Ruahine Range runs from centre left to top right. No. 1 catchment is in the foreground. The top half of the large slump in the Raparapawai catchment and the many other erosion scars are clearly seen. Date of photography is March 19 1975.

Photo: N.A. Trustrum



DETERMINATION OF PROCEDURES TO ESTABLISH
PRIORITIES FOR EROSION CONTROL AS
DETERMINED IN THE SOUTHERN
RUAHINE RANGES, NEW ZEALAND.

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

Peter Robert Stephens.

1975.

A B S T R A C T.

The aim of this study was to investigate several methods of potential usefulness in identifying some of the factors causing erosion in two catchments 'typical' of the southern Ruahine Ranges.

The condition of the southern Ruahine Ranges, in the headwaters of the Manawatu River catchment, is deteriorating. The state of equilibrium which has periodically existed between rock, soil, slope, vegetation, and climate has recently been upset, and the area is now in a state of decline. Unless remedial action is taken promptly, farm land will go out of production, public water supplies could be ruined, communications by rail, road, and telephone severely hindered, and the benefits of both the Pohangina-Oroua and Lower Manawatu Flood Control and Drainage Schemes could be lost. This study attempts to establish a basis from which positive steps to rectify the situation can be implemented.

Methodology involved the use of aerial photography and on-the-ground observations and measurements. Colour and colour infrared film types were compared with standard black-and-white panchromatic film to establish which was the most suitable to use in determining priorities for erosion control. Sequential panchromatic aerial photographs were taken in 1946, 1961, 1966, and 1974. In this mountainous area, aerial photographs are essential tools for determining the extent of eroded surfaces and erosion types.

Between 1946 and 1974 there has been a 120 percent increase in area of eroded slopes in the study area. The worst erosion in 1946, at which time herbivorous mammals had had little effect on vegetation, and in 1974, occurred in the 700 to 900 m altitudinal zone. This zone has the highest fault density in the study area, which consists of densely faulted and mélangé-like rocks. This area has also undergone the most dramatic vegetation changes since 1946. Herbivorous mammals are considered to be only partly responsible for such changes. As a corollary, the highest percent increase in erosion has occurred in the altitudinal zone with the most intact vegetative canopy.

A positive relationship between the frequency of medium-sized earthquakes and increase of eroded areas has been tentatively

established. Further, most erosion has occurred during and following intense rainstorms. These two factors are considered to be the main ones causing erosion in the area.

Once factors causing erosion had been established, colour, colour infrared, and panchromatic film types were compared. Photographs used in this comparison were taken periodically throughout 1975 using a 35 mm camera. An assessment was made of the capabilities of each film type to show the following features: alignments, eroded surfaces, erosion types, vegetation types and condition, rock types, pug zones, seepage areas, and drainage pattern. Colour infrared was found to be the most suitable to use when determining priorities for erosion control.

A number of salient procedures that should be undertaken to determine priorities for erosion control are outlined. These include acquisition of all sequential photographs, photography using colour infrared, or preferably, using colour infrared and panchromatic film, a sound knowledge of ground conditions, and collation of relevant erosion, geological, botanical, and animal ecological data. A system that enables priority for erosion control of subcatchments to be established, using a rating value for factors causing erosion, is outlined.

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SECTION 1INTRODUCTION1.1 Aim of study.

The aim of this study was to investigate several methods of potential usefulness in identifying some factors causing erosion in two catchments 'typical' of the southern Ruahine Ranges. These methods are detailed in such a sequence that priorities for erosion control can be determined. It was not intended to discuss or recommend erosion control procedures.

1.2 Reasons for investigation.

The condition of the southern Ruahine Ranges in the headwaters of the Manawatu River catchment is deteriorating. Most of its indigenous vegetation has been damaged by herbivorous mammals. Large portions of this protection forest have also died. This has upset the state of equilibrium which has periodically existed between rock, soil, slope, vegetation, and climate. The area is now in a state of decline.

The streams that rise in these ranges are heavily laden with shingle and logs which are rapidly feeding into the main river system. Unless remedial action is taken promptly, farm land will go out of production, public water supplies could be ruined, communications by rail, road and telephone severely hindered, and the benefits of both the Pohangina-Croua and Lower Manawatu Flood Control and Drainage Schemes, in which \$12 million (as at 31.3.73) have been invested, could be lost. Large financial losses would occur in the Manawatu farming area and Palmerston North city without the protection of these schemes.

The nation has such a large financial interest in the 24,000 to 28,000 ha of fertile, flood free plains in the Manawatu that A.L. Poole (1973), Chairman, Soil Conservation and Rivers Control Council, stated that: "preservation of the Ruahines is far more important than 'saving' Lake Manapouri".

These brief introductory remarks outline the complex situation existing in the southern Ruahine Ranges. This study attempts to establish a basis from which positive steps to rectify the situation can be implemented.

1.3 Location of study area.

The study area, consisting of two catchments, is located 29 km north-east of Palmerston North, and 18.5 km north of Woodville in the southern Ruahine Ranges (see Figs. 1 and 2). The catchments are on both side of the range, their common boundary being its main divide.

The Raparapawai catchment is in Woodville County and the No. 1 catchment to the west, is in Pohangina County. Both catchments are located on the New Zealand Mapping Series (N.Z.M.S.) 1 Sheet N144 Feilding topographical map. The area is in the southern portion of State Forest 24.

On the N144 map, the stream at the end of No. 1 Line is unnamed. For the purpose of this study it has been named No. 1 Stream.

The Raparapawai Stream drains into the Manawatu River east of the Manawatu Gorge. The No. 1 Stream drains into the Pohangina River, a major tributary of the Manawatu River.

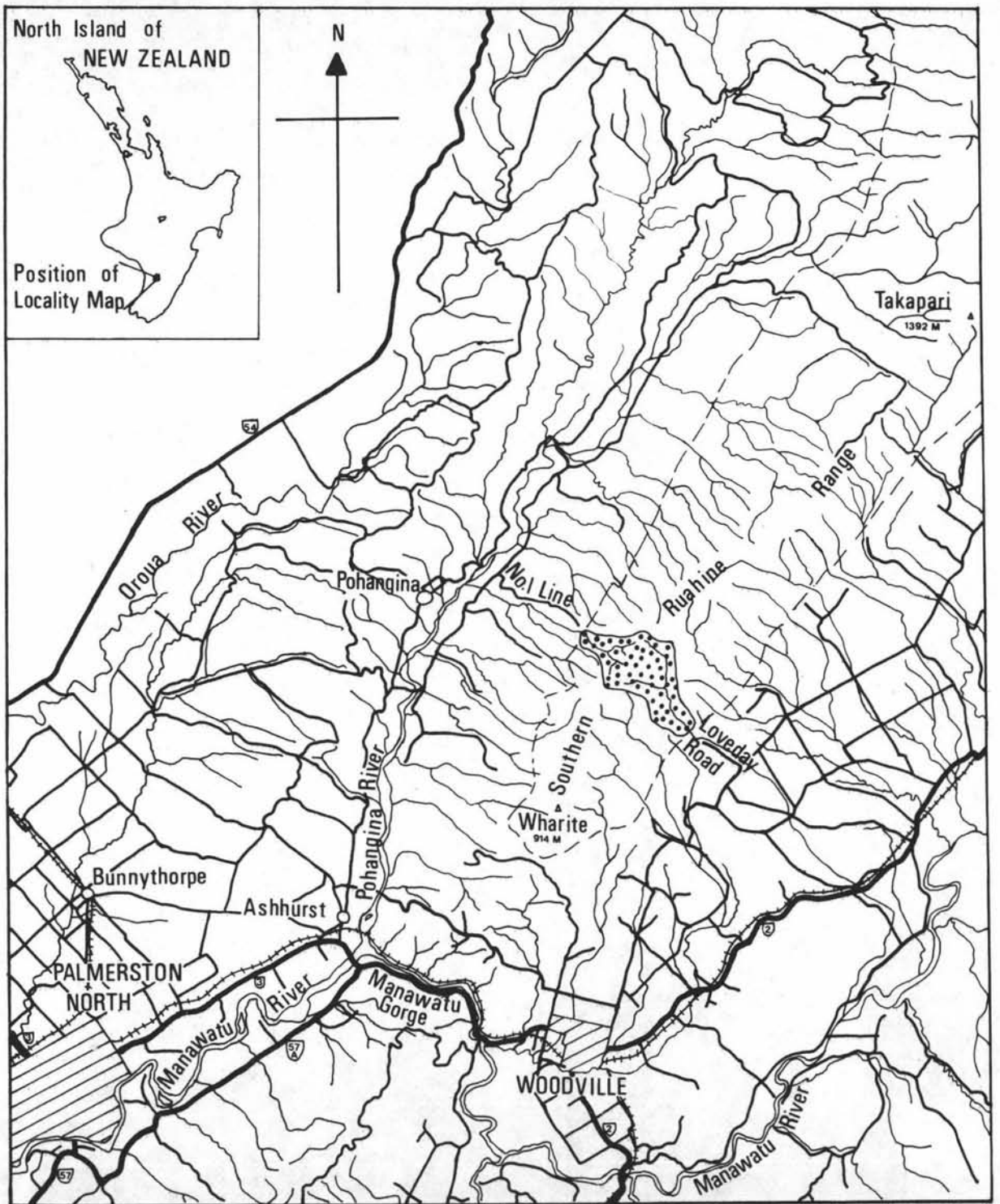
1.4 Criteria for choosing study area.

The criteria for choosing the Raparapawai and No. 1 Stream catchments as the study area are explained.

(i) It is important in a study such as this, that the area being investigated is 'typical' of the southern Ruahine Range, so that conclusions reached can be applied to the whole area, and not specifically to the study area. A catchment on each side of the range was chosen so that any major aspect factor or factors would be noticed.

After studying the 1946 (1:17,500) and 1966 (1:67,000)² panchromatic (or black-and-white panchromatic) aerial photographs

²The 1974 (1:27,000) photographs had not been taken at this stage.



REFERENCE

- | | |
|------------------------|----------------------------|
| State Highways | Rivers |
| Roads | Trig stations |
| Cities and large towns | Indigenous forest boundary |
| Railway lines | Study area |

10 km

Fig.1. Locality map.

Fig. 2. Oblique aerial photograph of the southern portion of the southern Ruahine Ranges. Prominent peaks Wharite (W), altitude 914 m, and Maharahara (M), altitude 1,096 m are shown.

Photo: N.A. Trustum



for vegetation distribution and condition, and degree of erosion, several possible catchments were selected. The Raparapawai on the east side, and the No. 1 and Opawe on the west side of the range were some of these. The Opawe Stream is 4.8 km north of the No. 1 Stream.

Based on discussions with the staff of the New Zealand Forest Service and the Manawatu Catchment Board and Regional Water Board, the Raparapawai and No. 1 were finally chosen. Vertical aerial photographs of the two catchments are shown in Figs. 3 and 4. The Opawe catchment has been subject to more intensive animal control than its surrounding catchments (I.L.Logan, pers.comm.), so that it was considered that the vegetation condition and possibly erosion pattern may not have been representative of the southern Ruahine Range.

(ii) The distance from Palmerston North and ease of access was also taken into account. This was not a significant criterion for catchment selection. The waterfall in the No. 1 Stream was a deterrent at first, but once the authors mountaineering skills developed this was easily overcome.

(iii) It was also important that the study area be reasonably compact so that aerial photographic flights could be easily executed without encountering navigation problems.

(iv) Although the two catchments could easily be investigated on foot, it was impractical to cover them completely with the regular photographic flights employed in this investigation (See Section 3). A south-east transect was drawn across the two catchments from the ends of Loveday Road and No. 1 Line (see Fig.1). Two areas at the same altitude were then selected on this transect for film type comparisons. The mean altitude of these is 820 m, within the most poorly vegetated and eroded zone of the range.

1.5 Methodology of the study.

At the commencement of this study the author had no preconceptions of factors causing erosion in the southern Ruahine Range.

Dr. R.N.Colwell, an authority on aerial photography and aerial photo-interpretation, considers that aerial photography used in conjunction with on-the-ground observation and measurements, is a

Fig. 3. Vertical aerial photograph of the
Raparapawai catchment. Date of Photography is
December 7 1961. Scale is approximately
1:22,000.

Photo: New Zealand Aerial Mapping.
(Reproduced with permission of Lands
and Survey Department).

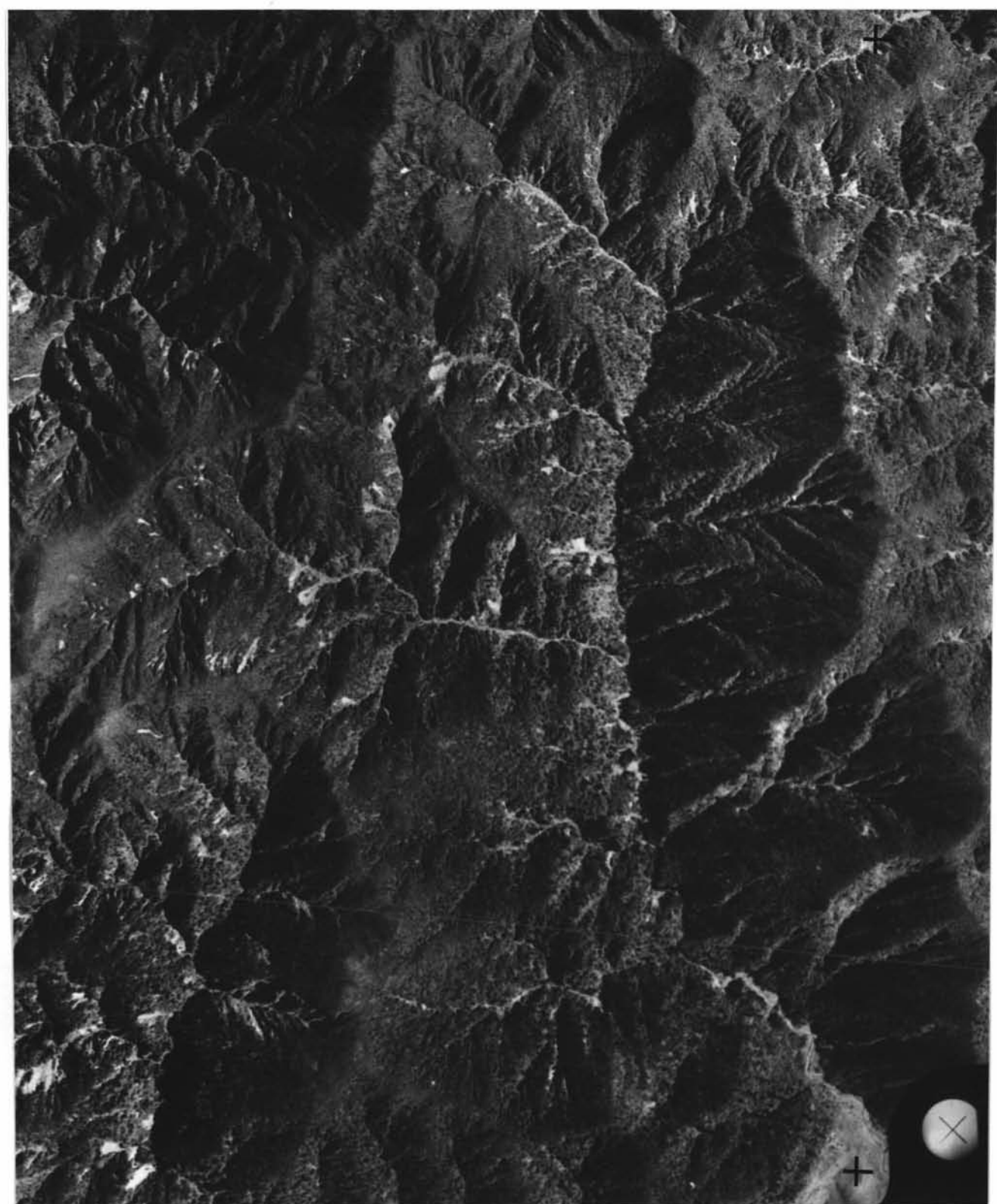


Fig. 4. Vertical aerial photograph of the No. 1 catchment. Date of photography is December 7 1961. No. 1 Line is visible on the centre left of the photograph. Scale is approximately 1:22,000.

Photo: New Zealand Aerial Mapping.
(Reproduced with permission of Lands
and Survey Department).



valuable aid in obtaining an inventory of natural resources in undeveloped lands (Colwell, 1960). This approach of combining aerial photography and field work was used to identify some factors causing erosion in the No.1 and Raparapawai catchments.

In photography of an area undergoing change, particularly if access is difficult, it is vital that the maximum amount of information be recorded. For this reason, film types were compared to establish whether or not they are capable of recording information more effectively than the standard panchromatic film type. The other film types assessed were colour and colour infrared.

Field work commenced in February 1974, when a reconnaissance of the study area was made. Following this a further eleven days in 1974 were spent in the field. Most of the detailed investigations and measurements were made while living in the area for ten days during January 1975. Periodically throughout 1975 a further eight days were spent in the field obtaining information and observing any changes.

The existing sequential vertical aerial photographs of the whole study area that were used for photo-interpretation are shown in Table 1. Run and photograph numbers are appended (See Appendix 1). These photographs were supplemented by vertical and oblique negative panchromatic, and positive (reversal) colour and colour infrared aerial photographs taken by the author at various times during the study period (see Section 3).

Table 1 - Sequential aerial photographs of study area.

<u>Date flown</u>	<u>Scale</u>	<u>Film type</u>	<u>Focal length</u>
9.10.46	1:17,500	Panchromatic	209.7 mm
7.12.61	1:44,000	Panchromatic	114.3 mm
26.1.66	1:67,000	Panchromatic	114.3 mm
28.3.74	1:27,000	Panchromatic	209.7 mm

SECTION 2

REVIEW OF LITERATURE ON THE USE OF CONVENTIONAL AERIAL PHOTOGRAPHY FOR EROSION AND RELATED STUDIES

2.1 Introduction

Conventional aerial photography is defined here as aerial photography taken from aircraft using film types sensitive to 400 to 1,000 nanometers (nm) of the electromagnetic spectrum.

Aerial photographs, which present a complete map as well as a three-dimensional model of an area, are essential for erosion and related studies (Vink, 1968; Vinogradov, 1968). In mountainous areas aerial photographs are particularly useful because they largely overcome access and ground visibility problems. Other advantages of aerial photographs in erosion investigations mentioned by Liang and Belcher (1958) are:

- (i) Catchment and erosion boundaries can be readily delineated.
- (ii) Surface and near-surface drainage channels can be traced.
- (iii) Important relationships in drainage, relief, and other natural and man-made elements that are seldom correlated properly on the ground become obvious on aerial photographs.
- (iv) Field investigations can be effectively planned.
- (v) Sequential photographs illustrate changes in erosion and vegetation.
- (vi) Aerial photographs can be studied at any time, in any place, and by any person.
- (vii) Through aerial photographs, erosion information can be transmitted to others with a minimum of ambiguous description.

There are limitations however when interpreting aerial photographs, some of these are:

- (i) Experience of interpreter, both in photograph interpretation and field knowledge of area under study. These aspects have been discussed by Benninghoff (1953), Rogers (1953), Lueder (1959), Colwell (1960), Miller (1968), Vink (1968), and Vinogradov (1968).

(ii) Scale of photography is important. Miller (1968) considers the larger the scale, the more discernible are details of slope, dissection, eroded surfaces, vegetation, and tonal variations. Large scale, however, makes it more difficult to study regional relationships and characteristics. He suggested the use of two sets of photographs, at appreciably different scales, for the study of an area. Miller (1968) also indicated that confusion may arise if such a multiple coverage has been obtained during different seasons and time of day.

Vinogradov (1968) suggested the following scales for various studies: 1:1,000 to 1:3,000 for vegetation cover structure research; 1:10,000 to 1:20,000 for detailed geological, forestry, and soil mapping; 1:20,000 to 1:30,000 for reconnaissance mapping; and smaller scales for regional mapping. A. Cunningham (pers.comm.) has found large scale photography (1:4,000) the most suitable for mapping erosion surfaces in the Kaweka Range. Poole (1969) considers that 1:20,000 aerial photographs are suitable for recognition and positive identification of erosion types, and 1:10,000 or larger for microstudies of slope failure phenomena.

(iii) Quality is one of the most important properties of an aerial photograph. Quality, especially poor quality, imposes a firm limit on what can be seen and how well it can be seen. The quality of a photograph depends largely on the type of camera, film and filter properties, conditions of exposure, season, and time of day (Spurr, 1960; Heller, 1970). Colwell (1954), however, is of the opinion that tone, colour, image sharpness, and stereoscopic parallax characteristics are the primary factors governing the quality of photographic images.

Carroll (1973) lists several disadvantages of photographic sensors, these are:

(i) For conventional aerial photography, sunlight and clear cloudless weather are needed. Radar mapping is not dependent on these factors.

(ii) Photographic sensors cover only the visible and near-infrared portion of the electromagnetic spectrum. More information is obtained from thermal infrared and microwave sensors.

(iii) Photography does not lend itself to automatic analysis,

unlike other sensors whose output can be stored directly on magnetic tape as well as displayed visually.

(iv) Nonphotographic sensors are capable of recording more information. The number of discernible density gradations that are possible with various photographic methods are shown below

(Holter, 1970):

Panchromatic film	1.2×10^2	states
Colour film	6.4×10^4	states
Nonphotographic multispectral sensor	10^{12}	states

(v) Photographic sensors only record ground surface information. Some nonphotographic sensors can record subsurface information.

2.1 Film types used in conventional aerial photography.

In the past, for reasons of both cost and state of the technology, most aerial photographs have been taken on panchromatic film, and most prints made on a paper base. In recent years the technology has improved and costs have decreased (Allum, 1970). This provides for a choice of film types to expose and method of printing. Carneggie and Lauer (1966) and Fritz (1967) have reviewed research projects that used these new recording techniques. Carneggie and Lauer (1966) compared the advantages of multiband sensing for forest and range inventory surveys, as well as giving instructive examples.

Films can either be negative or positive (reversals). With negative films, tonal qualities on the final print can be altered in processing (Mott, 1966). Positive film, however, is more exposure critical, and the processing procedure is less tolerant. Thus once a positive film is exposed, the tonal qualities on a final print can be changed very little. This is an advantage negative film has over positive film. Furthermore, from negative colour film, high quality colour and black-and-white prints can be obtained.

However, Welch (1968) considers that transparencies (from positive film) are preferred to prints by most professional photo-interpreters and photogrammetrists. Positive transparencies viewed by transmitted light offer a greater wealth of detail and in roll form are easier to handle than a set of prints. Multiple internal reflections of light trapped between a reflecting base and

the surface of an emulsion layer considerably reduces definition in both black-and-white and colour prints, giving transparencies a greater definition. Welch (1968) found that colour and panchromatic film negatives had to be enlarged 4X through a high quality enlarger lens before their lack of sharpness equalled that of a paper print. Because of their greater definition, transparencies can be subjected to greater optical magnification.

Panchromatic films utilize the visible part of the electromagnetic spectrum (400 to 700 nm). Images on panchromatic photographs are in varying shades of grey, with each tone comparable to the density of an objects colour as seen by the human eye. These films provide reasonably good tonal contrast, a wide exposure latitude, satisfactory resolving power, and low graininess (Avery, 1968). A minus-blue (yellow) filter, which cuts haze, is generally used with this film type. Colwell (1965) considers that panchromatic-minus-blue is the best film-filter combination for general purpose use.

Gas molecules in the atmosphere scatter light at a rate inversely proportional to the fourth power of the wavelength (Rayleigh effect), which affects sensing of the ultraviolet and blue portions of the electromagnetic spectrum more than sensing of the longer wavelengths (red and infrared). This explains why most panchromatic aerial photography is exposed through a filter such as the minus-blue, reducing the fogging effects that haze causes on aerial exposures (Heller, 1970).

Infrared film is primarily sensitive to blue-violet and infrared light radiation. When exposed through a red filter, exposures are made of the red and infrared wavelengths only (700 to 900 nm), so that it is generally described as 'near infrared' (Avery, 1970). The grey tones on infrared film result from the degree of infrared reflectiveness of an object, rather than its true colour. Broadleaved vegetation is highly infrared reflective and therefore photographs in light tones, coniferous vegetation tends to absorb infrared radiation and consequently registers in dark tones. This enables conifers to be easily distinguished from hardwoods (Colwell, 1960; Haack, 1962). Infrared film normally penetrates haze better than panchromatic, but it will not penetrate

extremely dense haze or clouds. This film is inexpensive and easy to process. However, it does suffer from the disadvantage that it is somewhat 'grainy' and does not show the same degree of contrast as infrared colour film (Brooks, 1972), panchromatic and colour film (Avery, 1968).

As there is little diffuse light in the infrared part of the electromagnetic spectrum (Rayleigh's Law), there is very little diffuse or 'scattered' light to illuminate shaded areas. This inability to see detail in shaded areas is regarded as a major limitation of infrared aerial photographs (Colwell, 1960).

Colour films are generally reversal films of the subtractive type. They are sensitized to all visible colours, and provide positive transparencies (reversals) with natural colour rendition when properly exposed and processed. They have a limited exposure latitude compared with black and white emulsions, and should preferably be exposed under conditions of bright sunlight (Avery, 1968; 1970). However, Mott (1966) states that "when cloud and aerial haze conditions are satisfactory for panchromatic air photography, they are also satisfactory for colour". An ultraviolet or skylight filter is normally used with colour film to cut haze. Sorem (1967) has outlined the principles of colour aerial photography. Ray (1960), considers that colour photographs have an important inherent advantage over panchromatic, in that the human eye can distinguish about 1,000 times as many tints and shades of colour as it can differentiate tints and shades of grey. This provides a more varied stimuli to the interpreter. Brock (1952), Lueder (1959), and Fezer (1971) warned, however, that in interpreting a colour photograph, there is some danger of neglecting details which would be clearly seen in a panchromatic picture. Fezer (1971) considers that colour offers an important advantage if the relief can be indirectly recognized via the vegetation pattern.

Colour infrared film comprises three image layers. The top layer is the cyan-forming layer, sensitive primarily to the near-infrared radiation; the middle layer is yellow-forming, sensitive to green visible radiation; and the bottom layer is magenta-forming, sensitive to red visible radiation. Thus two of the three layers are sensitive to visible radiation. Normal colour film has three layers,

which are sensitive to visible blue, green, and red radiation.

Misunderstandings about this film can arise if it is not realized that changes in reflectance in the visible part of the spectrum are as important in determining film colours as are changes in the infrared (Knipling, 1969).

Because of reversal processing during the film development procedure, the dye of an emulsion layer does not form if the layer was exposed to the radiation to which it is sensitive. All three emulsions of the film are sensitive to visible radiation below 500 nm. These wavelengths are eliminated by using a minus-blue (yellow) filter over the camera lens. Thus objects reflecting only blue radiation do not sensitize the emulsion and the dyes in all three layers form. Each layer acts as a discreet colour transparency or subtractive filter and when all three are superimposed, no light can be transmitted. Thus the image of blue-reflecting objects appear black.

An object that reflects only infrared energy will expose the cyan layer, leaving the yellow and magenta layer which combine in a subtractive mixture to form a red image when viewed by transmitted light. Blue image colours result from the reflectance of green radiation, and green images result from red radiation reflectance. This film is sometimes referred to as 'false colour' (Avery, 1968).

Colour infrared film has several disadvantages compared to normal colour film. The first of these is that exposure latitude is very limited ($\pm 1/2$ stop) (Brooks, 1972; Harris and Haney, 1973), and unless exposures are correct, disappointing results will ensue. Specialists generally have to be sought to process this film as most commercial concerns do not want to be concerned with it. Other disadvantages are that the infrared-sensitive image layer is somewhat unstable, has a short half life, and must be kept cool at all times. The positions for optimum focus are also different for the infrared image layer and for the other two layers (Brooks, 1972).

However, in spite of the above difficulties, Brooks (1972) has stated that good results can be obtained by relatively unskilled

personnel using conventional cameras operated from a light plane or helicopter.

Hunter and Bird (1970) investigated the photo-interpretation elements of tone and texture in colour and colour infrared films. These workers established that colour and colour infrared have significant advantages over panchromatic films for terrain data acquisition.

A two layered film, sensitive to both infrared and visible light used in the U.S.S.R. is referred to as spectrozonal (Mott, 1966).

Multiband or multispectral photography are terms that refer to the simultaneous use of two or more sensors designed to produce imagery from different parts of the electromagnetic spectrum (Colwell et al., 1966). Maximum enhancement of particular subjects under study can be obtained from multispectral images (Curtis, 1974). Multispectral images can be re-combined to provide black and white, or by colour addition, reconstituted colour images on an additive colour viewer (I²S) (Yost and Wenderith, 1968).

Multispectral reconnaissance encompasses more than improved cameras, sharper lenses, or faster films. In addition to conventional aerial photographs, interpreters are analysing images from manned space flights, from orbiting satellites, and from thermal and radar systems. Such imagery may be obtained from portions of the electromagnetic spectrum several million times wider than is available to ordinary camera systems (Leanardo, 1964). These sophisticated sensors have been discussed by Carneggie and Lauer (1966), Colwell (1968), and Avery (1968).

2.3 Use of conventional aerial photography in erosion studies.

One of the earlier publications that referred to the use of aerial photography in erosion studies was that of Gouffon (1953). He delineated areas of severe and moderate gully erosion in the Beech River catchment, Tennessee, and was able to calculate probable erosion control costs. This use of aerial photography was found to be accurate, simple, quick, and relatively inexpensive. In a more recent investigation, Totterdell and Nebauer (1973) used colour and colour infrared films at large and medium scales (1:3,550 and 1:12,000). They also found aerial photography to be a quick and accurate method of

assessing the erosion status and condition of plant communities in the Kosciusko National Park, Australia. These workers established that aerial photography costs were small compared to the information obtained and the planning that could result.

Landslides can be recognized on aerial photographs by the following features (Liang and Belcher, 1958; Dishaw, 1967; Breitag, 1968): their characteristic shape and striated texture, a sharp line of break at the scarp and hummocky relief of the sliding mass beneath it, the elongated depressions in the mass, abrupt differences in vegetation and tonal characteristics between the landslide and adjoining stable areas, bulging toes, irregular shoreline of lakes, and the inclined positions of trees in landslides which are often discernible. Poole (1969) discussed criteria for recognizing the following erosion types on aerial photographs: sheet, rill, gully, creep, flow, slide, and falls.

On the aerial photographs taken immediately after the Alaskan earthquake (27.3.64), the most conspicuous features were the 2,036 avalanches, snow slides, and rock slides. These were probably triggered by the earthquake and/or subsequent after shocks (Hackman, 1965). Avalanches were differentiated from slides by their linear pattern and generally greater length. The length of the longest avalanche was 4.83 km. Other features recognized on the aerial photographs were recent fractures near the snouts of some glaciers, cracks in surficial material, pressure ridges in lake ice, and activated fault lines.

Many landscape features peculiar to regions under intense frost climates are often well displayed on aerial photographs. Studies of micro-relief features produced by frost action and surveys of surface indicators of permanently frozen ground have relied to a large extent upon aerial photo-interpretation (Spurr, 1960). In these regions, solifluction is recognized by the molasses-like flow patterns, disrupted vegetation cover, and irregular surfaces upslope from the leading edge. In areas of intense freezing and thawing, rock shattering leads to the formation of rock screes, which are readily identified on aerial photographs, where they appear as steep regular slopes, often poorly vegetated and with steeper slopes and/or rock bluffs at their head.

The collective effect and feather patterns of rill erosion appear as changes in colour tones on aerial photographs, and are easily recognized (Lueder, 1959). The extent of gully erosion is readily mapped from aerial photographs with a minimum of field work (Bergsma, 1970).

According to Fezer (1971), the beginning of soil erosion caused by the hooves of cattle can be seen on aerial photographs of sufficiently large scale. Where continued soil creep causes a belt of broken ground, it is readily identified on aerial photographs, but not so easily appreciated from the ground. Similarly, sheet erosion is easily overlooked on the ground because there is no striking relief changes as there is in gully erosion, but is easily noticed on aerial photographs (Lueder, 1959; Bergsma, 1970).

Erb (1968) found that aerial photographs were most effective in determining the processes of mass-wasting in Jamaica. Soil flowage associated with faulting and rock slide/slump phenomena are two features that were most clearly illustrated on photographs.

In New Zealand, Stevens (1974 a) has described 'fossil landslides' being visible on aerial photographs. These were formed during the last stadial climate 14,000 to 15,000 years B.P.

Detailed interpretation of large scale (1:640 to 1:1,000) 70 mm colour and colour infrared aerial photographs (Carnegie and Reppert, 1969) showed the following soil surface features: surface erosion, rockiness, disturbance by grazing animals, rodent burrows and tracks, animal droppings, and dead leaf materials.

Totterdell and Nebauer (1973) reported that the scale of photography was an important factor in determining the cost of erosion control accurately, because the area of eroding landscape had to be estimated. Liang (1959) and Mike (1968) also mentioned scale as a limiting factor in landslide studies when trying to determine causes of movements and formulate corrective measures.

Liang and Belcher (1958), Eastman Kodak Company (1968) and Nossin (1972) consider that an investigation of existing landslides in an area gives an excellent basis for evaluating the possibility of future landslides. The features of an old landslide are similar

to those of new slides except that they are not as fresh or striking. The degree to which vegetation and drainage are established on the slide also helps determine the relative age and stability of the eroded land. Once an old landslide is located on photographs, it serves as a warning that the general area has been unstable in the past and that new disturbances may initiate new slides.

Kojan et al. (1972) described a study in the Santa Ynez-San Rafael Mountains, California, where they

- (i) evaluated the effectiveness of a technique, based entirely on aerial photo-interpretation, for the recognition, classification and delineation of 'active' and 'dormant' debris slides using various diagnostic morphological features;
- (ii) evaluated the utility of geomorphic criteria for forecasting the loci of future landslide incidence; specifically, to test the hypothesis that debris slides within the test area are most likely to occur in the future where they have occurred in the past. Kojan et al. (1972) found that
 - (i) aerial photo-interpretation (in the absence of any field work) was an effective and accurate method of recognising, classifying and delineating debris slides;
 - (ii) it was possible to predict the site of future landslides accurately on the basis of geomorphic evidence of past activity. Vertical panchromatic 1:17,000 and 1:11,000 aerial photographs were used in this study.

In Malaya, Kee (1962) demonstrated how aerial photographs can be used to detect potential landslides. The failure of slopes was characteristically preceded by the formation of tension cracks, often associated with indiscriminate clearing and removal of protective vegetation. At photographic scales of 1:5,000, and on surfaces free from undergrowth, these tension cracks were imperceptible, but the exposed laterite soils (within which the tension cracks form) stand out distinctly in light tones, different from the virgin vegetation of the adjacent undisturbed and stable land.

Bergsma (1974) demonstrated at two localities in Spain and at one in Texas, that soil erosion features may occur in a regular sequence on hillslopes. Interpretation of medium scale (1:10,000 to 1:35,000) aerial photographs, taken during the correct season, can

show the areas where an erosion sequence occurs. This enables the detection of erosion-prone hillslopes in an area where similar hillslopes have eroded in the past. Bergsma stated that the presence or absence of an erosion sequence depends on the runoff conditions.

The timing of an aerial photographic coverage is also useful in erosion studies (Colwell, 1954). Sequential aerial photographs have been used in erosion studies by many workers, some of these are: Richter (1962), Brundall (1966), Vink (1968), O'Loughlin (1969), Bryant (1971), Fezer (1971), James (1973), Rolston (1973), and Swanson and Dyrness (1975).

Richter (1962) found sequential aerial photographs useful in recognizing incipient signs of gully erosion; dark coloured grooves on the photographs had developed into gullies within a period of five years. Brundall (1966) used sequential aerial photographs to approximately date recent debris flows in the Cass Basin, Canterbury. O'Loughlin (1969) studied streambed changes, and James (1973) determined the increase in eroded surfaces between 1946 and 1963 in the Ruahine Ranges using similar approaches. Fezer (1971) has cited many instances where sequential aerial photographs had been used in the study of wind and sand dune erosion. Sequential aerial photographs can also be used to show the effectiveness of erosion control works.

Komarov (1968), Bergsma (1970), and Higginson (1970) are some workers that have used aerial photographs to map erosion types and severity of erosion. In his survey of the Shoalhaven Valley, New South Wales, Higginson (1970) relied primarily on stereoscopic interpretation of aerial photographs to map seven erosion classes, as well as nine land use and seven slope classes. Nakano (1968) mentions the use of aerial photographic analysis to investigate landslide and landcreep erosion in Japan. Using photogrammetry, Rice *et al.* (1969) studied microtopographical detail in an erosion study in Southern California; they used 1:5,000 panchromatic aerial photographs.

Totterdell and Nebauer (1973) found that colour infrared was superior to colour aerial photography for detecting recently eroded areas and naturally occurring fieldmarks in the alpine tract of the Kosciusko National Park.

Wobber (1975) described a study where the New Jersey Department of Environmental Protection used aerial photography for the assessment of shore erosion/accretion for the allocation of coastal zone funds. This study showed that in developed beach areas (groins, jetties, etc.), erosion had in fact occurred more often, was generally severe, and that the beach was slower to recover than in a natural beach setting. Wobber (1975) also discussed the State of Pennsylvania's remote sensing programme in subsidence detection of mined lands. Colour, colour infrared, and multispectral imagery were used in this programme.

2.4 Use of conventional aerial photography in geological studies.

A vast amount has been written on the use of aerial photography in geological studies. Aerial photographic texts by Tator *et al.* (1960), Avery (1968), Lueder (1959), and Spurr (1960) devote 279 pages to photogeology.

Geological interpretation is based on the fundamental recognition elements of photographic tone, colour, texture, pattern, relationships of associated features, shape, and size. Although oblique photographs are often used by the photogeologist, most detailed analyses make use of vertical photography (Avery, 1968).

Geological features that can be mapped from aerial photographs include rock types, faults, folds, dikes, veins, unconformities, and contacts. Avery (1968) describes how strike and dip measurements for sedimentary beds and faults can be determined on good quality aerial photographs at the correct scale. Parvis (1950) reported on the value of seeing drainage patterns on aerial photographs for the identification of regional bedrocks and soils in various physiographic regions of America.

When properly used in geologic work, aerial photographs add speed, economy, and accuracy to mapping and exploration, as well as certain geologic information that is impossible, difficult, or economically impracticable to obtain by routine field mapping methods (Ray and Fischer, 1957). Allum (1962) claims that aerial photographs provide geological data which in practice is unobtainable in any other way, and that they should be regarded as geological research instruments in their own right, and not merely as aids to other

geological work.

One of the first important geologic interpretation studies from aerial photographs was a reconnaissance study of 13,500 km² in New Guinea, which commenced in 1935 (Ray and Fischer, 1957).

Komarov (1968) reports that the vast inaccessible areas of the Soviet Union have been covered by geological survey in the last decade. This was considerably facilitated by the extensive use of aerial photography. This worker stated that the existing regulation (in Russia) now requires all establishments producing geological maps on a scale of 1:25,000 or less to use aerial photography in combination with other methods of survey. The film normally used in these surveys is panchromatic, although for detailed surveys colour and spectrozonal aerial photography are used.

Nakano (1968) mentioned the extensive use of aerial photography for geological mapping in Japan. This is supplemented by fieldwork to determine the significance of geologic features seen on the photographs.

Preliminary results of a study determining the geologic uses of colour aerial photography, conducted by the United States Geological Survey (Fischer, 1958), showed that photo-interpretation of colour photographs could be made with more assurance than with panchromatic photographs. Many colour differences clearly visible on colour photographs were manifested as slight tone differences on panchromatic photographs, and the interpreter often ignored slight tone breaks on the panchromatic photographs, which were shown to be significant by colour photography.

In an investigation to determine the relative value of colour and colour infrared aerial photography for geological purposes, Allum (1970) found that negative colour photographs, which provided the option of true colour or cheap black and white (colour) prints, or both, offered advantages both for interpretation and annotation. This worker also cited the findings of other photo-geologists with regard to the suitability of various types of film for geological studies. Colour and colour infrared were generally found to be superior to panchromatic films.

Norman (1968) considers that there are many factors which affect the choice of photography for geological purposes. The best choice can only be made with experience and judgement, because each geological project is unique in its demands.

Colwell (1965) and Komarov (1968) described a technique to overcome this problem in geological studies. It involves a spectrophotometric or densitometric analysis of the terrain to be mapped, so that the film-filter combination and time of photography to give the desired tonal contrast can be determined. Such a method can also be used for soil, vegetation, and erosion aerial photography surveys (Vinogradov, 1968; Gates, 1965; Hunter and Bird, 1970).

Cole et al. (1974) described how remote sensing techniques assist in mineral exploration. These workers discussed how ore bodies were located in the vicinity of the Dugald River Lobe, Australia, using the spectral signatures of vegetation species: these were most easily recognized and identified on colour infrared film. Trees which had distinctive dark red signatures on colour infrared film, were found to be growing on zones of copper mineralization.

Liang and Belcher (1958) reported that most of the landforms susceptible to landslides in America, are readily recognized on aerial photographs. They summarized the identifying elements and significant facts about each. It was found that, in general, the landforms most susceptible to landslides are basaltic lava flows, serpentine, clay shale, and tilted sedimentary rocks. Other landforms, such as glacial deposits, terraces, lake beds, and loess, were found to be susceptible occasionally, depending on local conditions.

Tator et al. (1960) discussed how the erosion of landforms is often very useful to the photo-geologist, particularly in the identification of secondary tectonic features, namely, those formed by other factors acting on faulted rock. Such landforms include fault line valleys, fault line gaps, fault induced dissection, fault induced deposition, and topographic fault line outliers. Many of these features can not be appreciated on the ground, but are readily captured on aerial photographs. Gross (1951), Lensen (1958), Ray and Fischer (1960), Orbell (1962), Paarma et al. (1968) and Allum (1970) have described how to map faults and lineations recognized

on aerial photographs. Pohn (1970) found a ronchi grating very useful for mapping strike directions of obscure faults.

2.5 Use of conventional aerial photography in soil studies.

It is over forty years since soil scientists in the U.S.A., U.S.S.R., Australia, and England began to systematically examine the value of aerial photographs as aids to soil mapping (Carroll, 1973). Vink (1968) and Carroll (1973) consider that field studies of soils today are unthinkable without the use of aerial photography.

Buringh (1960) and Vink (1968) have contributed much to the use of aerial photographs in soil science, especially soil survey. The soil survey procedures of Buringh (1960) have defined clearly the value of photographs at different scales of survey. Both workers, however, recognize the limitations of photo-interpretation, Buringh insisting that "photo-interpretation is guesswork, whereas soil survey is not" (Vink, 1968: p.90). Both workers recognize that deductions from aerial photographs are valuable in locating soil boundaries.

Kristoff and Zachary (1974) were quickly able to identify gross variations in soil features with a computer-aided classification of multispectral scanner data (12 bands, 400 to 1,000 nm). They regarded this technique as augmenting, rather than replacing traditional soil mapping.

Aerial photographs have been described as an indispensable tool in the study of patterned ground in East Anglia (Perrin, 1962).

Vinogradov (1968) has established that the use of aerial photography increases the speed of soil mapping by a factor of 2 to 3, and decreases the amount of necessary soil sampling in the field by 60 to 70 percent, especially at medium scales. Rijkse (1962) also considers that aerial photography is a valuable aid in obtaining quicker results while mapping soils in the field.

Detailed soil surveys in mountainous areas are greatly facilitated by the use of aerial photographs (Retzer, 1962; Coen, 1973), but because of the large amount of photo-distortion in areas of high relief, an accurate transfer of boundaries to planimetric base maps is

difficult. However, prints made by orthophotography (see Spurr, 1960: p.219), which provide an accurate planimetric map of stereoscopic overlap, could be used as a base for accurate superimposition of soil and vegetation boundaries, contours, geological data, and eroded areas.

In some respects the value of photo-interpretation is inversely proportional to the scale of a soil survey (Saintilan, 1972). Reconnaissance soil surveys rely heavily on photograph deductions for interpolation and extrapolation from field traverses, whereas in detailed surveys the emphasis will be on field work. Some field observations will always be necessary. It is much easier to study photographs than soils, "but dig we must" (Kellog, 1954).

Frost et al. (1960) outlined in some detail the pattern elements used in the photo-interpretation of the four principal 'soil classes': eolian, alluvial, glacial, and residual soils formed in place. The pattern elements included landform, drainage, erosional features, vegetation, photographic tone, and land use features. These workers also described the nature and regional aspects of each class.

Evans (1974) discussed the importance of timing of aerial photography to record soil variability revealed by tonal differences in bare soil and differential crop growth in England. Evans found that for aerial photographs to record soil tone patterns and changes they must be taken in winter and spring, the best months being March and April. Crop patterns were best recorded in July and August.

Myers et al. (1966) have shown that available soil moisture can be determined by detecting vegetation condition. These workers established that moisture stress changed vegetation reflectance patterns. Moisture stress apparently causes physiological changes in leaves that influence the reflectance of solar radiation from the canopy. There is a decrease in infrared reflectance from the plant canopy with increasing moisture stress.

Dominquez (1960) presented one of the earliest comparisons of colour and panchromatic photography at the relatively large scale of 1:5,000. He concluded that soil series within his test area (a forested region of the Californian Sierra Nevada mountains) could be quite accurately mapped using surface colours visible on aerial colour photography as the primary criterion. Dominquez (1960)

also found the use of colour aerial photography was more accurate and increased the speed with which soil boundaries could be delineated.

Anson (1970) determined that colour aerial photography had two main advantages over panchromatic film: it allowed greater soil differentiation and gives the interpreter more confidence in his decisions. This work showed, however, that colour infrared photography was unequalled for the differentiation of bare soil. Totterdell and Nebauer (1973) reached similar conclusions to Anson (1970).

Parry *et al.* (1969 a) demonstrated the advantage of colour over panchromatic aerial photography for identifying and plotting soil boundaries, differentiating soil types, and distinguishing variations in soil moisture and organic content. Kuhl (1970) showed the superiority of colour stereoscopic aerial photography over both panchromatic and colour infrared for interpreting soil drainage classes and for classifying slopes.

Mintzer (1968) suggested the use of colour infrared film for studies of landform, drainage systems, and vegetative cover, and colour film for gully shape, gradient, erosional features, and natural colour of soils.

In arid areas of Australia, Brooks (1972) has shown that underdeveloped colour infrared film can be used to differentiate soils. On underdeveloped images, soils derived from serpentine appear as blue-green, whereas those from gabbro or basalt show as green areas with a tinge of yellow.

In an investigation to determine the value of multispectral photography for soil surveys in the Tologa Bay area, Gisborne, Rijkse (pers.comm.) found black-and-white infrared photography, using spectral bands 700 to 800 nm and 800 to 1,100 nm superior to other film types. Soils of poorly drained areas, i.e. fans and levees, were most easily identified on these spectral bands. However, using an additive colour viewer (I^2S), maximum enhancement of the above features was also possible, aiding interpretation of the multispectral photographs.

2.6 Use of conventional aerial photography in vegetation studies.

Aerial photography was first used to map vegetation in 1887

(Spurr, 1965). In the opinion of Spurr (1960), aerial photographs are a unique tool for surveying vegetation and interpreting patterns of vegetation in relation to other landscape features. Aerial photographs provide a precise representation of forms and spatial arrangements of plants in plan view, both as individual species and aggregations of species. They also show their actual spatial relationships with landforms, drainage, and land use features, from which further relationships with geologic structure, lithology, and soil types can be discovered or deduced.

The type of photography is very important in the identification of plant species. Scale, type of film and filter, and season of year (see Olson, 1962), in particular affect the ease of species recognition. Ground reconnaissance is also important. The elements of photographic images used in the identification of plant species and vegetation types are commonly considered to include tone, texture, shadow, shape, size, pattern, and site (Spurr, 1960). Northrop and Johnson (1970) also include ecological criteria for vegetation identification.

Forest trees, because of their individual crown size, are particularly suited to identification on aerial photographs. Spurr (1960) described identifiable photographic features of major forest biomes. Spurr (1956), Komarov (1968), and Vinogradov (1968) showed that aerial photography is used world wide for forest type mapping, forest inventory, and forest management.

Willingham (1959) has reported how a 35 mm vertical photographic coverage could be used in forest management. Franklin (1967) determined forest type boundaries in the Tararua forests by scanning aerial photographs stereoscopically and ground reconnaissance.

Individual non-forest species can not be identified ordinarily on aerial photographs (Spurr, 1960), because of their small size and stature. Totterdell and Nebauer (1973), however, could detect clumps of vegetation 152 mm in diameter with large scale colour infrared aerial photography. These workers also found that homogeneous plant communities could be delineated in many instances and their composition determined by ground reconnaissance. Vegetation patterns which are obscure on the ground can often be identified on

aerial photographs.

McCown et al. (1973) described an aerial photographic acquisition system tailored for agricultural research with due regard to capability and cost. They found the best scale was 1:5,000 to map patterns of variation in the vegetation studied. Harris and Haney (1973) reported their method of field trial aerial photography. High oblique photography was employed in this instance.

As vegetation has generally high reflectance and large reflectance variation between species in the infrared portion of the electromagnetic spectrum, film types sensitive in this region are valuable for detecting differences in vegetation condition and between plant species (Fritz, 1967; Marshall, 1968). Many workers have erroneously attributed the high level of infrared reflectance to chlorophyll content (Knipling, 1969). Knipling (1969) has found that infrared reflectance is about the same for both white and green parts of the leaf, and concluded that infrared reflectance is caused by the internal leaf structure. Gausman (1974) has found that infrared reflectance of leaves is light scattered by refractive index discontinuities

(i) at the surface of the hydrated cell walls with intercellular air spaces and

(ii) among cellular constituents.

However, actual values of foliage reflectance are in many instances greatly affected by such conditions as the leaf age, season, water content, and mineral content of soil or soil type.

Doverspike and Heller (1962), Anson (1966), and Parry et al. (1969 b) have demonstrated the superiority of colour film over panchromatic for the identification of tree species. They found that tonal and textural differences were usually enhanced by colour variations.

Lauer (1966) and Cochrane (1970) found colour infrared more useful than colour film for the consistent identification of tree species. Both colour and colour infrared films were reported to be vastly superior to infrared and panchromatic (minus-blue) film. Tarkington and Sorem (1963) earlier emphasized some of the uses of colour infrared film in aerial photography.

Cochrane (1970) considers that colour and colour infrared films are more suitable than panchromatic or infrared in distinguishing burned and unburned areas in Australian forests.

Northrop and Johnson (1970) compared medium scale (1:12,000 to 1:20,000) panchromatic, infrared, colour, and colour infrared aerial photography for the identification of mixed hardwood and pine forests in Alabama. They concluded that panchromatic film was definitely inferior to the other film types. Because of its relatively low cost, they suggested that infrared film, using a red filter, would be the most desirable film to use for forest type identification. Malmgren and Garn (1975) compared panchromatic and colour infrared aerial photography for mapping land conditions in a mountainous, heavily forested complex geologic area (Bitterroot National Forest, Montana). They found colour infrared vastly superior to panchromatic photography as it produced specific, accurate land inventory data and reduced the field time needed to collect this information by 25 to 75 percent, depending upon an area's complexity and accessibility.

Sequential aerial photographs can show vegetation trends (Vink, 1968). Vegetation aids erosion prevention by acting as a buffer against climatic elements, namely, rainfall and temperature, as well as stabilizing soil and rock on slopes. Detection of vegetation deterioration by aerial photographic methods should be beneficial in erosion control and prevention. Many plants under stress from insects or disease can be detected by infrared photography, because there is usually a loss of infrared reflectance from affected verdure (Eastman Kodak Company, 1972). Totterdell and Rains (1973), however, presented comparison laboratory photography on colour and colour infrared films of mesomorphic and xeromorphic plants in a healthy state, and in varying degrees of disease, wilt, and desiccation. Their results indicated that it is not possible to record on colour infrared film, for the species used in the test, visual evidence of disease or stress symptoms which was not recorded on colour film.

Carnegie and Lauer (1966) considered that at large scales, colour film is useful for the distinguishing between healthy and

diseased or damaged trees. Meyer and French (1966, 1967) and Marshall (1968) reported that colour infrared film is more widely used than colour film for disease detection of vegetation. Eastman Kodak Company (1968, 1972) cited many references that considered disease detection by aerial photography using colour infrared film. Benson and Sims (1967), however, considered that colour infrared was less suitable than colour film for disease and insect damage detection. Cochrane (1968) advanced evidence refuting their claim. He, (Cochrane, 1968) concluded that colour infrared portrays forest condition as well, and often better, than colour film. Anson (1966) holds a similar view to Cochrane. Cochrane suggested that the use of colour compensating filters to achieve the desired colour balance may augur well for wide and more varied use of colour infrared photography in forestry.

Comparison of large scale 70 mm colour and colour infrared aerial photography for the identification of shrubs in different plant communities (Driscoll and Coleman, 1974) showed that colour infrared was significantly better than colour aerial photography.

Bell (1974) described research using panchromatic and infrared aerial photography to detect airborne, seed-borne, and soil-borne diseases of crops in south England.

2.7 Summary.

Aerial photography is an indispensable tool in erosion investigations and related problems. Such photography presents a three-dimensional image of an area which illustrates important features. Where sequential aerial photographs have been taken, the initial photographs of an area provide reference datums against which subsequent erosion and vegetation changes can be measured.

Interpretation of aerial photographs is a quick, accurate, and relatively inexpensive method of studying erosion problems as well as mapping geology, soils, and vegetation. This method is particularly useful in mountainous regions. Spectral reflectance characteristics of an area under study or of features within such an area can be obtained prior to aerial photography by spectrophotometric analysis. This enables the use of the most suitable film-filter combination for terrain data acquisition.

SECTION 3EQUIPMENT AND TECHNIQUE USED FOR AERIAL PHOTOGRAPHY3.1 Equipment used for aerial photography.

Two 35 mm Asahi Pentax cameras were employed for aerial photography; one a Spotmatic F, the other a Spotmatic II. The Spotmatic F was preferred, but when it was not available the Spotmatic II was used. The focal length of the Takumar lenses used was 35 mm, 50 mm and 55 mm. The 35 mm lens was used at an altitude of 1,460 m, the 50 mm lens at 1,720 m and the 55 mm lens at 1,810 m, so that scale of photography was approximately 1:18,000. For all photography the camera was hand held by the author.

For aerial photography a Middle Districts Aero Club Cessna 172 was used. The oblique photographs were taken through an open window and the verticals through a square hole (20 cm by 20 cm) in the floor behind the pilot's seat.

3.2 Conditions governing date of photographic flights.

Successful vertical aerial photography necessitates cloudless weather or very high fine cloud. The southern Ruahine Range, unlike the northern Tararua Range (on the south side of the Manawatu Gorge) and the central Ruahines, has a higher frequency of fog and low cloud (Elder, 1965). The cloud condition can change very quickly especially when a south-easterly wind is blowing. Within half an hour the conditions can change from cloudless to a solid bank of cumulus cloud, at least 300 m thick, along the length of the southern Ruahine Range. Consequently there are not many days suitable for vertical aerial photography. During the 12 month period November 1 1974 to November 1 1975, there were 28 days suitable for such photography (see Table II). Cravat (1968), and Evans (1974) discussed the effect of climatic factors on timing of aerial photography.

Table II - Dates when weather conditions permitted photographic flights

Year	Month	Days [*]
1974	November	19, 20
1974	December	12, 13, 21, <u>26</u>
1975	January	3, 4, 5
1975	February	2, 10
1975	March	7, <u>19</u> , 21, 23
1975	April	<u>19</u> , 27
1975	May	8, 9
1975	June	4, <u>6</u> , <u>30</u>
1975	July	7, 13, <u>31</u>
1975	August	13
1975	September	13, 17
1975	October	-

Factors, other than weather, which affected whether or not a flight was possible were: aircraft not in area or previously booked, no pilot available, aircraft being serviced, no film on hand, author in field, availability of camera, or too soon after previous flight. Whenever possible the aircraft was booked for a week at a time when weather forecasts appeared favourable.

3.3 Flight procedure.

Before taking off the purpose of the flight was explained to the pilot. The pilot was also shown the intended flight path on an enlarged photograph of the study area so that oblique and vertical aerial photographs could be taken. With a detailed knowledge of the area, the author could accurately navigate and direct the pilot.

For the first flight the aircraft was flown in a southeast direction from the end of No. 1 Line. Such a course would have taken the aircraft over the two photographic study areas. With a light

*Dates underlined indicate days when photographic flights were undertaken.

plane in turbulent conditions however, it was difficult to maintain a precise course. In later flights a different navigation strategy was employed. Over the Raparapawai catchment the aircraft was flown due-west following the main tributary and directly over the photographic study area. Over the No.1 catchment a south-east course was flown from the main forks. Such a flight path is shown in Fig. 5. This enabled vertical photographs to be taken. For oblique photography the aircraft was flown around each study area and photographed from the north, west, south, and east. Each complete flight took just over one hour.

So that the amount of shadow was least, the author attempted to make the time of photography for each flight coincide with the sun's highest position in the sky.

3.4. Films types used.

(i) Colour. On the first flight, Kodak Ektachrome film, rated at 160 ASA, was used. However, it appeared to overemphasize yellow colours, so that on later flights, Kodachrome -X, rated at 64 ASA, was used. An ultra-violet filter was used for all colour photography. The correct exposure with through-the-lens metering was easily obtained for vertical and oblique photography. The lens was closed down one stop for oblique photography, compensating for the extraneous light the meter could not accommodate. Shutter speed was 1/250 second, and aperture settings ranged from f/4.0 to f/2.0, depending on weather conditions and time of year.

(ii) Colour infrared. Colour infrared film used was Kodak Ektachrome Infrared, sensitive to approximately 700 to 900 nm, with a dimensionally stable 0.1016 mm ESTAR-AH base. This film is rated at 100 ASA with a hand held light meter. The camera was set at 200 ASA with a medium yellow Hoya K2 filter (equivalent to a Wratten 12 filter) in place. As its exposure latitude is limited to $\pm 1/2$ stop, an exposure reading was taken over each photographic study area before the photographic run. The camera was focused on the infrared setting. Shutter speed was 1/250 second, and the aperture settings ranged from f/5.6 to f/2.8. Processing was done by Colourtrue Processing Services Ltd., Christchurch.

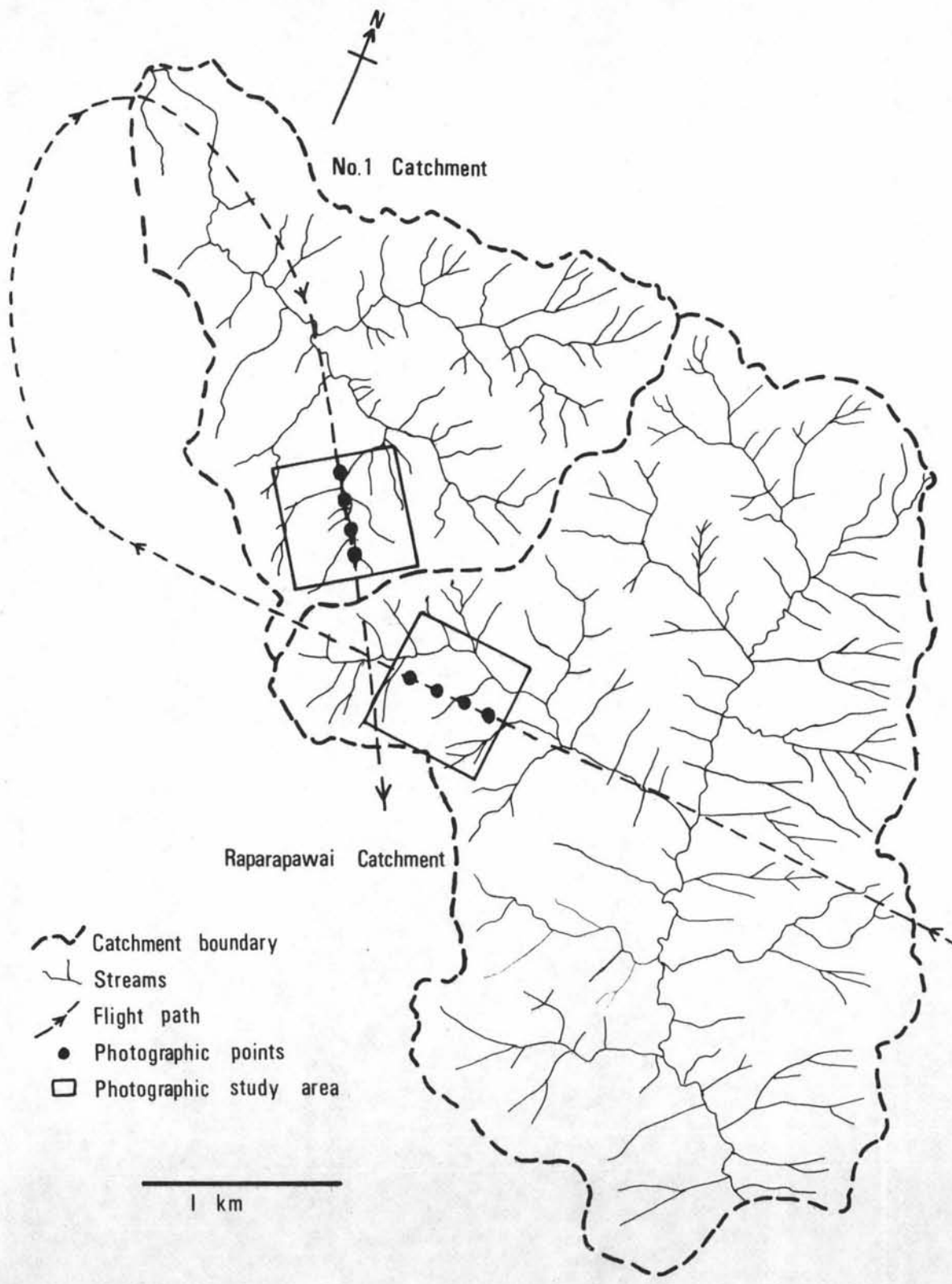


Fig.5. Typical flight path for vertical aerial photography.

(iii) Panchromatic. Ilford FP4 film, rated at 125 ASA, and exposed through a medium yellow Hoya K2 (minus-blue) filter, was used for panchromatic aerial photography. This film was not used on initial photographic flights as it was intended to compare colour and colour infrared aerial photographs with existing panchromatic photographs taken by New Zealand Aerial Mapping. However, so that valid comparisons could be made of the three film types, panchromatic photographs were also taken. Shutter speed was 1/250 second, and aperture settings ranged from f/4.0 to f/2.0.

For all flights colour infrared film was the last exposed. This enabled it more time to reach air temperature before being loaded into the camera. Films, filters and camera settings were changed in flight.

3.5 Focal length of camera.

A change from Ektachrome to Kodachrome-X film and the use of Ilford FP4 film meant that the 35 mm lens had to be changed to a 50 or 55 mm lens, as the widest stop on the 35 mm lens is only f/3.5. An aperture setting of f/3.5 was unsuitable for all weather conditions at a shutter speed of 1/250 second. The widest stop on the 50 mm and 55 mm lenses is f/1.4 and f/1.8 respectively. As the Spotmatic F camera had a 55 mm lens and the Spotmatic II a 50 mm lens, the availability of a camera dictated which of these lenses was used for a particular flight.

The higher altitude required with the 50 mm and 55 mm lenses enabled easier and more accurate navigation, especially when observations were made through the hole in the floor of the aircraft.

SECTION 4.

FEATURES OF THE STUDY AREA.

4.1 Regional setting.

4.1.1 General.

The southern Ruahine Range, which is covered in indigenous forest, is that part of the Ruahine Range south of the gap formed by the Pohangina Gorge and the Apiti-Norsewood Saddle (N144/533712). The area of the southern Ruahine Range is 19,438 ha. The maximum width of the southern Ruahines is 7.8 km, and the total length is 27 km. There is a marked physiographic, vegetational, and climatic difference between the southern Ruahine Range and the remainder of the Ruahine Range (Elder, 1958 a).

4.1.2 Geology.

Kingma (1962) described the Ruahine Range as a rugged range consisting primarily of well dissected Mesozoic sedimentary strata, which was intersected and bordered by many faults. Kingma (1962) said the southern Ruahine Range was extensively faulted, however, these were not mapped. The structure of the southern Ruahine Range is that of a wedge shaped horst, situated on the east flank of the North Island geanticline.

4.1.3 Physiography.

The highest point of the southern Ruahine Range, Takapari (1,392 m) is somewhat isolated, projecting above the Pohangina valley at its northern end. Tapakari is connected with a wide westerly tilting plane (\pm 1,212 m), which continues for about 12.8 km to a prominent peak Maharahara (1,096 m) (Fig. 2). South from this peak there is a narrow, undulating, and winding ridge to Wharite (914 m), which marks the end of the southern Ruahine Range. The remainder of the Ruahine Range is more rugged, the maximum altitude being 1,732 m. One third of the central Ruahine Range lies above the timberline (Elder, 1965). To the east, west, and south of

the Ruahine Range landforms are lower in altitude and slopes are not as steep, the dominant type of landuse being pastoral farming.

4.1.4 Vegetation.

Prior to the 1940s, the vegetation of the southern Ruahine Range had been mapped in three main altitudinal belts (Elder, 1965), namely, podocarp/hardwoods near the foothills, kamahi (Weinmannia racemosa) at medium altitudes, and leatherwood (Olearia colensoi) at the top of the range. Vestiges of two other formations, pink pine (Dacrydium biforme) and cedar (Libocedrus bidwillii) were also mapped.

In the remainder of the Ruahine Range kamahi is largely absent. Mountain beech (Nothofagus solandri) and red tussock (Chionochloa rubra) are prominent in the northern Ruahine Range, with cedar and red beech (Nothofagus fusca) prominent in the central portion. Above the timberline leatherwood scrub and snow grass tussock (Chionachloa pallens) dominate plant communities (Elder, 1965). A list of all plant names used in the text is appended (see Appendix II).

Herbivorous mammals present in the Ruahine Range are deer, opossum, goats, and hares. Their distribution in the southern Ruahine Range has been determined by James and Beaumont (1971).

4.1.5 Climate.

The climate of the southern Ruahine Range, though difficult to quantify accurately, is different from that of the central and northern Ruahine Range (Elder 1958 a). The main difference being a considerable decrease in sunny days and increase in low cloud (see Section 3.2). Elder (1965) considers that these climatic differences are responsible for the marked vegetation changes between the southern Ruahine and remaining Ruahine Range.

4.1.6 Erosion.

There is a paucity of detailed erosion information in the southern Ruahine Range. In his account of visits to, and a crossing of the Ruahine Range, Colenso (1884) made brief mention of erosion: - "... one in particular, as if an avalanche of half a mountain's side had suddenly slipped down into the distant gulph below, leaving a ragged razor-back edge of loose loamy sand at a very acute angle. On this which extended 100 m, connecting two peaks, nothing grew ..."

(p.17), and "... sometimes passing along the very edge of extensive landslips, down which it is fearful to look ..." (p.52). Another early worker, McKay (1877), reported that there were large shingle slips everywhere in the Ruahines. These observations were made prior to the liberation of herbivorous mammals in the Ruahine Range.

Grant (1965) described major regime changes in the Tukituki River (central Ruahines) showing that an erosion phase has occurred prior to the introduction of herbivorous mammals.

In a regional soil erosion survey of the southern half of the North Island, Grange and Gibbs (1947) mapped the southern Ruahine Range as class 11 (III):- slips exposing shattered greywacke, leading to significant rapid deterioration of the land.

Cunningham (1966, 1967) has made valuable comments on erosion types and some casual factors in the southern Ruahine Ranges. James and Beaumont (1971), Logan (1971), and the Manawatu Catchment Board and Regional Water Board (1972) have made general comments regarding erosion in the southern Ruahines. James (1973) has described the increase in erosion surfaces between 1946 and 1963, and factors causing such a deterioration in the upper Pohangina catchment. The data he obtained from aerial photographs showed that erosion surfaces had increased in area by 60 percent during the 17 years between photographic flights.

Land use capability subclasses^x VIIIe and VIIe have been mapped on the eastern side of the southern Ruahine Range (Kennedy and Fletcher, 1972).

Grant (1965) considered that the main cause of erosion and vegetation damage is probably the occurrence of extreme climatic events, in particular, high intensity rainstorms. All other workers mentioned in this subsection (4.1.6) consider that herbivorous mammals have been the main cause of vegetation and erosion damage in the southern Ruahine Ranges.

The remainder of this Section describes the study area in

^x See Ministry of Works (1971) for description of Land use capability classes, subclasses and units.

more detail. Brief mention is occasionally made to the use of colour and colour infrared aerial photography used in this study. An account of film type comparisons is contained in Section 5.

4.2 Morphometry.

Data for morphometric measurements were obtained from the 1:27,000 (1974) panchromatic aerial photographs and an enlargement (4X) of the N.Z.M.S. 1 N144 topographical map. Before any laboratory measurements were made, the enlarged contour map was checked in the field using an altimeter. Schumm (1968) describes methods of using aerial photographs and topographical maps for the quantitative study of landforms.

4.2.1 Area.

Areas of the No. 1 and Raparapawai catchments were determined by a Coradi compensating planimeter on the 1974 aerial photographs. The values obtained were cross-checked on the 1:67,000 (1966) aerial photographs. The range of altitude in the study area is 305 to 1,027 m. As scale differences caused by elevation changes result in non-compensating errors in area estimates of mountainous terrain (Aldrich, 1955), each catchment was divided into three altitudinal zones, and the scale of photographs altered to allow for their mean elevation. Areas were determined on the basis of the corrected photo-scale. The altitudinal zones, less than (<) 700 m, 700 to 900 m, and greater than (>) 900 m, coincide with the altitudinal zonation of vegetation in the area (see Section 4.6). The total catchment areas and areas of altitudinal zones are shown in Table III.

4.2.2 Average slope.

The average slope of the two catchments, and of the altitudinal (vegetation) zones, were calculated by a method based upon the area between different contours within a basin (Wisler and Brater, 1968: p.46), using the formula:

$$S = \frac{D \cdot L}{A}$$

where S = average slope of basin
 D = contour interval
 L = total length of contours
 A = area of basin

The total length of contours was measured by a map measuring wheel. Average slopes obtained are shown in Table III.

Table III - Area and average slope of study area.

<u>Altitudinal zone</u>	<u>Area (ha)</u>	<u>Average slope (degrees)</u>
<u>Raparapawai catchment.</u>	970	30
<700 m (podocarp/hardwoods)	565	31
700 to 900 m (peppertree/tree ferns)	356	29
>900 m (leatherwood)	49	30
<u>No. 1 catchment.</u>	375	30
<700 m (podocarp/hardwood)	155	29
700 to 900 m (peppertree/tree ferns)	169	32
>900 m (leatherwoods)	51	24

The average slopes are very similar in each catchment of the study area. However, the average slope for the 700 to 900 m altitude zones underestimates the steepness of some slopes, because there are many gently sloping ridge tops in this area. The slopes of this zone in the No. 1 catchment are steeper than in the Raparapawai catchment because of the many spilite bluffs present (see Section 4.3).

4.2.3 Longitudinal stream-channel profiles.

Longitudinal stream-channel profiles for the two catchments are shown in Fig. 6. This figure illustrates the obvious stream-channel slope differences. The sharp rise in stream-channel grade at 450 m altitude in the No. 1 catchment is due to a series of waterfalls. The average slope of the No. 1 stream-channel is 180 m/km and the average for the Raparapawai is 105 m/km. The easier stream gradient of the Raparapawai Stream, especially in the lower catchment, has

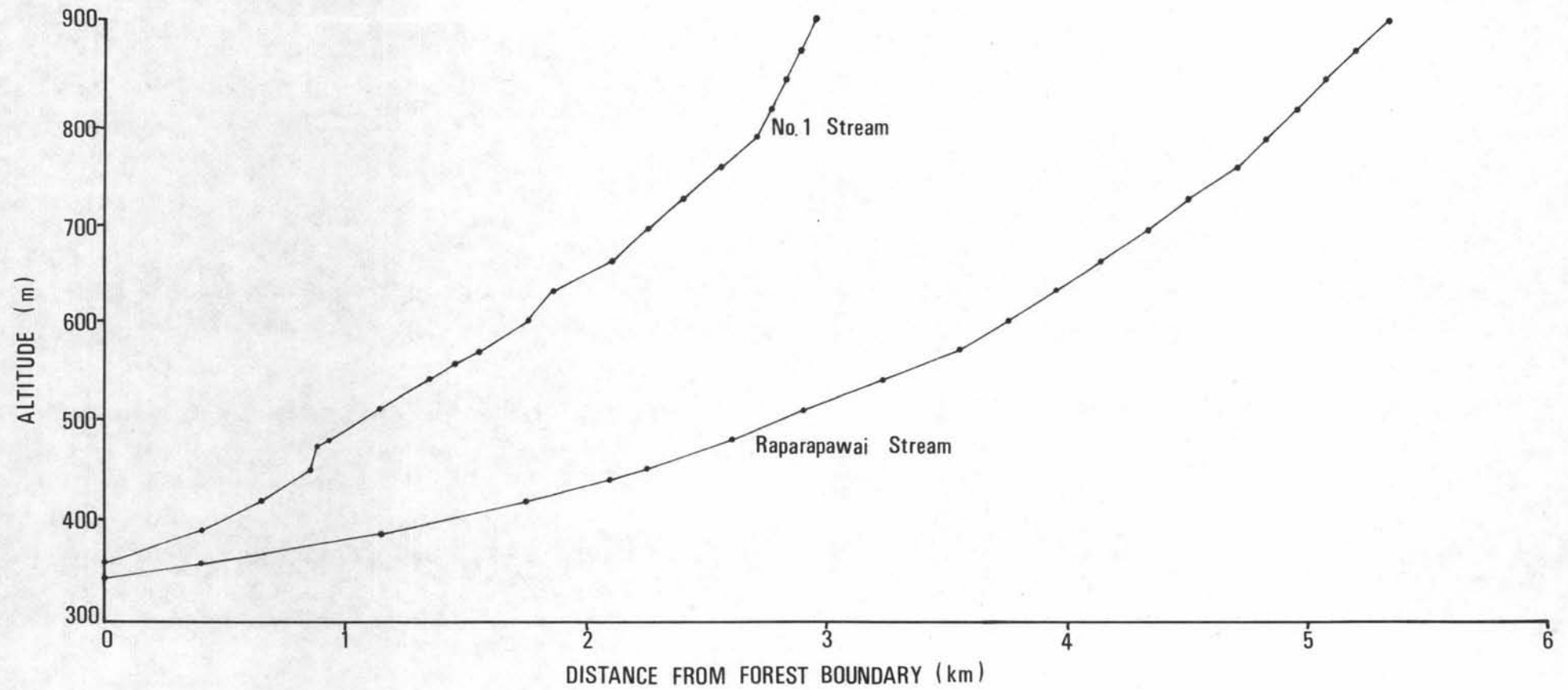


Fig.6. Longitudinal stream-channel profiles.

enabled aggradation of the channel. This has lead to the formation of depositional surfaces (see Section 4.7.1). The easier stream gradient also causes water to flow more slowly in its stream bed, thereby causing less undercutting of slopes, and resultant debris slides (see Section 4.7.2).

4.2.4 Hypsometric analysis.

Hypsometric (or area-altitude) curves for the two catchments are shown in Fig. 7. The method used to construct such curves is described by Strahler (1952), and Miller (1964: p.65). The parallel north-south lines were 10 mm apart on the 1:15,840 contour map. Comparing the two catchments, this analysis shows that the No. 1 catchment has a slightly higher median elevation (50 percent of area above and below) than the Raparapawai catchment. Median elevation on the No. 1 catchment is 671 m, that of the Raparapawai catchment is 620 m. Below 950 m altitude, the No. 1 catchment has consistently higher percentage areas above any given altitude. Because both streams leave the mountain lands at approximately 300 m altitude, this analysis offers a useful comparison.

4.2.5 Slope aspect.

Slope aspect of the No. 1 and Raparapawai catchments was determined by the method described by England (1971), using a T-square, triangle, and topographical map (1:15,840). East-west sample lines were 1 cm apart, so that there were 984 sample points. Four aspect classes were recorded. These were north, east, south, and west. North is between $N 45^{\circ} E$ and $N 45^{\circ} W$, east between $N 45^{\circ} E$ and $E 45^{\circ} S$, south between $E 45^{\circ} S$ and $S 45^{\circ} W$, and west between $S 45^{\circ} W$ and $W 45^{\circ} N$. Distribution of slope aspect classes in the two catchments is shown in Table IV.

Table IV - Distribution (percent) of slope aspect in study area

	North	East	South	West
No. 1 catchment	25	15	11	49
Raparapawai catchment	12	40	14	34

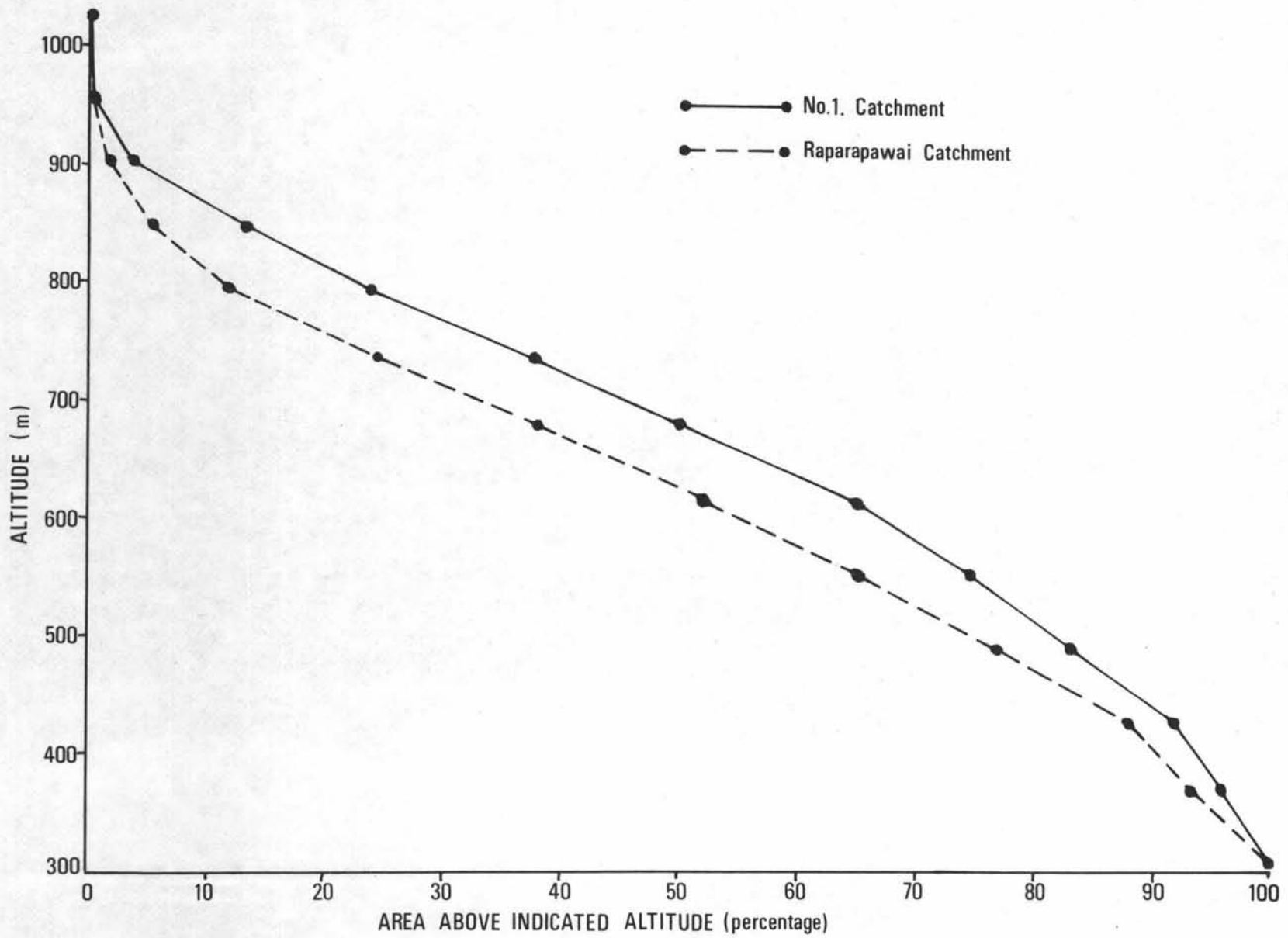


Fig.7. Hypsometric curves.

4.3 Geology.

An inspection of the No. 1 and Raparapawai catchments revealed that the geology was an important factor effecting the present day erosion pattern. A geological investigation was therefore a primary objective of this study, to assess the relative significance of geology and erosion in the two catchments.

4.3.1 Lithology of the study area.

A geological investigation of the study area disclosed five principal lithologic units (see Fig. 8). Descriptions of these units (greywacke and associated volcanic rocks) follow the terminology of Wellman (1949), Lillie (1953), Reed (1957 a), and Kingma (1962).

Lithologic unit A occurs in the north-west of the No. 1 catchment and in the central portion of the Raparapawai catchment. It consists of alternating dark grey argillite and sandstone. Towards the south-east of the No. 1 catchment the sandstone is a paler grey colour and coarser in texture than sandstone in the remainder of the unit.

Lithologic unit B occurs only in the upper No. 1 catchment, and comprises red and green spilite with pale grey coarse sandstone. Sandstone is the dominant rock type in this unit, occupying approximately 60 percent of the area. Red spilite occupies nearly all of the remaining area mapped in this unit. Many spilite bluffs are indicative of the more resistant nature of spilite to erosion compared with the sandstone, which is more fractured than the sandstone in lithologic unit A.

Lithologic unit C comprises the rocks forming the main divide, and is composed of intensely shattered and folded pale grey sandstone with occasional red spilite. The lithology was more difficult to map than the other units, because the area is largely covered with leatherwood scrub.

Lithologic unit D is a zone of red spilite, and red, green, and dark grey argillite, running across the Raparapawai catchment in a north-south direction. Exposed in streambeds are boulders of lithified pug material (see Reed, 1957 b).

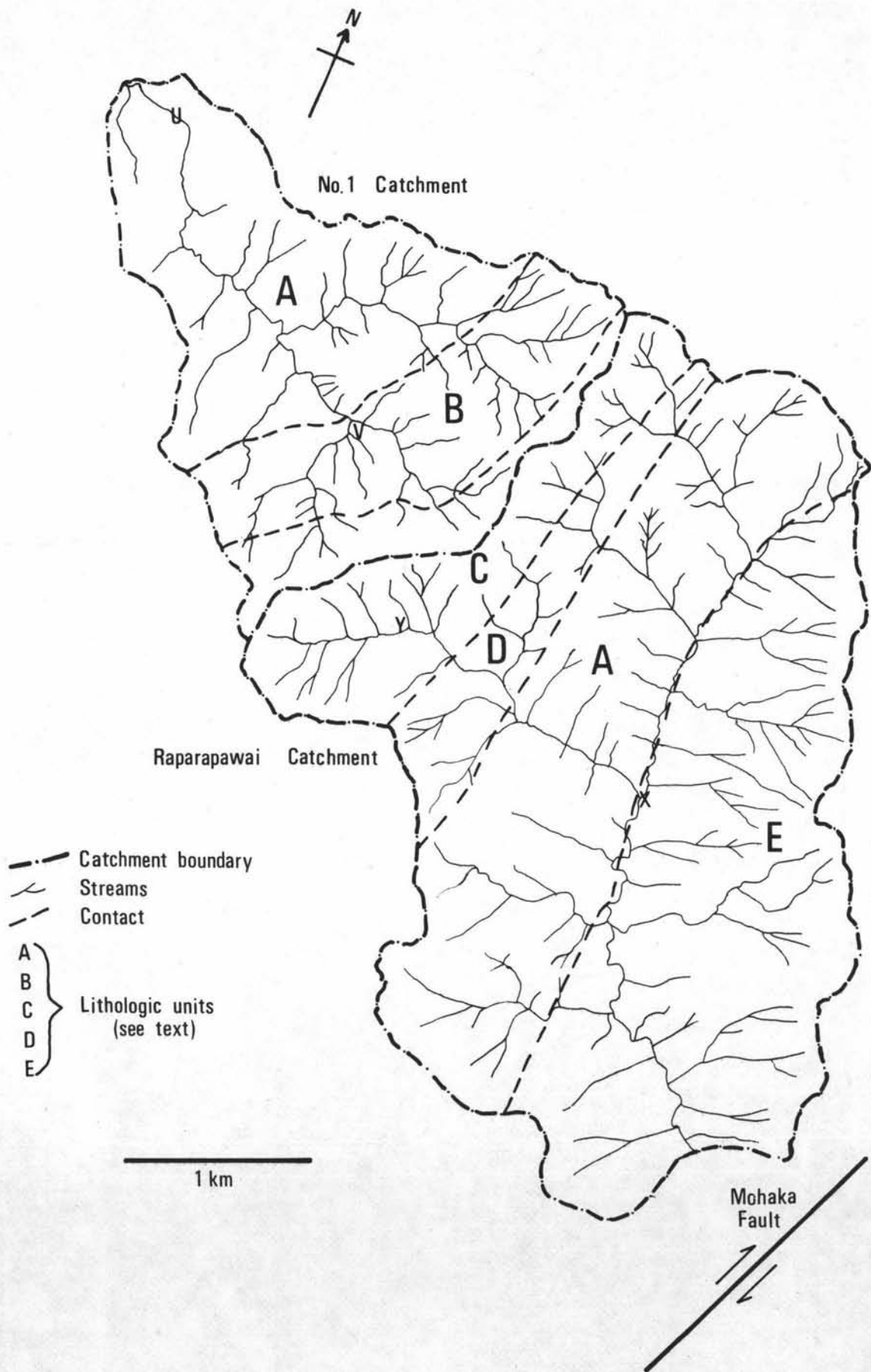


Fig.8. Geology map.

Lithologic unit E occurs in the eastern portion of the Raparapawai catchment, and is composed of coarse sandstone and pseudo-conglomerate, which contains angular rock fragments in a pelitic matrix, here referred to as 'chipwacke'. Chipwacke is less fractured than the other rocks in the study area. The sandstone is generally coarser than sandstones mapped in lithologic units A, B, C and D.

The rocks mapped as lithologic units A, B, C and D had previously been named Ruahine Greywacke, and those of lithologic unit E named Wakarara Greywacke (Kingma, 1962).

4.3.2 Presence of large rounded boulders.

An unusual feature in the study area is the presence of very large rounded boulders, either in streambeds, or within mass movements immediately above streambeds.

4.3.2.1 Characteristics of these boulders.

The boulders are composed of sandstone, spilite, or lithified pug material.

The maximum size diameter of the largest boulder is 8 m (see Fig. 9). This boulder is composed of coarse sandstone, and assuming a density of 2.65 gm/cc, its estimated weight is 270 tonnes. Once exposed in a streambed, they do not appear to have moved very far downstream. No boulders larger than 2 m maximum size diameter occur in lithologic unit E.

These boulders are well rounded and smooth, even when they have only been recently exposed. Fig. 10 shows a typical boulder at N144/345553, which had been exposed in the streambed for 10 months at the time of photography. It is now split in two, and a pug zone from which it originated, can be seen in the right of the photograph. Five percent of all large boulders observed are split in two. Only one group of large boulders at N144/354547 have an angular outline, having originated from a rockfall (see Section 4.7.2 and Fig. 26).

4.3.2.2 Relationship between distribution and size of boulders.

To establish the relationship between the distribution and size of the boulders, maximum size diameters of the two largest boulders were measured for every 100 m of streambed traversed. Data

Fig. 9. Showing the largest rounded boulder in the study area. This boulder is located at M44/367535, at the base of Slump A (see Section 4. 7. 2).

Fig. 10. The author standing beside a recently exposed boulder in the No. 1 catchment. Note that it is split in two and is well rounded. A fault pug is seen in the lower right of the photograph.



was collected between X and Y in the Raparapawai catchment, and between U and V in the No. 1 catchment (see Fig. 8). The position of faults and mass movements (see Section 4.7.2) were also recorded along the transects (see Fig.11).

Fig 11 illustrates:

- (i) The boulders in the streambeds are largest where faults occur, particularly at the base of mass movements. Only one exception exists: this is immediately upstream from the debris slide in the Raparapawai catchment where the two largest boulders in the 100 m section of streambed, are opposite one another, and may be concealing a fault trace.
- (ii) The spilite boulders in spilite zones are much smaller than sandstone boulders in sandstone zones. In the upper histogram of Fig.11, the spilite zone is in lithologic unit D, the spilite zone in the lower histogram is in lithologic unit B.

4.3.2.3 Significance of the large boulders.

It is considered that the large rounded boulders have been subject to low temperature metamorphism, because they can split in two once exposed in streambeds and on eroding slopes. They are not considered to have formed as resistant 'marbles' in the fault zones because they would not be expected to break apart on exposure. If the boulders have undergone low temperature metamorphism, they must have existed prior to uplift and faulting. Primary deposition by submarine landslides is considered to be the process by which these large boulders were initially formed within the greywacke strata. Faulting however, has intensely shattered the less resistant rocks, and in extreme cases, crushed them to a mylonite. This has enabled fluvial processes to remove smaller incoherent materials from fault zones, leaving large boulders remnant in streambeds and on eroding slopes.

North-west of the study area, a belt of disrupted sandstone, argillite, chert, volcanics, and marble, mapped as the Pohangina mélangé^x (Spörli, 1974), also contains similar sized boulders.

^x A mélangé (Fr., mixture) has been defined as a mappable body of deformed rock characterised by the inclusion on native and exotic blocks, which may range up to several kilometers long, in a pervasively sheared, commonly pelitic matrix. Fragmentation and mixing of a mélangé results from the tectonic deformation under an overburden pressure (Hsu, 1968).

However, in the Manawatu Gorge, a strongly-sheared mélange-like zone mapped as the Ashhurst Belt (Zutelija, 1974), which contains several massive sandstone units ranging from 10 to 50 m thickness, contains no large boulders.

It is considered that lithologic units, A, B, C, and D constitute part of the Ashhurst Mélange, a 4 km wide belt of intensely faulted and disrupted sandstone, argillite, and spillite.

4.3.3 Faults and lineations.

Extensive transcurrent faulting has been described in the southern Ruahine Range (Lillie, 1953; Kingma, 1962), but has never been mapped in detail. Kingma (1962) mapped three faults in the study area. The Ruahine and Mohaka Faults were mapped east of the main divide, and an unnamed fault on the western margin of the range. The Ruahine and Mohaka Faults were mapped as active faults, the latter being a continuation of the Wellington Fault, (Lensen, 1958).

4.3.3.1 Use of aerial photography to map faults and lineations.

The 1946, 1961, 1966, and 1974 panchromatic aerial photographs all show a high intensity of alignments that are largely inconspicuous on the ground. The 1:67,000 (1966) aerial photographs show the best regional pattern of alignments, while the 1:27,000 (1974) photographs and 1:13,000 enlargements made from them, show the best detailed alignment pattern.

Alignments are expressed on photographs of the study area as: alignments in vegetation patterns; collinear stream courses; waterfalls; alignments of relief, including knick points, straight scarps, and trenches; as well as conspicuous changes in photographic tone and erosion pattern.

Extensive pug zones on eroding slopes are visible on the 1:27,000 (1974) panchromatic aerial photographs because of a subtle tonal change, being slightly darker than the exposed bare rock and soil. These zones are also identifiable on colour and colour infrared aerial photographs (see Section 5.3).

4.3.3.2 Field evidence of faulting.

Alignments on photographs were only mapped as faults if

field evidence was found to indicate fault movement (see Figs. 12 and 13), such as: fault pugs (a blue-black sticky clay, sometimes containing lenses of red and green clay); shatter zones (usually grey or blue-black in colour, and coarser in texture than fault pug); and abrupt changes in rock type with the presence of fault pugs or shatter zones.

If no field evidence was found to indicate that an alignment was a fault, then it was mapped as a lineation. Transparent overlays^{*} show the faults and lineations identified in each catchment. The photographic base maps give a better appreciation of the faulting density in relation to the small size of the catchments, compared to planimetric base maps. Included on overlay 1 (a) is the position of the Ruahine Fault (Kingma, 1962), but it is only shown as a lineation because the author could not find evidence of fault movement.

The strike of faults was measured, but because of the chaotic nature of many fault exposures, it was not always possible to measure dip directions. Most faults strike in a north-east direction, parallel with the axis of the main range. A rose diagram constructed for the strike of all faults in 10 degree arc groupings (Fig.14) illustrates this.

4.3.3.3 Interpretation of fault pattern.

Heine (1962) considers that second-order effects of trans-current movements along some New Zealand faults could explain some New Zealand structural features, in particular, the major features of the Tararua and Rimutaka Ranges. Heine has attempted to explain the formation of the Tararua Range, an elongate dome (Wellman, 1948), on the basis of a wrench-fault tectonics model of Moody and Hill (1956). The essential part of this model is that it predicts stresses that would produce drag folds or thrust faults at angles less than 15 degrees to a major wrench fault. The angular relationship of the West Wairarapa Shear Zone to the Tararua Range may explain the formation of the Tararua Dome as a drag fold, an interpretation which

* Transparent overlays are contained in a pocket at the rear of this thesis. Overlay 1 (a) should be placed over Fig. 3, and overlay 1 (b) over Fig. 4. To position them correctly, the crosses on the overlay should fit over the crosses on the photographic base maps.

Fig. 12. Showing pug zone on a fault in the No. 1 catchment. Location is at M144/353548, and clay mineralogy is shown in Appendix III. The pug zone has been eroded by high stream flows and seepage waters. Either side of this fault, and of many others, there is a marked change in dip of the sedimentary beds.

Fig. 13. Fault exposure in Raparapawai catchment at M144/376555. Rock types visible from right to left are red spillite, sticky blue-black clay with some sandstone, and a lense of green argillite.



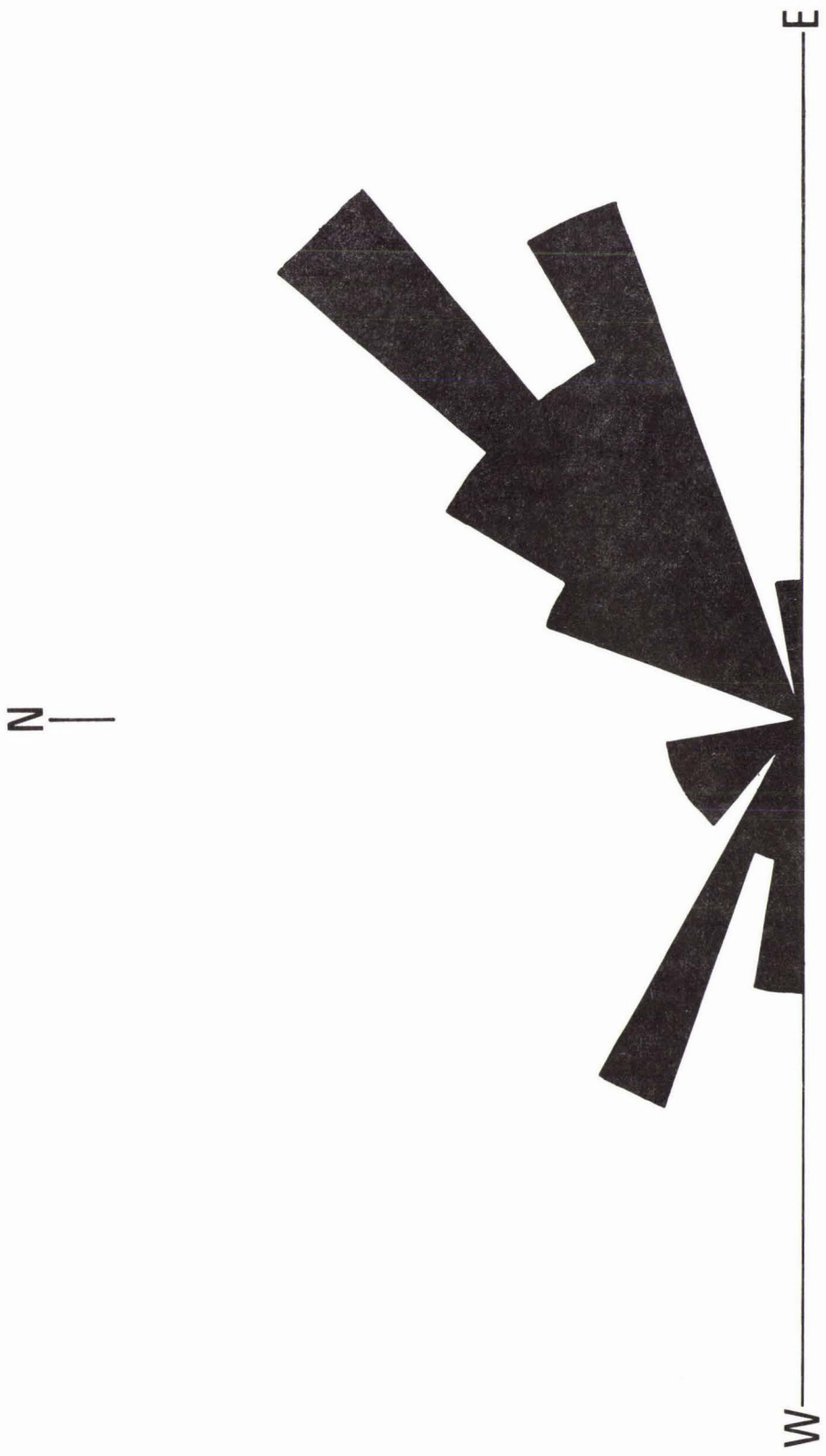


Fig.14. Rose diagram of fault strikes.

Moody and Hill (1956) applied to several Californian hills near the San Andreas Shear Zone. It is tempting to consider that the fault pattern of the study area belongs to this model. The primary wrench being the active transcurrent Mohaka Fault on the eastern margin of the Ruahine Range (see Fig. 8), secondary faults (see Stevens, 1974 a), being first order wrench and second order drag folds.

Some of the faults and lineations close to, and parallel with the axis of the main divide, could be small discontinuous scarps (induced gravity faults) similar to those described in the main dividing range of the South Island (Beck, 1968). Beck deduced that such scarps were the result of gravitational adjustment to an over-steepened topography.

4.3.4 Clay mineralogy of pug material.

Clay mineralogy of soils and rocks can have a significant affect on reducing shear strength of materials on slopes (Akehurst, 1963; Selby, 1970). The clay mineralogy of fault pug material was determined by X-ray diffraction to establish the significance of this pug component which could affect mass movements.

Preparation. Half of the <1 micron clay fraction of each sample was Na^+ saturated, and the other half Mg^{2+} saturated and mounted on glass slides by the standard method (see Jackson, 1964), so that X-ray diffractograms could be obtained. Following this the Na^+ saturated sample was heated to 550°C for 1 hour, and the Mg^{2+} saturated sample treated with glycerol. Further X-ray diffractograms were then obtained.

Percent total clay in each sample was determined by mechanical analysis (see Piper, 1942). Dispersion with Calgon was achieved using an ultrasonic probe (20 kHz for about 2 minutes). Results are shown in Appendix III.

Conclusion. Dominant clay minerals present in pug zone material are mica, kaolinite, and chlorite. Less significant are vermiculite, mixed-layer material, montmorillonite, and iron oxides (in spilite pugs).

The dominant clay minerals are non-expanding, and their presence in the clayey fault pug material is unlikely to effect

slope stability to any degree.

4.4 Soils.

The yellow brown earths and related steepland soils of the study area have been mapped by Rijkse (1971, in press), who found loess, colluvium, and solifluctial debris overlying bedrock. Rijkse (in press) stated that the depth of loess was largely determined by slope, the soil parent material being closely associated with topography. Relief and climate are also important soil forming factors contributing to the subdivision of soils. The author has not mapped any soils, but has examined the profiles described by Rijkse. Within each soil series there are marked profile thickness and descriptive variations. The soil series are briefly mentioned below. Profile descriptions are appended (see Appendix IV).

Ruaroa sandy loam. This soil occurs on the terraces of the lower Raparapawai Stream.

Renata silt loam. This soil occurs on rolling slopes at altitudes up to 900 m.

Ramiha hill soils. These occur at altitudes up to 600 m, on moderately steep to steep slopes.

Renata hill soils. These occur on moderately steep to steep slopes at altitudes ranging from 600 to 900 m.

Ruahine steepland, and Ruahine steepland soils, very steep phase. These soils are related to Ramiha hill soils. McDonald (1961) has analysed some of the physical properties of these soils.

Rimutaka steepland and Rimutaka steepland soils, very steep phase. These soils are related to Renata hill soils and are formed at a higher altitude and under a higher rainfall than Ramahi soils.

Takapari peaty loam. This soil occurs on the gently sloping land of the main divide between the two catchments of the study area (see Fig. 15).

At a depth of 15 cm in most profiles there is a 2 cm band of rhyolitic tephra, considered to be Taupo Pumice, which was erupted c.1844 years B.P. (Healy *et al.*, 1964). Pumice fragments of this tephra are elongate in shape, with largest diameters

Fig. 15. Showing Takapari peaty loam on sandstone.
Vegetation is leatherwood. Hammer is 30 cm long.
Location is at N145/475648.



between 2 to 3 mm. Taupo Pumice is the most likely tephra to be in such a locality (see isopach map - Puller et al., 1973). At M144/463636 there is a 5 cm layer of undecomposed vegetation mixed with rounded lithic fragments up to 2 mm in diameter beneath the sticky peaty silt loam. Assuming a constant rate of peat accumulation, the peat has only been accumulating for the last 3,500 to 4,000 years.

Rijkse (in press) did not find any tephra deposits in this soil. However, phosphate retention, Tamm-extractable aluminium and iron reach high to very high values in the lower profile, indicating appreciable quantities of allophane. Rijkse (in press) suggested the allophane accumulation was a result of loess and volcanic ash in the lower profile.

4.5 Climate.

There is no climate data that applies specifically to the study area. Rainfall information comes from the seven storage gauges in the southern Ruahine Ranges and Wharite meteorological station (see Fig. 16). Climate data for Wharite, which was established in 1966, is taken from New Zealand Meteorological Service (1967-1973). Average annual rainfall figures for the storage gauges (see Table V) were obtained from cumulative rainfall curves for the period 1965 to 1972 (C.R. Renton, pers. comm.). The Takapari Road (D) storage gauge has only been installed since early 1970. The Stanfield Hut gauge was removed by flood waters during cyclone Alison, which occurred during March 1975.

Table V - Average annual rainfall readings from raingauges in the southern Ruahine Ranges.

Gauge	Symbol (Fig. 16)	Altitude (m)	Annual rainfall (mm)
Wharite	Wh	914	2,129
Coppermine	C	519	1,780
Kumeti	K	864	2,540
Maharahara	M	925	2,110
Opawe	O	580	1,950
Diggers	Di	464	1,730
Takapari Road	D	1,140	2,920
Takapari	T	1,140	not established
West Tamaki	W	400	not established
Stanfield Hut	S	548	2,800

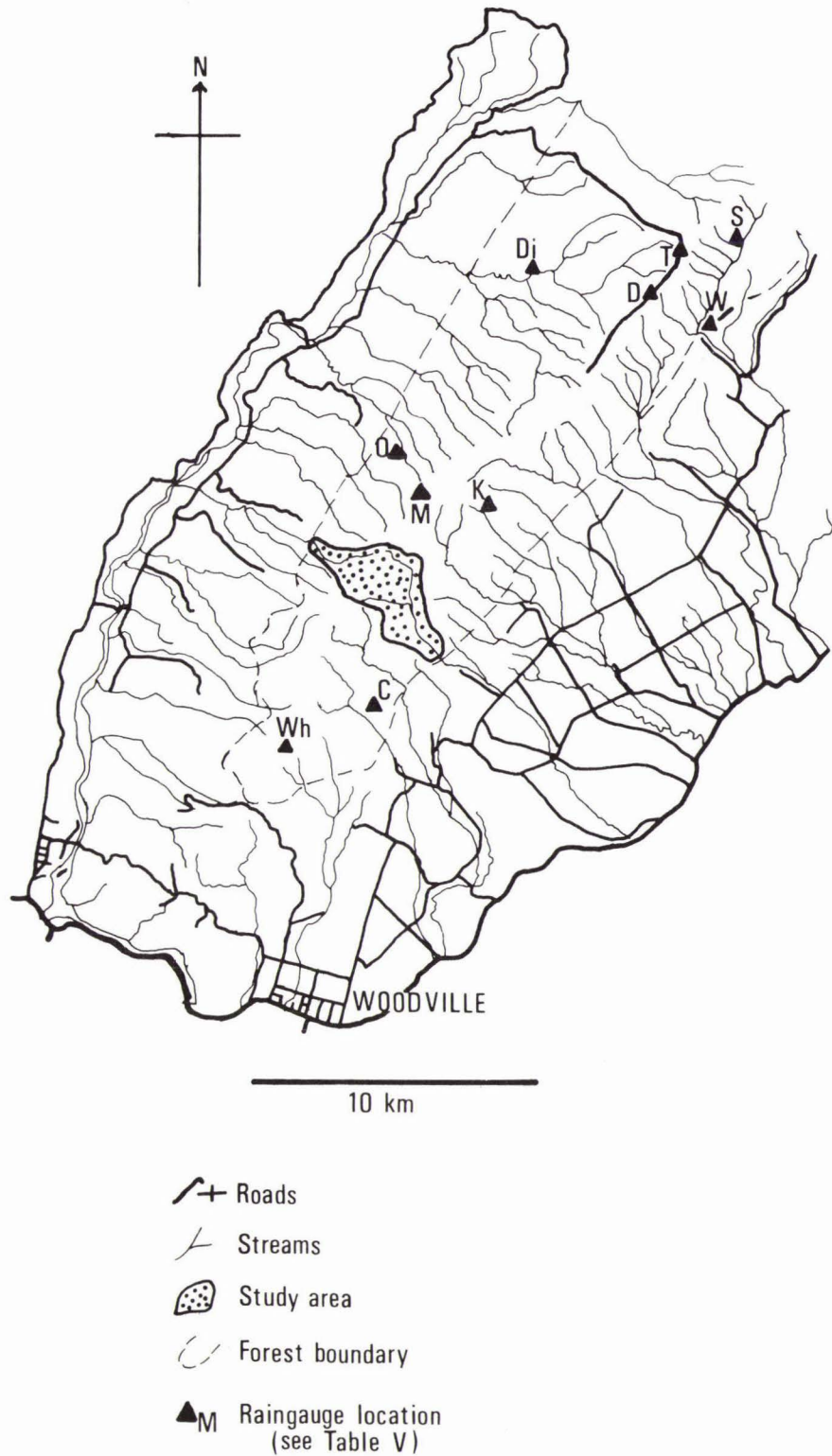


Fig.16. Location of raingauges in southern Ruahine Ranges.

Takapari and West Tamaki gauges are both Fischer and Porter tipping bucket automatic rainfall recorders, installed in October 1974. They were installed by the Manawatu Catchment Board and Regional Water Board so that useful climate information relating to this problem area could be obtained. Both of these gauges were working during the month that cyclone Alison swept the range. Rainfall intensities during this time are shown in Table VI (C.R. Renton, pers. comm.).

Table VI - Rainfall intensities during March 1975.

Time period	West Tamaki (mm)	Takapari (mm)
12 min	7.5	5.0
18 min	8.0	7.5
30 min	10.5	12.5
60 min	15.5	22.5
2 hrs	28.0	41.0
6 hrs	64.5	103.5
12 hrs	92.0	148.0
24 hrs	133.5	241.0
48 hrs	224.0	317.5
72 hrs	260.0	350.0
Month	342.0	517.0

From the data available it can be seen that rainfall intensities and annual rainfall increase with increasing altitude. Climate information for Wharite is shown in Table VII. This gives an indication of overall climate in the southern Ruahine Range.

Table VII - Wharite meteorological station (E0 5282) climate data.

Mean annual rainfall	2,129 mm
Highest daily rainfall	160 mm (4.5.71)
Mean daily temperature	7.7° C
Mean daily maximum temperature	16.4° C
Mean daily minimum temperature	0.8° C
Minimum temperature	-4.0° C (17.7.73)
Maximum days of gales/annum	105 (1972)
Maximum days of snow/annum	18 (1968 and 1969)
Maximum days of fog/annum	252 (1973)
Prevailing wind	North-west (56% of all observations)
Mean wind speed	22.5 k.p.h. (Logan, 1971)
Maximum wind speed	148.1 k.p.h. (Logan, 1971)

4.6 Vegetation.

The vegetation of the southern Ruahine Range has been described on numerous occasions (Elder, 1958 a, 1965; McKelvey, 1960; Nicholls, 1962; Cunningham, 1966, 1971; James and Beaumont, 1971). Descriptions of forest composition and structure, however, made prior to 1945 (Elder, 1965: p. 42) are unrecognizable today, due largely to animal induced changes (James and Beaumont, 1971). Fig. 17 shows some of the changes that have occurred in a 17 year period (1958 - 1975) in the lower Raparapawai catchment.

The vegetation pattern and composition of the study area, as observed in the field and on panchromatic, colour, and colour infrared aerial photographs is now described. The vegetation type boundaries (see Fig. 18) were determined by stereoscopic photo-interpretation of the 1974 (1:27,000) panchromatic aerial photographs.

Vegetation of the river terraces (T) has only been mapped (Fig. 18) in the lower Raparapawai catchment. The vegetation described however, applies to all river terraces in the study area. The dominant species are ragwort (Senecio jacobaea), Californian thistle (Cirsium arvense), foxglove (Digitalis purpurea), sweet vernal (Anthoxanthum odoratum), Yorkshire fog (Holcus lanatus), koromiko (Hebe stricta), hookgrass (Uncinia spp.), occasional wineberry (Aristotelia serrata), with rushes (Juncus spp.) in seepage areas. Associated with these are rimu (Dacrydium cupressinum) below 700 m altitude, toetoe (Cortaderia fulvida), mahoe (Meliccytus ramiflorus), and rangiora (Brachyglottis repanda).

Lower podocarp-hardwood forest (P/H) occurs below an altitude of approximately 700 m. The forest consists of emergent rimu, rewarewa (Knightia excelsa), miro (Podocarpus ferrugineus), tawa (Beilschmieda tawa), with some live rata (Metrosideros robusta) and rare beech (Nothofagus spp). A secondary tier consists of mahoe, putaputaweta (Carpodetus serratus), heketara (Olearia rani), pigeonwood (Hedycarya arborea), with some kamahi and fuchsia (Fuchsia excorticata) in damp sites. The understory and shrub tier consists of rangiora, five-finger (Neopanax arboreum), tree ferns (Dicksonia and Cyathea spp), peppertree (Pseudowintera colorata), and supplejack (Rhipogonum scandens). Toetoe and manuka (Leptospermum scoparium) are colonising many eroded surfaces. There are some dead heketara.

Fig. 17. Repeat photographs of the Raparapawai catchment taken from N144/393512. The top photograph was taken on February 11 1958, the lower one on March 21 1975. Noticable differences between the two are: amount of logs in the now wider and more eroded channel, evidence of more standing dead vegetation (rata) in the lower forest, and more erosion in the upper catchment area (see centre background).

Top photo: M.L. Elder

(New Zealand Forest Service 58/85).



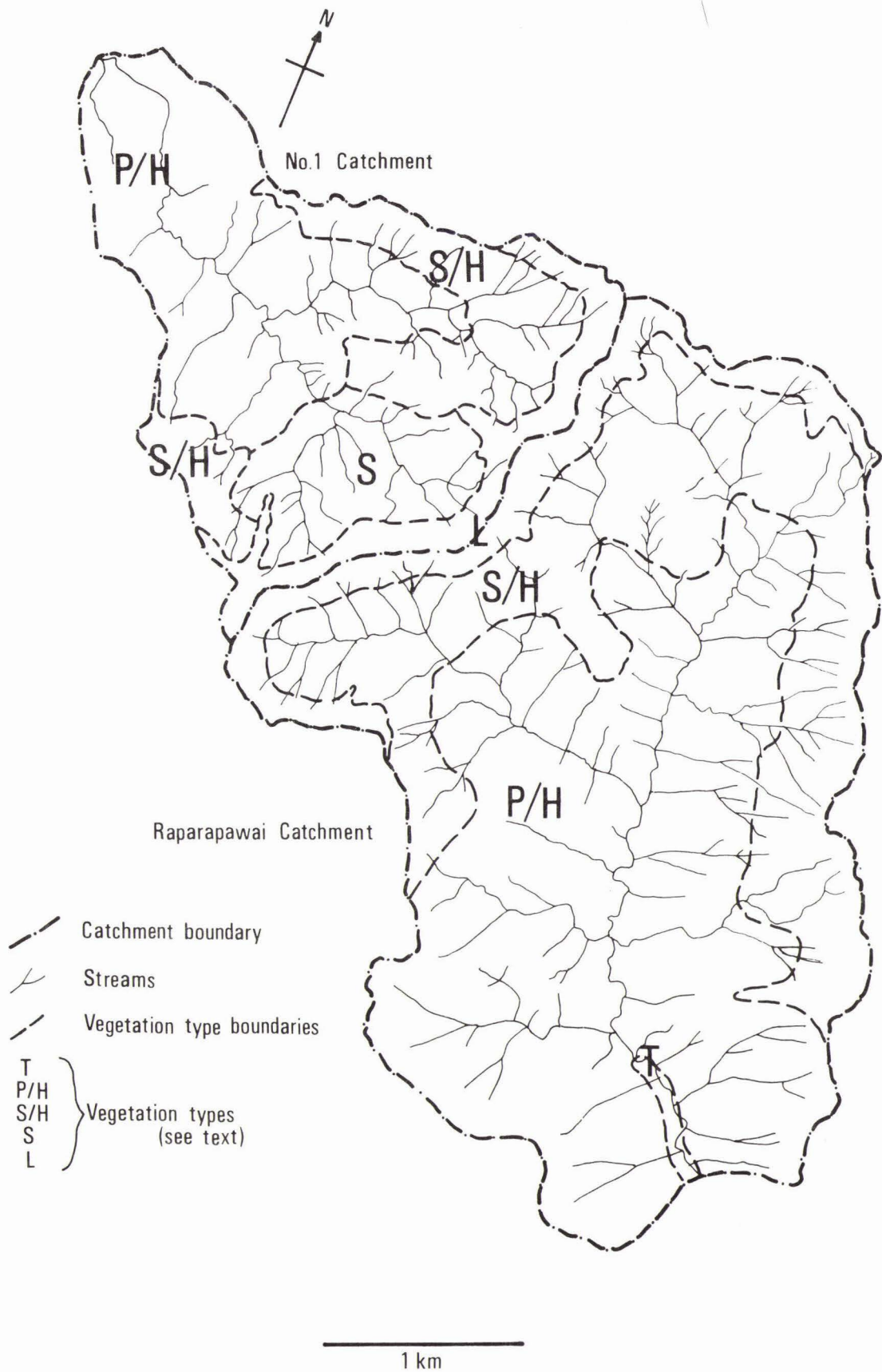


Fig.18. Vegetation map.

Peppertree-tree fern scrub (S) was only mapped in the No. 1 catchment, in a similar altitudinal belt to the mid-altitude scrubland-forest (S/H). As seen on the 1946 aerial photographs, this belt thirty years ago was largely dominated by emergent kamahi. Today the dominant species are peppertree and tree ferns. Also present are toetoe and miro, the latter particularly on spurs. At the margin of many eroding slopes peppertree and tree ferns are dead. The vegetation has a wind blown appearance, and exposure is thought to be the cause of their death. Moisture deficiency was not considered to be a causative factor because the vegetation would not have grown as rapidly as similar species in the remainder of the community until they died.

Upper scrubland-forest (S/H) was mapped between approximately 700 to 900 m altitude. This community is dominated by peppertree, tree ferns and mahoe. Subdominant species are Hall's totara (Podocarpus hallii), putaputaweta, miro, fuchsia in gully head localities, especially in the Raparapawai catchment, Coprosma, and broadleaf (Griselinia littoralis). Toetoe, manuka and bush ricegrass (Microlaena averacea) are common on eroded surfaces. Cedar is rare in this community, although there is considerable evidence of dead cedar.

Leatherwood scrublands (S) which occurs largely above 900 m altitude, is dominated by leatherwood. Other species in this community are pink pine on ridges, bush ricegrass in isolated areas and haumakaroa (Neopanax simplex). Leatherwood is migrating down spurs into the upper scrubland-forest, and onto eroded surfaces.

On colour infrared vertical aerial photography many areas of dead vegetation and bare soil were seen (see Section 5.3). Field inspection revealed that the dead vegetation was largely mature leatherwood and pink pine.

4.7 Erosion.

4.7.1 Previous erosion phases.

In the lower Raparapawai catchment there are numerous aggradational surface remnants represented by terrace deposits (see transparent overlay 2 (a)). Most of these show no soil development

and carry little vegetation. However, there are two surfaces which occur in the lower 2.4 km of the stream channel that appear much older than the remainder. On the lowermost surface (N144/392514), 2 m above stream level, are some large rimu trees. The other surface (N144/386516) which is 3.5 m above present stream level, was noticed by the author once it was exposed by streambank erosion in July 1974. At a depth of 180 cm in this terrace is a 20 cm thick paleosol, which contains some matai (Podocarpus spicatus) (N. Patel, pers. comm.) root remains.

Using an increment borer, the author determined that the minimum age of the rimu trees on the lowermost terrace is 200 years. The rimu trees have an average height of 29 m and the minimum diameter at breast height (over bark) is 1.1 m. As it would take some considerable time for rimu trees to establish on an aggradational surface, it is considered that this terrace is at least 250 to 300 years old. The matai root remains were collected for radiocarbon dating, but unfortunately had not been processed at time of writing.

Grant (1963, 1965), Pain (1968), Pain and Hosking (1970), and Blong (1975) have described depositional surfaces formed during previous erosion phases in North Island greywacke catchments. These workers consider that the main cause of the periods of increased debris supply are probably the occurrence of extreme climatic events, most likely high intensity rainstorms with associated high wind velocities and attendant wind throw of trees. Blong (1975) however, listed a variety of mechanisms which can create depositional surfaces in small catchments.

In catchments where mass movements are the main contributors of sediment to a channel, sediments deposited in channels must be related to the frequency of occurrence of mass movements (Pain and Hosking, 1970). Cunningham and Arnott (1964) and Grant (1966) have found that most mass movements in forested greywacke mountains occur during high intensity, low frequency rainstorms.

As mass movements in the study area are the main contributors of sediment to drainage channels (see Section 4.7.3), it is considered that aggradational surfaces formed 250 to 300 years ago, occurred during high intensity rainstorms. The absence of

aggradational surfaces in the No. 1 catchment is considered to be due to its steeper, narrower channel (see Section 4.2.3).

It is important to emphasise that any erosion that occurred 250 to 300 years ago, took place prior to the liberation of herbivorous mammals in the Rushine Range.

4.7.2 Erosion types.

In this study erosion types are classified according to the landslide classification of Varnes (1958). This classification is based on type of failure, material involved, water content, and velocity of movement. Campbell's (1951) classification, although arranged according to New Zealand conditions, was not used. Its use is more difficult, e.g., soil and earth slips are difficult to separate in the field.

Erosion types were largely determined in the field. However large mass movements, namely slumps, were initially identified on the 1974 (1:27,000) aerial photographs. Field identification of slumps is difficult because of visibility problems. At the commencement of the study, slumps were thought to be absent in greywacke landforms. This affected the authors perception in recognising such features, particularly on aerial photographs.

Erosion types are now discussed.

(i) Debris slides. These are the most common erosion type resulting from shear failure along one or several surfaces, where the moving mass is greatly deformed, or consist of many small units (Varnes, 1958). Such slides occur in both catchments of the study area. Slope angle range, measured by an Abney in the field, on which debris slides occur is 20 to 60°. The average eroded slope varies between 38 and 42°. Most debris slides are 1 to 2 m deep, the zone of failure being generally within weathered and shattered rock (see Fig. 19). Debris slides are most frequent in the 700 to 900 m altitude zone, although slopes leading into the lower portion of the No. 1 Stream channel are badly eroded (see Section 4.2.3 and Fig. 20). The base of most debris slides occur at stream level. A close relationship between debris slides and their proximity to stream channels in Southern California was described by Rice *et al.* (1969). These workers reasoned that erosion was caused at such

Fig. 19. Debris slide in the peppertree - tree fern dominated zone of the No. 1 catchment. Note the straight fault controlled upper margin of this debris slide. This movement can also be seen on the Frontpiece (slightly left of centre, one third of the way up from the bottom).

Fig. 20. Debris slides in the lower No. 1 catchment. Farmland can be seen in the background.



localities by stream undercutting and higher porewater and seepage pressures. It is considered that such factors are partly responsible for increasing shear stress and decreasing shear strength of soil and rock on slopes of the study area. Other factors predisposing slopes to mass movement are discussed in Section 4.7.4.

(ii) Slumps. These comprise one or a few moving units, and are described by Varnes (1958) as underformed slides, in which movement takes place only along internal slip surfaces. Exposed cracks are concentric and concave toward the direction of movement. In slumps the movement is more or less rotary about an axis parallel to the slope, the top surface of each unit tilting backward toward the slope. Some common varieties of slump failure are illustrated in Varnes (1958: p.25).

From an aircraft the author has recognized several slumps in the southern Ruahine Ranges, some of which are visible on the 1946 panchromatic aerial photographs. James (1973: p.99) referred to slumps in the upper Pohangina catchment of the Ruahine Range, and Blair (1972) described three slumps in crushed, clayey Torlesse Fault Zone material in the Blakely River catchment, Canterbury. Structures resembling the small discontinuous scarps described by Beck (1968) in the Southern Alps, have been interpreted as slumps in the Tararua's by Williams (1975), who said that similar structures occur in the Ruahines.

Three slumps occur in the study area, two are in the Raparapawai catchment, slump A (N144/367533, see Fig. 21 and Front-piece) and slump B (N144/378552), and the other in the No. 1 catchment (slump C - N144/358543). Slump A occurs in the film type comparison area (see Section 1.4), and its boundary is indicated on transparent overlay 2 (a).

Slumps A and B are large movements, slump A covering 14.5 ha, the latter 33 ha. Slump C covers 0.5 ha, and because of its small size will not be discussed any further. However, due to their size, and capability of causing considerable damage should they discharge large quantities of material into stream channels, slumps A and B will be described in more detail.

Fig. 21. Oblique aerial photograph of Slump
A. Eroding headscarp and toe slopes are
clearly seen. No. 1 catchment is partly visible
in the top right of the photograph.

Photo: N.A. Trustrum



Slump A is elongate, covering an altitudinal range of 214 m with a maximum width of 350 m. The average slope of the headscarp is 55°, while the eroding toe has an average slope of 40°. Below the arcuate headscarp, a depressed ponding area lies between 5 and 15° to the horizontal. Assuming a concave shear plane, slump A has an estimated 1 million m³ of material within it.

The ponding area is fed by a fracture spring (see Fig. 32), situated in a fault zone at the base of the headscarp. The detailed alignment pattern on this slump is shown in Fig. 29 (Section 5.3). Ponding of water in such a position no doubt maintains a constant lubricant for the shear plane. It is considered significant that the ponding of water has only recently occurred, suggesting rotary movement and backward tilting. The 1946 aerial photographs show a uniform vegetation cover over the upper slump area. The author considers that the vegetation at this time (1946) was dominated by kamahi and peppertree on the present ponding area, and leatherwood on the now well-defined headscarp. Present vegetation at the base of the headscarp is dominated by rushes, rautahi (Carex geminata), bush ricegrass, and peppertree (some of which are dying). Numerous dead tree trunks are present. Another plant present is liverwort (Marchantia spp.). Leatherwood is extending down some portions of the headscarp. The extent of the ponding area is shown in Fig. 22.

Dennes (1974) established that landslips in Colombia, South America, which had surface morphology similar to mudflows, were attributable to a continuous supply of water from a major fault.

The general deterioration of toe and headscarp slopes of slump A is shown in Fig. 22. Data for this figure was obtained from the sequential panchromatic aerial photographs taken in 1946, 1961, 1966, and 1974 using a Nikon reflex stereoscope. Data for 1975 was taken from 35 mm colour aerial photographs using a Cassella pocket stereoscope on a light table. The slope deterioration shown in Fig. 22 is considered to indicate gradual downslope movement of the complete slump. Triangulation measurements over a period of time would positively determine if there was such a downward movement. Changes in angle of slope of large trees (miro) growing on the bulging lower portion of the movement would probably give the same information.

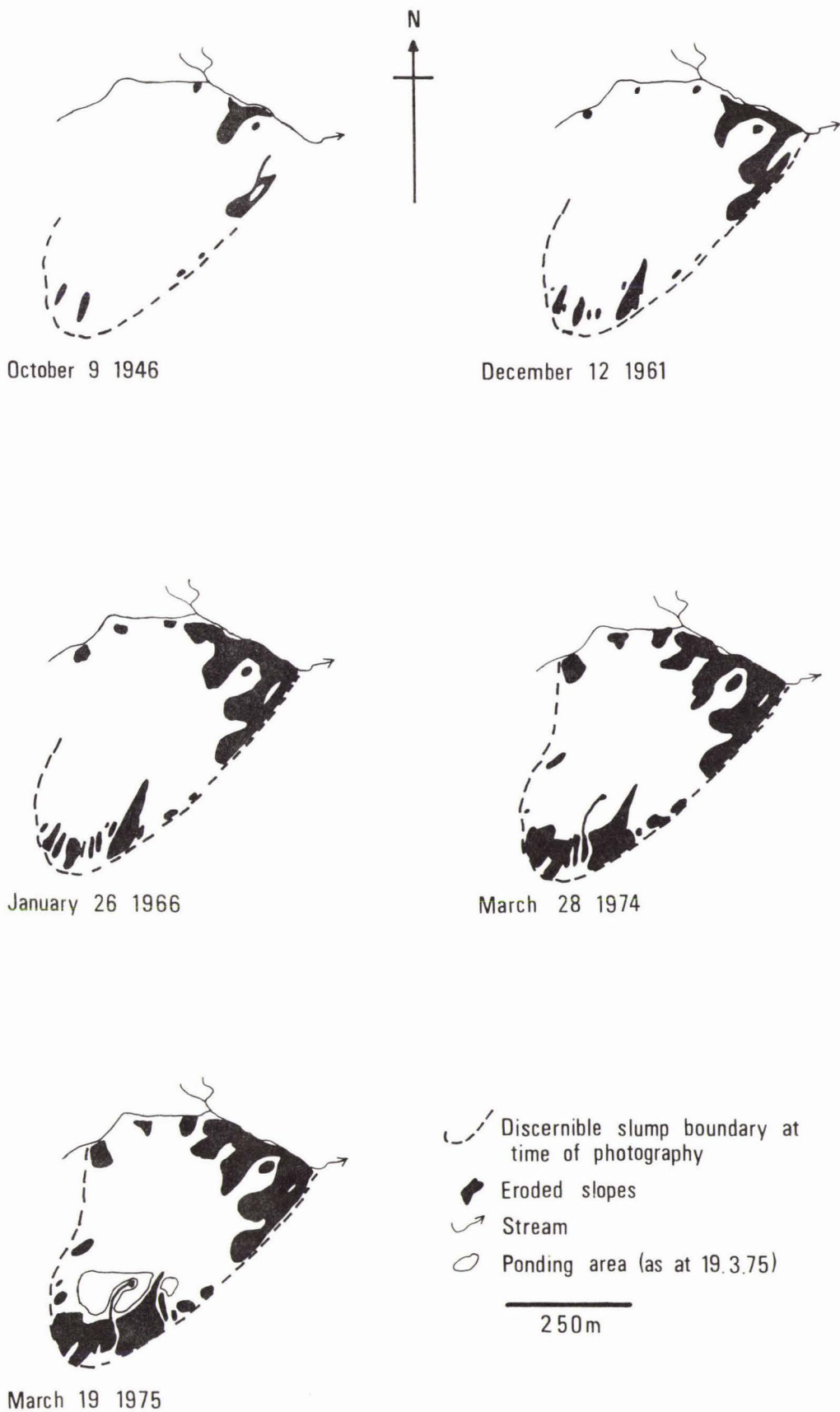


Fig.22. Deterioration of slopes on slump A.

The author unsuccessfully attempted to date when the slump first began to move by searching for an established tree that had a bent trunk. If such a tree were found, and it had elliptical growth rings outside concentric ones, the number of elliptical rings would give a date when downslope movement commenced. Lawrence and Lawrence (1928) were able to date landslides in Wyoming by such a method. These workers found that landslides caused trees to tilt, and the pre-movement concentric growth pattern contrasted markedly with the post-movement elliptical growth pattern. Parizek and Woodruff (1957) and Ritchie (1958) consider that sudden slumping of surficial soils and root mat can tilt trees downslope, after which they righted themselves geotropically, producing a straight trunk above a single bend.

The author considers that slump A is in a precarious position, and may slide into the stream channel. It is not known whether the material would dam up the channel below it, or flow down the stream and onto the farmed land east of the southern Rushine Range. However, a small slump/debris slide blocked a major tributary of the Raparapawai Stream (N144/374543) during the 1975 winter period. Water content of the material in the slump at time of movement will probably determine whether the material flows or creates a dam. Large rounded boulders in a flowing mass would add to any damage caused. Wolman and Miller (1960) cite examples in America where large boulders, up to 100 tonnes weight, were carried downslope by flows and floods. Conditions capable of causing slump A to slide into the stream below it are considered to be a severe earthquake centred close to the area, when the whole movement is saturated with water. The chance of two such events occurring close together admittedly are rare, but as the vegetation on the movement deteriorates, the boundary of the movement becoming less and less stable, with the gradual increase in frequency of intense rainstorms (Grant, 1965) and earthquakes with magnitudes of 5 and above (see Section 4.7.4.6), the situation is not one of long-term stability.

Slump B is in the shape of a sector, the circular portion being the headscarp. This movement covers an altitudinal range of 183 m, and has a maximum width of 600 m. There is no headscarp erosion, only toe erosion. However, at the head of the movement there are six concentric concave terracettes (see Sharpe, 1938: p.71) which are slightly

backward tilting, and ponding water. Between each terracette there is a vertical drop of 6 to 12 m, the largest displacement being at the head of the movement. Except for the continual removal of material from the toe, slump B does not appear to be particularly unstable at present.

(iii) Debris avalanches. These result from rapid flowage of material which is unconsolidated at time of flow (Varnes, 1958). As the material involved in debris avalanches has a high water content, enabling rapid flowage, they only occur during or following heavy rainstorms (Sharpe, 1938; Wright and Miller, 1952; Varnes, 1958).

Debris avalanches are characterised by their long narrow shape, often occurring in small fault controlled drainage channels (see Figs. 23 and 24). The longest debris avalanche in the study area is about 200 m in length, with a width of 10 m.

Debris avalanches only occur above an altitude of 700 m in the study area, the movement often commencing within the leather-wood-peppertree/forest ecotone (altitude approximately 900 m).

(iv) Gully and rill. These erosion types are confined to localities where water flows over fault pug material, red and green argillite, disrupted soil and rock on eroded slopes (see Fig. 25), in small drainage channels, and deer tracks in steep headwater areas. Deer tracking is very common in areas covered by fuchsia. Stevenson (1954) and Blair (1972) have described gully erosion in greywacke fault pug material.

(v) Rockfalls. Rockfalls occur when moving rock travels mostly through the air by free fall, leaping, bounding, or rolling with little or no interaction between one moving unit and another (Varnes, 1958). The frequency of rockfalls in the study area is difficult to establish as their path downslope is not easily detected (c.f. Ritchie, 1958; Rapp, 1960). However, in the No. 1 catchment there is a jumbled heap of large sandstone boulders (N144/354547), which have recently been deposited by a rockfall (see Fig. 26). Beneath these boulders are branches that have not yet rotted. The site of detachment, a vertical rock bluff of shattered sandstone close to a fault, is clearly visible above the stream where the

Fig. 23. Debris avalanche which occurred during cyclone Alison (March 11 and 12 1975). Detritus to the right of the small drainage channel is lying on top of 4 m high peppertree vegetation. The figure in the channel gives an indication of scale. Location is N144/357545.

Fig. 24. Debris avalanche on fault line in the No. 1 catchment (N144/365548). Note the depressed ridge on the skyline (fault trench) and remnants of the former vegetation.



Fig. 25. Showing rill erosion which has occurred in material at the base of a debris slide/slump movement. Location is N144/375533.

Fig. 26. Showing angular sandstone rocks deposited by a rock fall. The tree trunk in the top left of the photograph has a diameter of 50 cm.



rocks came to rest. Following a snowfall in August 1974, the author saw some small rocks, up to 5 cm in diameter, bounding down poorly vegetated slopes. It is suggested that as the time of observation was 1300 hours, the erosion trigger could be the thawing of soil and rock.

(vi) Rock slides. These result from shear failure along one or several surfaces, where the moving rock is greatly deformed, or consist of many small units (Varnes, 1958). Movement is controlled by pre-existing structural features, such as faults, joints, and bedding planes. Rock slides have occurred in both catchments of the study area during 1975. The most common site of failure is steep shattered rock bluffs leading into stream channels.

(vii) Wind. Wind erosion has been witnessed by the author in the study area. However, the significance of wind erosion is unknown. All factors predisposing bare soils to wind erosion (Butterfield, 1971) occur in the study area. Between 800 and 900 m altitude in the south-east of the No. 1 catchment, soils at the margins of debris slides have all been smoothed by the wind, so that rock fragments protrude from the exposed soil. Vegetation at these points, namely peppertree and tree ferns, is dying. The cause is considered to be exposure to strong winds, possibly containing soil material (see Section 4.6). Zotov *et al.* (1939), Elder (1965), Esler (1969), and Logan (1971) describe soil and forest damage caused by very strong winds in the Ruahine and northern Tararua Ranges.

(viii) Channel erosion. During the 18 month period the author has been observing changes in the study area, considerable channel erosion has occurred. Such erosion occurs when streams incise into channel deposits, meander patterns change, and stream flow rises following heavy rain in the study catchments. Although no bedload measurements were made, a line was painted across rocks and logs from one streambank to another (at N144/387516), this line being visible from a photographic point. Sequential ground photographs from this point gave a record of streambed changes that have occurred. The largest streambed changes at this point were stream incision and channel widening which occurred after cyclone Alison in March 1975.

4.7.3 Increase in area of eroded slopes since 1946.

The increase in area of eroded slopes was determined using a dot grid (25 dots/cm) and a Nikon reflex stereoscope on the 1946, 1961, 1966, and 1974 panchromatic aerial photographs. Each catchment of the study area was divided into three altitudinal zones (see Section 4.2.1). Figures obtained for each zone were corrected for photo-scale. Eroded slopes were classed according to aspect. Four aspect classes were recorded (see Section 4.2.5). Data are shown in Fig. 27 and summarized in Tables VIII and IX. These data are only for eroded (bare) slopes: a large portion of slump A and slump B (see Section 4.7.2) is not shown in these results. There is another 10.7 ha of slope on slump A that is still vegetated.

Table VIII - Areal increase in eroded slopes between 1946 and 1974.

Altitude	Area (ha)	1946		1974		Percent increase
		Area eroded (ha)	Percent	Area eroded (ha)	Percent	
<u>No. 1 catchment</u>						
<700 m	155	4.9	3.2	8.6	5.5	72
700 to 900 m	169	7.2	4.2	13.7	8.1	93
>900 m	51	0.25	0.5	0.8	1.6	220
<u>Raparapawai catchment</u>						
<700 m	565	5.5	0.97	15.7	2.8	189
700 to 900 m	356	9.4	2.6	19.6	5.5	111
>900 m	49	0.4	0.8	1.1	2.2	175
Totals	<u>1345</u>	<u>27.65</u>	2.0	<u>59.5</u>	4.4	120

No.1 Catchment (375 ha)

Raparapawai Catchment (970 ha)

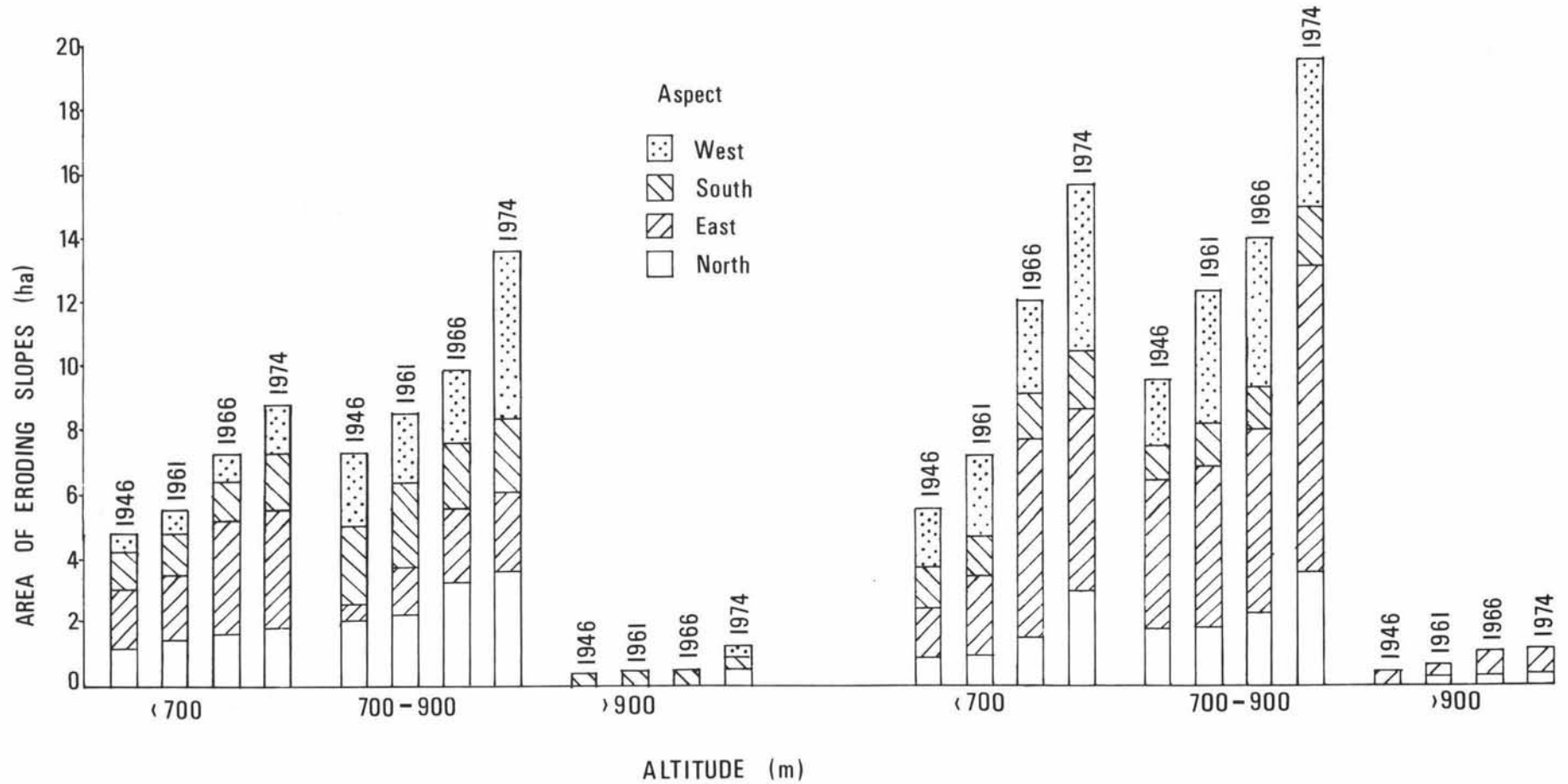


Fig.27. Relationship between erosion, altitude, aspect and time.

Table IX - Comparing eroded slopes (as at 28.3.74) and slope aspect (percentage).

Altitude	North	East	South	West
<u>No. 1 catchment</u>	25	15	11	49
< 700 m	21	40	19	20
700 to 900 m	28	18	14	40
> 900 m	30	-	-	70
<u>Raparapawai catchment</u>	12	40	14	34
< 700 m	15	37	12	35
700 to 900 m	18	50	8	24
> 900 m	25	75	-	-

These data show that:

- (a) Between 1946 and 1974, a period of 28 years, there has been a 120 percent increase in the area of eroded slopes in the No. 1 and Raparapawai catchments. The highest percentage increases have occurred in the >900 m altitude zones (leatherwood scrublands) and the <700 m zone (lower podocarp/hardwood forest) in the Raparapawai catchment. These three zones however, still have a significantly lower percentage area of eroding slopes than the remaining zones. As these three zones had <1 percent of slopes eroding in 1946, it is considered that any erosion subsequent will show a more dramatic percent increase than in the areas that had between 2.6 and 4.2 percent eroded slopes in 1946. This illustrates the fact that percent increase is not necessarily a good criteria for locating the worst erosion areas. The worst erosion has occurred in those altitudinal zones that had high percentages of eroded slopes in 1946, and a moderately high percentage increase in eroded slopes between 1946 and 1974, namely, the 700 to 900 m altitudinal zones in both catchments:
- (b) The most erosion prone slopes in both catchments have an easterly aspect. North-facing slopes are less stable than west-facing slopes. South-facing slopes are the most stable. A higher percentage of eroded slopes occur in the dominantly west-facing No. 1 catchment, than in the Raparapawai catchment. However, the Raparapawai catchment has 40 percent of its slopes facing east. Only 15 percent of the slopes in the No. 1 catchment have an

easterly-aspect. This indicates that the factor or factors predisposing east-facing slopes to erosion is dominated by some other influence (see Section 4.7.4.5 and 4.7.4.6). It is considered that the slightly higher percent of the No. 1 catchment in the worst eroding zone (see Section 4.2.4) would not have a significant affect on the overall percentage of eroded slopes.

Between 1946 and 1974 a minimum of 320,000 m³ of material has been removed from slopes in the study area.

4.7.4 Factors causing erosion.

4.7.4.1 Variety of factors.

Varnes (1958) said that in only a few instances can a particular mass movement be attributed to a single definitive cause. The processes which lead to slope failure might well have begun when the rock was formed, and subsequent movements, weathering, and erosion, have all contributed to potential slope instability. The last event which causes a mass movement to begin movement downslope may be quite trivial, even though it is necessary in the chain of events. Sowers and Sowers (1951) consider that in most cases a number of causes exist simultaneously, and so attempting to decide which one finally produced failure is difficult and may be incorrect. Often the final factor is nothing more than a trigger that set in motion an earth/rock mass that was already on the verge of failure.

All slides and flows, but not falls, involve the failure of earth/rock materials under shear stress. Varnes (1958) gives a comprehensive list of factors that can initiate such failures. Varnes divided these into (a) the factors that contribute to high shear stress and (b) the factors that contribute to low shear strength. The latter were discussed in detail by Selby (1970).

4.7.4.2 Effect of herbivorous mammals on vegetation, soil, and erosion.

Comments are restricted to the effect of deer, goats, and opossums, those mammals continually present within the study area. Sheep and cattle periodically graze the indigenous vegetation. Hares frequent sub-alpine scrublands in the southern Rushine Range, but in very low numbers (James and Beaumont, 1971).

Committee of Inquiry (1939), Zotov (1940), Holloway (1951, 1959), Van't Woudt (1951), McKelvey (1959), Pohlen (1959), Pracy and Kean (1969), Holloway et al. (1963), Atkinson (1964), and Howard (1966) have outlined the effect of deer, goats, and opossums on indigenous vegetation, soils, and erosion on mountain catchments in New Zealand.

A. Cunningham, a New Zealand Forest Service scientist who has been working in the Ruahine Ranges since 1961, gives a comprehensive summary of these effects. Cunningham (1974: p.40-41) stated: "The influence of animals on vegetation goes far beyond the more obvious reduction of plant material by grazing and browsing. Secondary effects are insidious but cumulative, and can lead to an increase in pathogenic activity and to changes in microclimate which may combine to threaten the health or even existence of the plant community. Grazing and browsing remove foliage, reduce carbohydrate formation, restrict root development, and lower available water reserves. Browsing, in particular, reduces plant vigour, creates wounds for insect and fungal attack, and opens the canopy, increasing the temperature range and influencing the microclimate. Browsing of flowers, seeds, and seedlings may retard or halt the replacement cycle. Persistent selective browsing ultimately changes the vegetative structure and reduces diversity in the flora.

Antler rubbing causes damage to foliage, bark, and cambium, reducing plant vigour and opening wounds for the entry of disease. Bark rubbing, cutting, biting, and scratching may similarly expose the cambium or sapwood to disease. From time to time ungulate animals loosen stones and boulders on steep slopes, these roll down and damage plants in their path.

Perhaps the most insidious damage of all is soil deterioration. Cloven hooves of deer, pigs, and other ungulates expose raw soil to dessication, and soil compaction is probably one of the most serious of effects. A good soil should be moist, friable, well drained, and with adequate organic matter. Such a soil will be well aerated and will support a soil life rich in earthworms, arthropods, bacteria, and many other organisms which play a vital role in plant health. Compaction by animals reduces aeration and soil organisms and lowers soil drainage, all of which in turn reduce plant vigour and pave

the way for disease".

Vegetation is less able to ameliorate raindrop impact and retard surface runoff once it has been detrimentally changed by herbivorous mammals. Erosion potential on slopes and in stream channels is greater when this occurs.

Grazing animals, particularly goats (McKelvey, 1959), markedly slow down the rate of regeneration on slipped surfaces, thus predisposing already eroded slopes to further erosion. Since 1946 there has been very little regeneration of indigenous plant species on eroded surfaces in the study area.

As there is a higher percentage of palatable plants in the southern Ruahine Range than in the remainder of the Ruahine Range, James and Beaumont (1971) said that herbivorous mammals have caused more vegetation damage in the former. Repeat photographs taken in 1958 and 1975 show some of the vegetation and erosion changes over the period (Fig. 17).

Through their effect on vegetation and soil it is irrefutable that deer, goats, and opossums have increased the incidence of erosion in the study area: to what extent though is very difficult to determine. James (1973) attempted to define the extent to which the increased erosion between 1946 and 1963 in the upper Pohangina catchment, Ruahine Range, and mammal effects were interrelated. James concluded that the influence of mammals, particularly opossums, has had some part in causing erosion. Most of the increased frequency of erosion occurred in those vegetation types which have suffered most from mammals, in particular the rata/kamahahi and red beech forest. In addition, the area of mass movement in the sub-alpine scrublands, which were least influenced by mammals, declined during the same period (1946 to 1963).

In the study area, the highest percentage of eroded slopes occurs in the 700 to 900 m altitude zone, that portion that was largely dominated by kamahahi forest. However, the highest percentage increase in erosion, over the period 1946 to 1974 has occurred in the sub-alpine scrublands (see Section 4.7.3).

From observations made in the study area and in other southern Ruahine Range stream catchments, it appears that kamahahi, although very

palatable to opossums, may have died primarily owing to some other cause or causes. This is because:

(a) large kamahi in the subcanopy of the lower altitude podocarp-hardwood forest appear healthy. Even though there has been considerable browsing of young indigenous plants, some small kamahi plants have survived. Palatable rata, but strangely not the kamahi, in this forest were affected by opossums before the opossums moved into the higher altitude kamahi forests (Elder, 1965). If defoliation by opossums has been the main factor causing kamahi mortality, then surely one would expect the kamahi in the low altitude forest to succumb before those at a higher altitude, which grew in a much harsher climate.

(b) In the 700 to 900 m altitude zone where old kamahi trees have died, young shoots often appear at the base of the old stump. This phenomena is widespread in southern Ruahine Range, (A.H. Leigh, pers. comm.). These shoots have not been browsed to any extent and are sheltered by the now dominant peppertree and tree ferns.

(c) Statements by other workers, namely Elder (1958 b) and Franklin (1967), indicate that there is more involved in the death of kamahi (in the southern Ruahines) than just opossum defoliation. Elder noted the striking difference between kamahi damage in the Tararua and Ruahine Ranges. His only explanation was a possible shortage of nesting sites, which he said was hard to demonstrate. Franklin noted that in the Tararua Range many of the rata are dead or dying, their death no doubt hastened by the activities of opossums, but there was no widespread mortality of kamahi. It is also interesting to note that Elder (1965:p.52) said ... "It is, however, an open question how far the death of rata can be attributable to opossums; it's death on Kapati (1907) and it's sudden death over a short period at Waikanae (1936) appear to have other causes".

The author suggests that climate changes (see Section 4.7.4.3) may have been primarily responsible for causing kamahi mortality, as well as the death of the peppertree and tree ferns in certain areas of the 700 to 900 m altitudinal zone (Sections 4.6 and 4.7.2).

Introduction of herbivorous mammals to the study area.

Goats have been present in the study area longer than any other mammals. They were first seen in the head of the Raparapawai catchment as early as 1919, and were thought to have crossed the range from the Opawe catchment. However, their earliest reported liberation was in 1925 (Elder, 1965). Goats spread slowly from this point, reaching Wharite about 1955, and the upper Pohangina valley about 1959.

Deer were reported to be in 'heavy concentrations' in the upper Pohangina catchment by the early 1940s, but few deer were south of here. From 1945 until 1962 deer steadily increased throughout the southern Ruahine Range (Elder, 1965).

Opossums were liberated on both sides of the southern Ruahine Range between 1920 and 1936. By the late 1940s there was a general movement up into the mid-altitude forest, and in this favourable habitat numbers increased rapidly (James and Beaumont, 1971).

Present distribution of mammals.

James and Beaumont (1971) established the distribution of mammals in the southern Ruahine Range. Deer are more common in the south-west, preferring the zone just below the leatherwood scrublands. During the 30 days spent in the field no deer were sighted in the No. 1 catchment (south-west portion), but 11 were sighted in the Raparapawai catchment. Goats are common in the No. 1 catchment, 4 being sighted while in the field. Opossums have their highest frequency in the south-east, preferring the low altitude forests.

4.7.4.3 Effect of rainfall on erosion.

As streamflow is a residue of rainfall, it is axiomatic that floods result from rainstorms. Large rainstorms can cause serious erosion in mountain catchments, even when the indigenous vegetation is in a satisfactory condition (Cunningham and Arnott, 1964). However, the magnitude and frequency of storms is not constant from period to period and naturally floods and erosion damage follow a similar pattern. Although there may be cumulative effects from either one major storm or from several moderate storms, Grant (1966) considers that the history of major river regime changes, particularly

if the rate of change is considered, closely mirrors the history of storminess, flooding, and erosion.

From studies of major regime changes in the upper Tukituki River, Grant (1965) determined that prior to the introduction of herbivorous mammals, the tempo of change has accelerated. The last major river regime change was initiated in the 1930s, and had become pronounced by the late 1940s, and in the upper catchment is still continuing. Grant (1965) postulated that small area rainstorms had increased in intensity since about the 1930s. This postulate was later examined (Grant, 1966) using maximum daily rainfall data since 1900 for 16 rainfall stations having a coverage of 7,490 km². Although daily rainfall values may be of limited use, Grant (1966) considered that preliminary analysis strengthened his 1965 postulate.

Since 1900 the four decades of greatest regional storminess and erosion potential, in descending order of magnitude are (Grant, 1966):

1. 1931 to 1940
2. 1911 to 1920
3. 1951 to 1960
4. 1961 to 1965

Grant also found that the period 1931 to 1960 was stormier than the preceding 30 years, and the indications are that this higher level of average storminess persists.

As many new mass movements occurred during heavy rainstorms in the 1930s, 1950s, and 1960s, Grant (1965) suggested that a great deal of erosion on the eastern side of the Ruahine Range is primarily due to rainstorms. Grant (1969) stated that rainstorms "exert an influence that outweighs the influence of animals". As the pattern of erosion surface increase is similar in both catchments of the study area (see Section 4.7.3), it is considered Grant's (1965) suggestion is probably true for the western side of the Ruahine Range as well.

Grant (1968) has also established that the most droughty summer period of this century was 1946 to 1958, for autumn the current period since 1958 is the most droughty.

Flood history of the Manawatu River presented by James

(1973) suggests that Grant's findings are probably relevant for the Manawatu River catchment in general terms. However, floods recorded for the Manawatu River at Palmerston North, do not necessarily give a complete record of localized intense rainstorms in the southern Ruahines, as such events can be largely unnoticed downstream. Nonetheless, James (1973) said it could be argued that the increased frequency of mass movements between 1946 and 1963 in the upper Pohangina catchment could be simply related to the greater number of storms that occurred in that period.

4.7.4.4 Effect of fire on erosion.

The influence of fires on vegetation and erosion has been discussed by Esler (1963; 1969), who worked in the Tiritea catchment. The vegetation of the Tiritea catchment, in the northern Tararuas, and the vegetation of the southern Ruahines can be regarded as mirror images (Elder, 1965: p.41). Esler (1963) considered that a fire in 1760 was the primary cause of forest cover destruction, which was further damaged by herbivorous mammals and wind, lead to bare ground and erosion. James (1973) mentions fire-damaged vegetation in the southern Ruahine Range, evidence of which still exists today.

Except for areas adjoining the farmed foothills, the author is not aware of any fires having occurred in the study area.

Although fire has not been a significant factor to date in causing erosion in the southern Ruahines, it could be in the near future. Cunningham (1972) considers that the peppertree-tree fern scrub (S) and the upper scrubland-forest (S/H) vegetation types (see Section 4.6 and Fig.18) now contain much potential fuel which readily dries out in summer, and thus constitutes a serious fire risk.

4.7.4.5 Relationship between faults and erosion surfaces.

The close relationship between faults and lineations and erosion surfaces for the Raparapawai Catchment is seen when transparent overlays 1 (a) and 2 (a) are placed over Fig. 3. A similar relationship is seen for the No. 1 catchment when transparent overlays 1 (b) and 2 (b) are placed over Fig. 4.

Fault density and percentage area eroding of the three altitudinal zones in the study area are shown in Table X.

$$\text{Fault density} = \frac{\text{Length of fault trace (km)}}{\text{Area of zone considered (ha)}}$$

Table X - Comparison between fault density and erosion severity

	Fault density (km/ha)	Percent of area eroded (at 28.3.74)
<u>No. 1 catchment</u>		
<700 m	0.052	5.5
700 to 900 m	0.13	8.1
>900 m	0.065	1.6
<u>Raparapawai catchment</u>		
<700 m	0.004	2.8
700 to 900 m	0.050	5.5
>900 m	0.065	2.2

Data from Table X show that for the <700 m and the 700 to 900 m altitudinal zones, the percentage area eroded increases with increasing fault density. Compared to the other altitudinal zones, the >900 m zones which have the smallest percentage area eroding, have quite high fault densities. It is considered that the more gentle slopes (see Section 4.2), more intact vegetation (see Section 4.6), and the possibility of small discontinuous scarps (Beck, 1968) being present, and not faults as mapped, explain this difference. As small discontinuous scarps are gravity rather than tectonically controlled, earthquakes would not disturb them as much as faults, so that erosion is less likely following such an event.

Comparing the No. 1 and Raparapawai catchments, the No. 1 catchment has the highest fault density and the highest percentage area of eroded surfaces as at 28.3.74 (see Section 4.7.3).

4.7.4.6 Relationship between earthquakes and erosion occurrence.

The study area is in a tectonically active region that is characterised by shallow or normal earthquakes (Eiby, 1958), i.e., those within the crust or close to its base, of large to intermediate average displacements (Gibowicz, 1975). Many research workers studying erosion processes have indicated that earthquakes can be an

important trigger causing mass movement (Sharpe, 1938; Terzaghi and Peck, 1948; Varnes, 1958; and Selby, 1970).

It is generally considered (Eiby, 1957; Hodgson, 1964; Press and Brace, 1966; and Menard, 1974) that the earthquake mechanism is most adequately explained by the elastic-rebound theory, proposed following geodetic measurements before and after the 1906 Californian earthquake (Reid, 1911). According to this theory an earthquake is the result of strain release caused by the sudden shearing motion along a fault.

Many workers have mentioned the effect of earthquakes on erosion in New Zealand axial ranges. Waghorn (1927) observed fault and associated erosion features in the northern Ruahine Range. He considered that the features were probably caused during the violent 1866 Hawke's Bay earthquake. Eiby (1968), however, only described an earthquake centred in Hawke's Bay on February 23 1863, which was felt over most of the country. This earthquake caused damaged and ground fissures at Napier.

Campbell (1945) reported that a considerable number of landslides occurred in the Ruahine Ranges following the 1931 Hawke's Bay earthquake. This earthquake had a magnitude of 7.75 on the Richter scale (Eiby, 1968). However, Elder (1965) noted that no damage had been seen in the Ruahine Range attributable to this earthquake, but extensive slip and rockfall damage followed the 1929 Murchison earthquake, magnitude 7.75 (Eiby, 1968).

Robbins (1958) described the large scale mass movements and vegetation damage in the Rimutaka Range caused by the 1855 Wairarapa earthquake. This earthquake which had a magnitude of 8.0, is the most severe known in New Zealand (Eiby, 1968).

Burrows (1975) has found evidence that a large landslide was initiated by an earthquake caused by movement on the Porters Pass fault. He suggested that earthquakes have probably caused hillside instability in the Acheron River valley, Canterbury.

To determine the relationship between erosion and earthquakes in the proximity of the study area, the number of earthquakes with magnitude ≥ 5 on the Richter scale and epicentres within 100 km of the study area were plotted against time (see Fig. 28). The number

No. OF EARTHQUAKES (MAGNITUDE 5+) WHOSE
 EPICENTRES ARE WITHIN 100 km OF STUDY AREA
 (1970 data not complete)

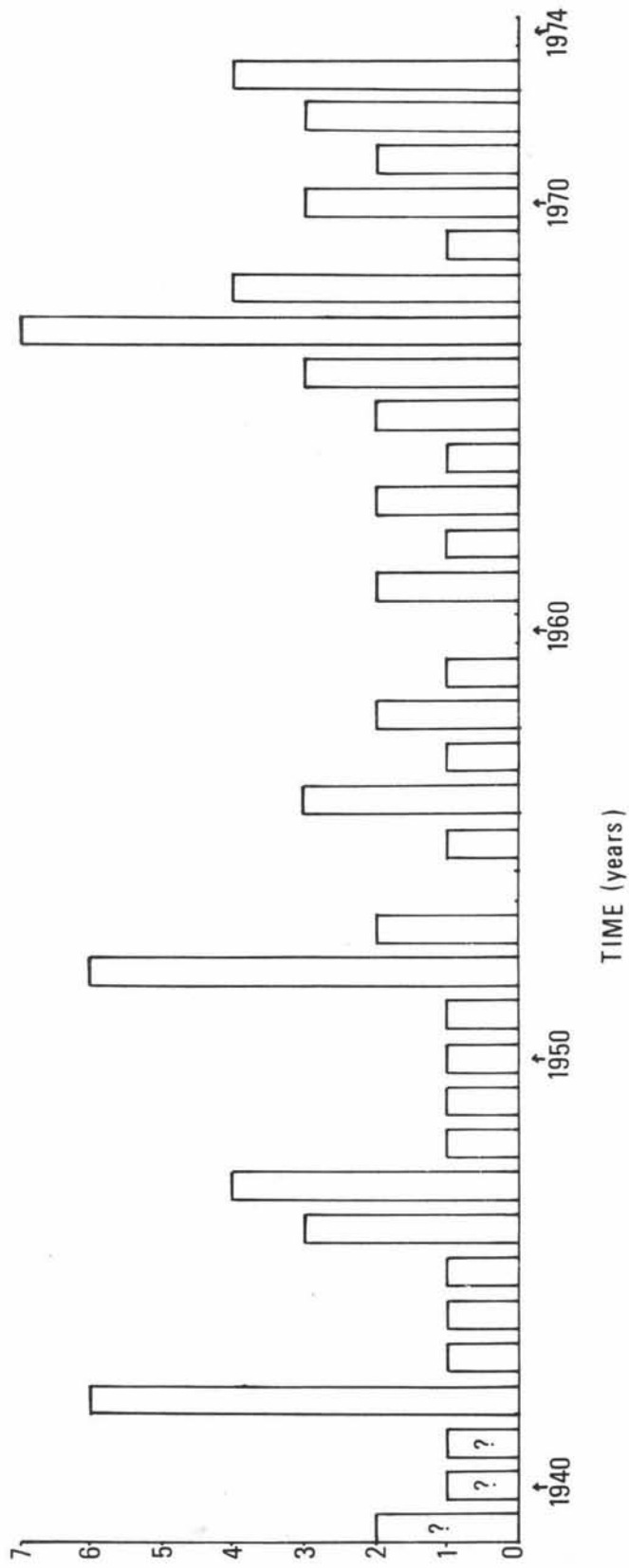


Fig.28. Frequency of earthquakes.

of magnitude 4 shocks would be roughly 10 times as great as the number of magnitude 5 shocks, and of magnitude 3 shocks, 10 times as great again (G.A.Eiby, pers. comm.). Only four earthquakes shown in Fig. 28 have magnitudes > 6 . In 1942 two earthquakes had magnitudes of 7.0, in 1947 an earthquake had a magnitude of 6.1, and in 1951 there was a 6.2 magnitude earthquake.

Earthquake data was obtained from Hayes (1953), Seismological Observatory (1939 to 1954, 1955 to 1968, and 1971), Eiby (1968), and unpublished Seismological manuscripts covering periods 1969, 1970 (January to March, and November to December), 1972 to 1974 (up to March 28).

The number of earthquakes per annum are not plotted beyond 1939 due to the nature of information available. Data for 1939 to 1941 is not as accurate as the remainder of the data. Since 1941 the more sophisticated seismological instruments used to detect earthquakes would not account for the increasing frequency of earthquakes with time (G.A.Eiby, pers. comm.). This might have been the case if earthquakes with magnitudes < 5 were being considered. Hayes (1953) has recorded 38 earthquakes with magnitudes ≥ 5 between 1848 and 1948 with epicentres within 100 km of the study area. Earthquakes recorded between 1848 and 1930 were destructive shocks only, those between 1931 and 1948 were all shocks recorded.

The relationship between earthquake frequency and increase in eroded slopes in the study area is shown in Table XI.

Table XI - Relationship between earthquakes and eroded surface increase.

Period	Earthquakes/ annum/period	Eroded surface increase/annum (ha)	Eroded surface increase/period (ha)
1.1.39 to 9.10.46	2.1?		
9.10.46 to 12.12.61	1.8	0.3	6.4
12.12.61 to 26.1.66	2.0	2.0	10.0
26.1.66 to 28.3.74	3.4+	2.0	15.6

Data from Fig. 28 and Table XI indicate that there has been an increase in frequency of earthquakes since about 1939. However, there has not been a similar increase in the area of eroded surfaces/annum. Thus earthquakes with magnitudes ≥ 5 , located within 100 km of the study area, do not directly trigger mass movements in the study area. Total increase in eroded surfaces for the periods between aerial photographic flights and increase in earthquake frequency/annum for the same periods, however, have a similar pattern. It is considered that earthquakes with epicentres within 100 km of the study area and magnitudes ≥ 5 , have an indirect effect on mass movement in the No. 1 and Raparapawai catchments. Once earthquakes have caused movement along the many fault lines in the study area, predisposing slopes to erosion, there must be some other factor or factors that have a more direct triggering effect on mass movement occurrence. Such a trigger mechanism is thought to be rainstorms of a certain return period. However, due to the lack of any rainfall intensity data, this can not be substantiated.

The last rainstorms of any consequence in the southern Ruahine Range occurred in early 1971. Resultant flood damage was recorded by Manawatu Catchment and Regional Water Board (1972). Monthly rainfall at Wharite meteorological station for January and March 1971 is 395 and 375 mm respectively. The high January figure is due to cyclone Rosie which passed over the area between January 3 and January 8 (New Zealand Meteorological Service, 1971).

4.7.4.7 Summary.

The main points emerging from this section are:

- (i) Erosion is a recurring feature of this area. Erosion phases have occurred prior to the introduction of herbivorous mammals.
- (ii) Between 1946 and 1974 there has been a 120 percent increase in area of eroded slopes. A 60 percent increase has occurred in the upper Pohangina catchment between 1946 and 1963 (James, 1973).
- (iii) The worst erosion in 1946, when animals had had little effect on vegetation, and in 1974, was in the 700 to 900 m altitudinal zone. This zone was largely dominated by kamahi. The highest fault density of each catchment is in this zone. However, the highest percentage

increase in erosion between 1946 and 1974, was in the area where vegetation has been least affected by herbivorous mammals. These animals have had their most dramatic effect on the vegetation of the 700 to 900 m altitudinal zone. It is probable that many of the affected plant species were in a delicate state of equilibrium, to which the influence of animals 'broke the camels back'. Animals are very efficient at halting revegetation on eroded slopes, predisposing them to further erosion.

(iv) Most erosion occurs on easterly-facing slopes, but the west-facing No. 1 catchment has more eroded slopes than the largely east-facing Raparapawai catchment. Fault density is considerably higher in the former catchment, and it also has a higher percentage of mélangé-type rocks (see Section 4.3). All other factors considered likely to have caused erosion have had approximately the same effect on both catchments.

(v) A positive relationship between earthquakes and erosion has been tentatively established.

(vi) Most erosion occurs during and following intense rainstorms.

(vii) Mass movements, in particular slumps, pose a considerable threat to downstream inhabitants and property.

(viii) As there have not been any low frequency rainstorms in the southern Ruahine Range for some time, the erosion causing effects of the many earthquakes which have shaken the area recently, have not yet been realised. Thus the next low frequency rainstorms in this area will cause substantial erosion damage. The effects of this on erosion control have been briefly discussed by Stephens (1975).

4.7.4.8 Conclusion.

Erosion in the study area is the result of a number of interacting causal factors.

It is considered that the main factor predisposing the steep slopes in the study area to erosion is the instability of the densely faulted and shattered mélangé-like rocks. The increasing frequency of medium sized earthquakes since about 1939 is thought to have caused movements along faults, making slopes even more susceptible to other erosion causing factors, the main one being low frequency

rainstorms. The period 1931 to 1960 has been stormier than the preceding 30 years. The effect of herbivorous mammals and other causes has had a devastating influence on some plant communities, reducing canopy protection, ground litter, and soil stability.

Since 1946 very little revegetation has occurred on eroded surfaces.

SECTION 5.

COMPARISON OF COLOUR, COLOUR INFRARED, AND PANCHROMATIC FILM TYPES.

5.1 Introduction.

The purpose of this section is to establish which is the most suitable film type to use in determining priorities for erosion control. The main objective of colour, colour infrared, and panchromatic aerial photo-interpretation was to assess the capability of each film type to show the following features which effect erosion in the study area: alignments, eroded surfaces, vegetation types and condition, rock type, pug zones, seepage areas, and drainage pattern. For this assessment transparencies of the three film types were compared stereoscopically on a light table.

5.2 Considerations relevant to this assessment.

(i) Tone and colour range. The amount of information that can be recorded on a photograph is related to its tone or colour range. Thus a black-and-white photograph, having all tones (values) from black to white, is better than a similar photograph of which the tonal range is from dark grey to light grey (Allum, 1970). The different intermediate tones are analogues for the various colours, and the easier they can be separated, the better. Colour film offers two additional dimensions of hue (colour) and chroma (strength of colour). These two dimensions can be quantified by use of a Munsell Colour System. Hue, value, and chroma make colour films easier to interpret and provide an interpreter with one more factor on which to base his judgment. The human eye can separate more than 100 times more colour combinations than grey-scale values (ratio 20,000:200) (Heller, 1970).

Any advantage true colour has over colour infrared (false colour) photographs, has to lie in the similarity between the colour depicted on the photograph, and the colour of corresponding objects on the ground (Colwell, 1954). Thus the more realistic the colour, the more useful the photographs should be. In these circumstances

there is no point in having a wide colour range: the true colour range is what is required.

With colour infrared photographs, the visible colour range from red to blue depicts scenes photographed. As these colours are unlike the natural colour of an object, the lack of realism can cause initial interpretation difficulties (Allum, 1970). However, the greater range of vividly contrasting colours used in the depiction of a scene makes possible the separation of images that would not be possible on true colour photographs.

(ii) Familiarity with film types. Prior to this study the author had not worked with colour or colour infrared aerial photographs. Interpretation difficulties were not encountered with either of these film types. Before the first aerial photographs were taken (26.12.74) the author had some ground knowledge of the photographic study areas, and could identify objects on the photographic images with ease. Colour infrared photographs were more satisfying to work with because of the bright contrasting colours (reds, blues, and purples. See Figs. 31 and 32*), compared with the dull greens and browns on the colour photographs. Carroll (1973) noted that many workers have difficulty in interpreting the unfamiliar tones of colour infrared photographs, and others have experienced confusion and irritation caused by the vivid blues and reds of the natural landscape.

(iii) Threshold of interpretability. The point at which a photographic image is interpretable is known as its threshold of interpretability (Allum, 1970). The lower the threshold of interpretability, the easier and more accurate is image interpretation. Factors other than film type which affect threshold of interpretability, namely, the interpreter, scale, atmospheric conditions, and resolution were approximately the same for each film type being compared. There appeared to be very little loss of definition on transparencies which

* All colour and colour infrared photographs shown in this thesis are taken from transparencies, and colour reproduction and image sharpness are not perfect. All photographs have been enlarged approximately 3.5X.

were made from panchromatic negatives. Although resolution is a negative function of the lens, type of emulsion, aperture, size and contrast of object being photographed, image motion, and processing conditions (Welch, 1968), the author could detect boulders, maximum diameter 3 m, in streambeds equally well on all three film types.

5.3 Comparative photo-interpretation.

(i) Alignments. Alignment patterns in the two photographic study areas (see Fig. 5) were determined using 1:18,000 vertical colour, colour infrared, and panchromatic aerial photographs. In an attempt to make the comparisons as objective as possible, film types were interpreted at weekly intervals. It was hoped that during such an interval the location of alignments previously mapped by the author had been forgotten, so that at the commencement of photo-interpretation of each film type, the author had an open mind. The order of film type interpretation was panchromatic, colour, and then colour infrared.

Aerial photographs taken on June 6 1975 (see Fig. 31) were used for comparative photo-interpretation. These photographs were chosen because the colour infrared film was considered to be in good condition (see Section 5.4), and no shadows existed at the time of photography, the sunlight being diffused by high cloud. Figs. 29 and 30 show the alignment patterns mapped using the three film types. The total length of alignments mapped on each film type is shown in Table XII.

Table XII - Length of alignments mapped on each film type (km).

Film type	Photographic study area	
	No. 1 Catchment	Raparapawai Catchment
Colour	4.2	3.8
Colour infrared	7.3	7.1
Panchromatic	2.9	4.5

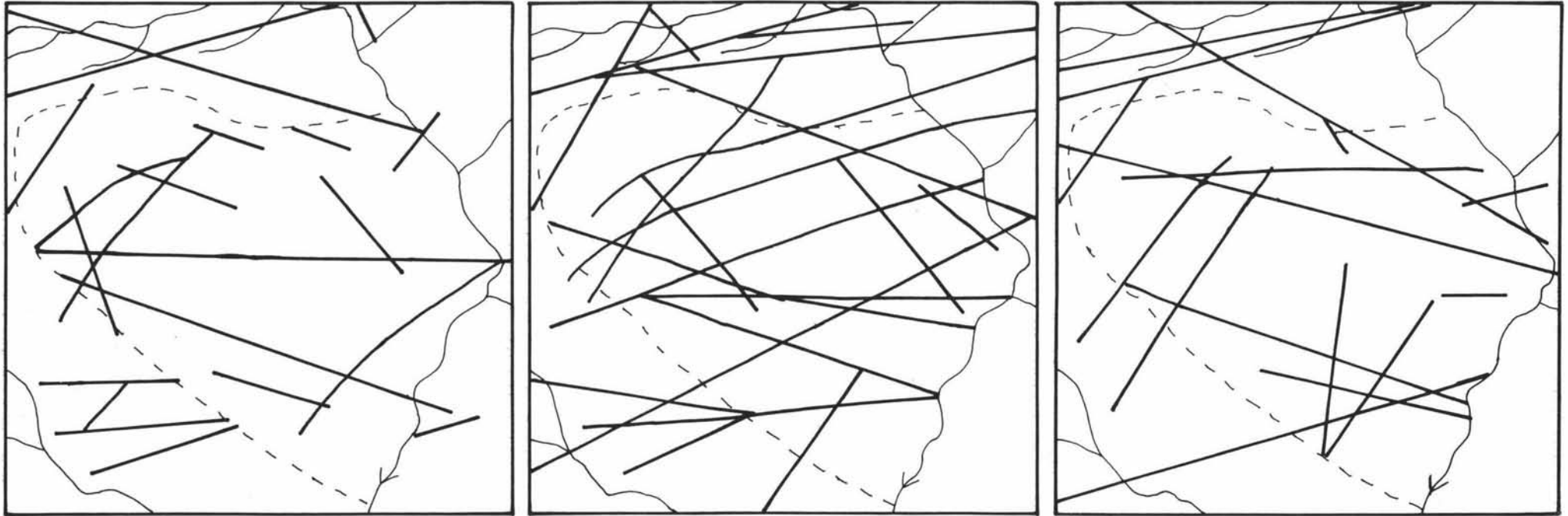
It is obvious from these results that colour infrared is the most suitable film type to use for mapping alignments in the study area. Owing to the very complex pattern of alignments, and the lack



COLOUR

COLOUR INFRARED

PANCHROMATIC



RAPARAPAWAI CATCHMENT PHOTOGRAPHIC STUDY AREA

100 m




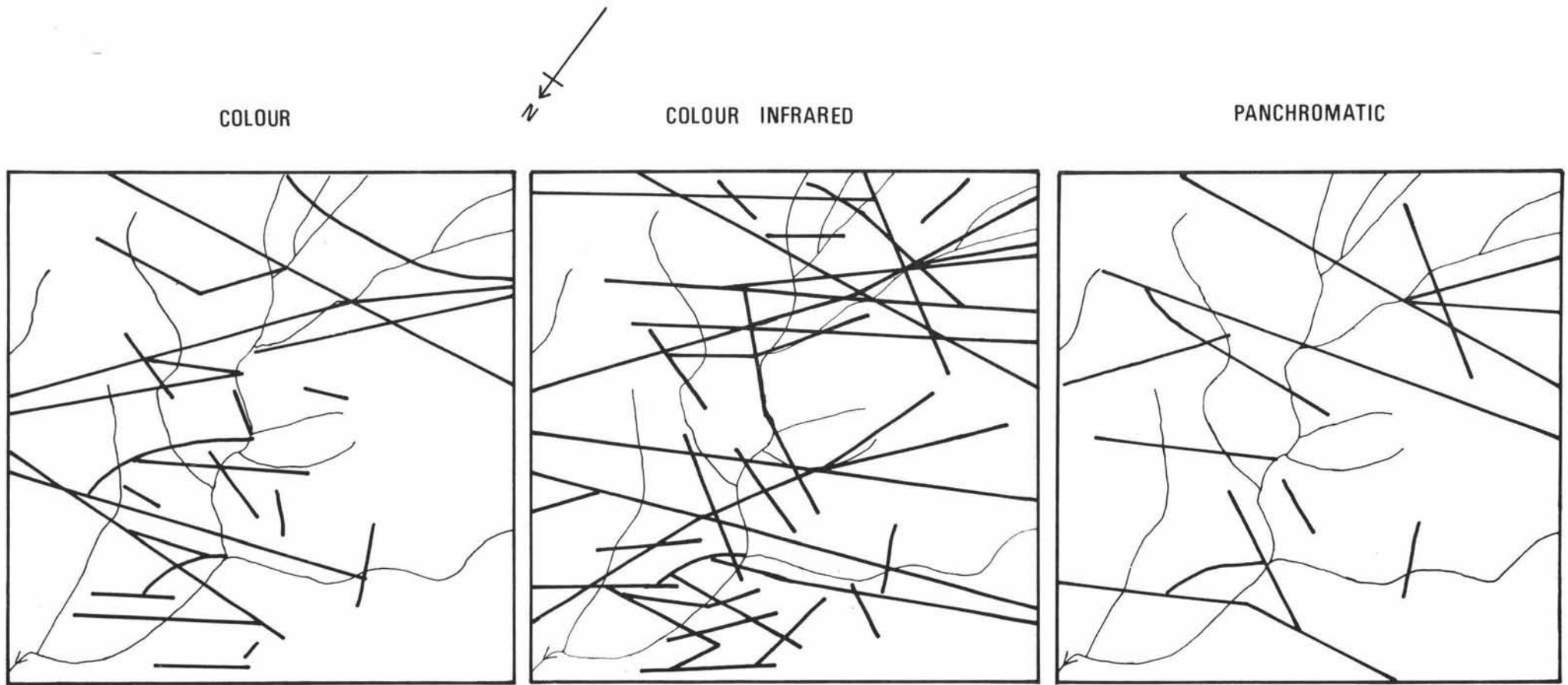
-  Streams
-  Alignments
-  Slump A boundary

Fig.29. Alignments; comparative interpretation.



No.1. CATCHMENT PHOTOGRAPHIC STUDY AREA

100 m

Streams
Alignments

Fig.30. Alignments; comparative interpretation.

of suitable bedrock exposures along most of them, faults and lineations were not considered separately. It was assumed that the most suitable film type for mapping alignments is also the most suitable for mapping faults. Colour and panchromatic film types have approximately the same level of interpretability for mapping alignments.

It is not known why a low number of alignments were mapped in the No. 1 catchment using panchromatic film. A possible reason could be that the alignment pattern is not as clearly defined in the young dominant vegetation of this photographic study area (see Section 4.6), and panchromatic is the worst film type for recognizing vegetation communities and patterns within them (see Section 5.3).

It can be seen on Figs. 29 and 30 that some alignments were recognized on panchromatic and colour photographs, but not on colour infrared photographs. This indicates that more information is available to an interpreter who uses a combination of film types.

Alignments can also be recognized on oblique aerial photographs, but no comparative tests were made because of difficulties in obtaining stereoscopic photographs of each film type.

When colour infrared transparencies were projected onto a screen, alignments were also more easily recognized than on projected images of colour and panchromatic transparencies. However, once an alignment was recognized on a colour infrared transparency, it could invariably be seen on the other two when the three were projected onto a screen side-by-side, or compared over a light table. This indicates that the threshold of interpretability of colour infrared photographs is lower than that of panchromatic or colour photographs. It is considered that the ease with which plant species and communities can be distinguished by observing differences in hue, value, and chroma of vegetation spectral signatures (see Table XIII) is the main factor responsible for a lower threshold of interpretability.

(ii) Eroded surfaces. Eroded surfaces can be easily seen on photographs of the three film types. However, such surfaces are more discernible on the colour infrared aerial photographs because of the greater contrast between eroded surfaces (brilliant green-blue, see Table XIII) and vegetation (purples, reds, and light browns), than

Table XIII - Spectral signatures of dominant vegetation types, bare ground, rock and seepage areas as determined by colour and colour infrared aerial photography using Inter-Society Colour Councils - National Bureau Standards (ISCC-NBS) centroid colour chips (Kelly and Judd, 1968).

OBJECT	COLOUR	COLOUR INFRARED
	ISCC-NBS DESIGNATION/ MUNSELL NOTATION	ISCC-NBS DESIGNATION/ MUNSELL NOTATION
Leatherwood	medium yellow green/ 0.5G 5.5/4.8	medium purple/ 6.6P 4.5/7.1
Tree ferns	"	light purple/ 6.2P 6.5/6.5
Mahoe	"	very light purple/ 6.5P 7.8/5.1
Miro	greyish yellow olive green/ 4.6GY 3.5/2.0	very red/ 5.0R 3.9/15.4
Rimu	medium olive green/ 5.7GY 3.6/4.8	deep red/ 5.1R 2.8/10.1
Pink pine	"	"
Peppertree	dark orange yellow- purplish orange yellow/ 9.3YR 6.0/7.9 - 9.2YR 8.7/4.4	light yellow brown- deep yellow brown/ 8.7YR 6.5/5.0 - 8.8YR 3.1/5.0
Toetoe, Grass	light yellow brown/ 5.0GY 8.4/5.6	pale yellow/ 4.7Y 9.0/3.8
Bare ground, Sandstone	yellow white/ 4.5Y 9.2/1.2	brilliant green blue/ 4.6B 5.9/7.7
Spilite	greyish brown/ 5.5YR 3.5/1.8	very dark greenish blue/ 5.0B 1.5/3.6
Seepage areas, Pug zones	"	"
Poorly drained areas	medium yellow green/ 4.8GY 6.0/5.0	dark grey blue/ 9.2B 2.7/2.0
Fuchsia summer 26.12.74 winter 6.6.75	deep olive green/ 8.0GY 2.2/3.6 medium yellow brown/ 9.5YR 4.4/3.9	not established dark grey/ N 3.5/
Dead vegetation	light grey/ 6.7Y 7.4/0.2	dark grey blue/ 3.7B 2.7/5.0

between yellow-white and green colours, respectively, on the colour, and differences in grey tones on the panchromatic aerial photographs. Some small areas of bare ground are only distinguishable on the colour infrared aerial photographs.

On cloudless days erosion surfaces facing directly into the sun at the time of photography tended to be slightly over-exposed on photographs, with a resultant loss of surface detail. However, as tonal qualities on the print of a negative film can be altered in processing, it has an advantage over positive film in this regard.

(iii) Erosion types. Identification of erosion types on the three kinds of aerial photographs is possible using morphological criteria. However, microtopographical detail on erosion surfaces is more discernible with colour infrared and colour aerial photographs. Flow patterns on some debris avalanches can be recognized using colour infrared aerial photographs. Gullies in debris slides and debris avalanches are more prominent on panchromatic and colour infrared photographs. This is possible because the dark grey tone of water channels on panchromatic, and dark blue-black channels on colour infrared provide sufficient contrast against eroded surfaces on the respective photographs. These channels are difficult to detect on colour aerial photographs, particularly when eroded surfaces have a high moisture content.

(iv) Vegetation types and condition. Vegetation types and communities are readily distinguished by observing differences in hue, value, and chroma of their spectral signatures (see Table XIII) on colour and colour infrared aerial photographs. On panchromatic aerial photographs, vegetation types and communities can be distinguished with difficulty by observing differences in grey tones. Other less important elements of photographic images used in identifying vegetation in the photographic study areas are texture, shadow, shape, size, pattern, and site. Colour infrared spectral signatures have a greater range of hues, values, and chromas than colour signatures. This is because the sensitivities of the emulsion layers and the colour balance of the dyes of the former, enhance and amplify colour differences more than on colour photographs. Thus colour infrared photography enables more accurate and quicker vegetation identific-

ation than colour or panchromatic photography.

The author was able to distinguish low growing vegetation (grasses and toetoe) on eroded surfaces using colour infrared photographs. This vegetation was generally not visible on either colour or panchromatic photographs (see Fig. 31).

A poorly-drained area (ponding area of slump A, see Section 4.7.2) is more easily identified on colour infrared photographs (see Fig. 32). The absorption of infrared and red radiation, and the reflection of some green radiation by water which is surrounded by green plants (reflecting mainly infrared radiation), shows as a dark grey-blue colour with some red and yellow mottling on colour infrared photographs. The colour of mottles is dependent on the type of vegetation present. This contrasts markedly with the signatures of surrounding vegetation. On colour photographs there is a very slight colour change between vegetation in this poorly-drained area and its surrounding vegetation. On this film, water surrounding plants is not recorded. On panchromatic film, vegetation height and texture is the only means of delineating this poorly-drained area.

The presence of dead vegetation is easily seen on colour infrared photographs. This is shown by green-blue to blue colours, depending on the extent of dead foliage at the time of photography, green-blue signatures occurring when vegetation has only recently died. When vegetation has been dead for some time, bare ground reflects more green light through the depleted bare branches, stems, and canopy (which reflects red light) giving a blue signature. Dead vegetation can be seen on colour and sometimes on panchromatic photographs when dead trees protrude through the live canopy. Where dead trees are approximately the same height as the live canopy, e.g., dead pink pine amongst leatherwood, they can only be detected on vertical colour infrared aerial photographs.

(v) Pug zones and seepage areas. Pug zones and seepage areas are clearly seen on colour infrared aerial photographs (see Fig. 32). However, the spectral signature of these objects and of spilite are very similar for each film type, and generally field investigation is needed for positive identification. The author found that without

Fig. 31. Vertical aerial photographs of the No. 1 catchment photographic study area using different film types. Top, centre, and bottom photographs are colour, colour infrared, and panchromatic respectively. Date of photography is June 6 1975. Major vegetation types are indicated: peppertree (P), tree ferns (T), and miro (M). Grass and toetoe (V) are clearly visible on the colour infrared photograph, but are difficult to see on the other two photographs. Stream channels and eroded areas are also more clearly seen on colour infrared. Scale is approximately 1:5,000.

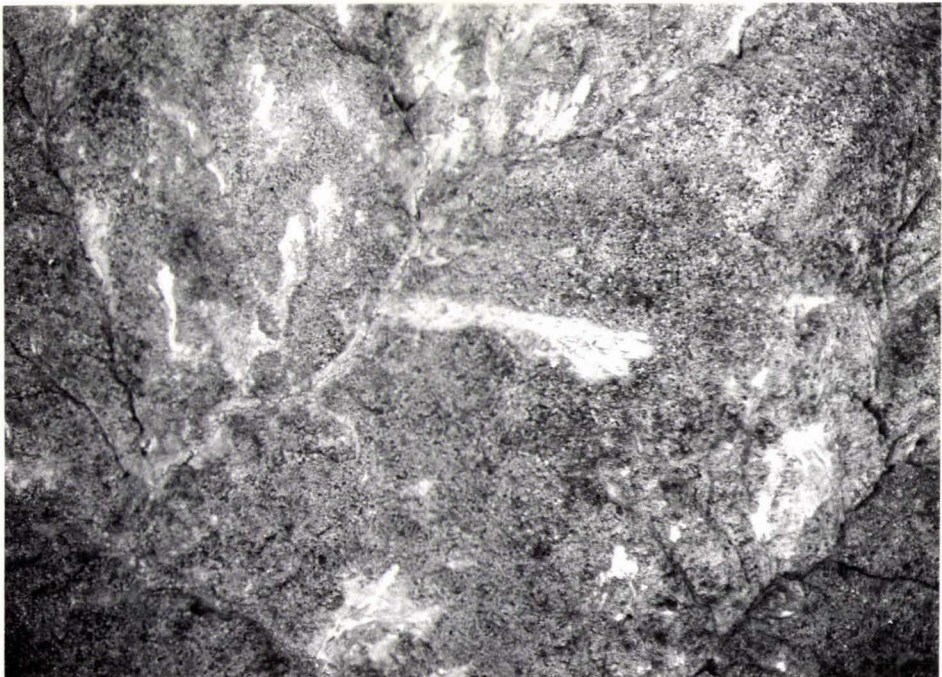
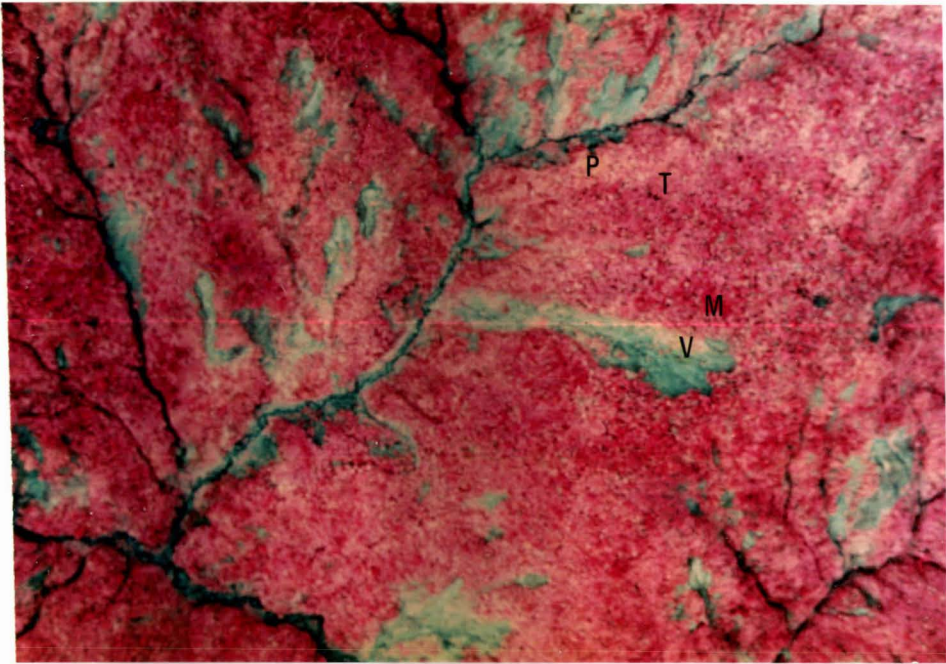
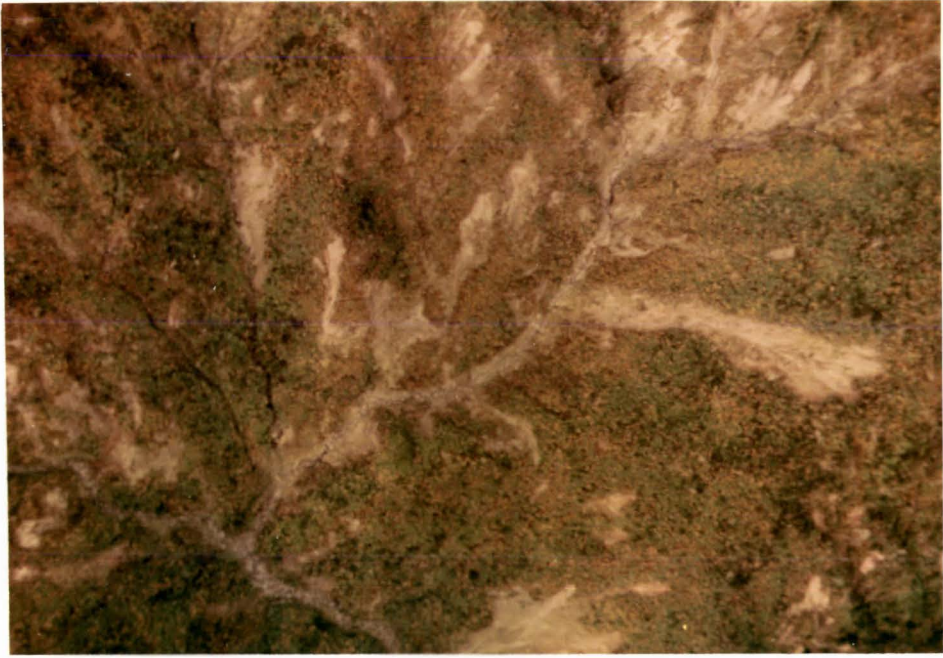
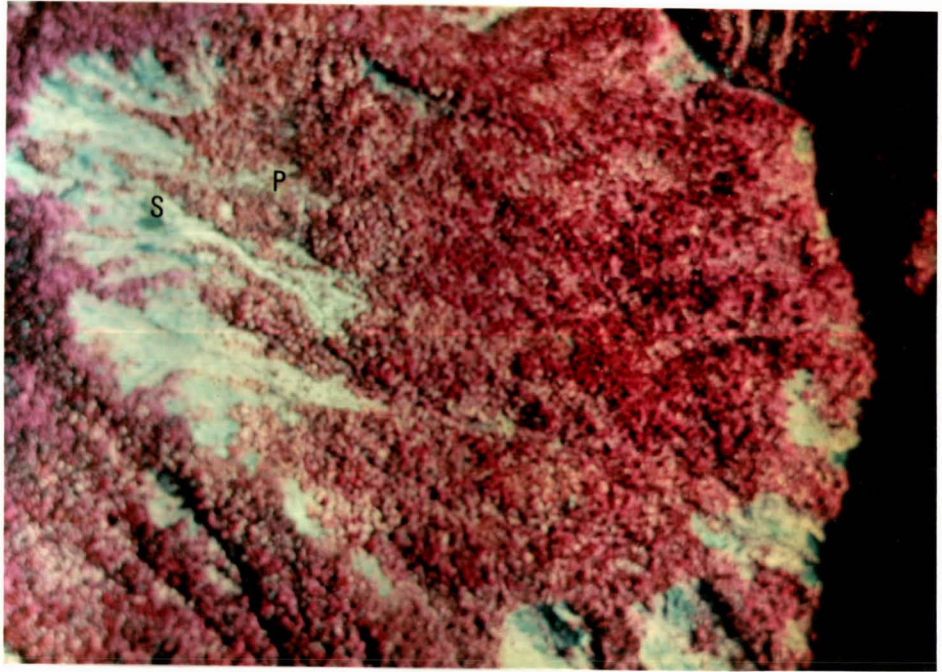


Fig. 32. Vertical aerial photographs of the Raparapawai catchment photographic study area using different film types. This study area also encompasses Slump A (see Section 4.7.2). Date of photography is April 19 1975. Note effect of shadow on right of each photograph. Seepage area on a fault (S) and ponding area (P) in the upper portion of Slump A are indicated on the colour infrared photograph. Note the difficulty of seeing the seepage area on the other two photographs. Scale is approximately 1:5,000.



using colour infrared alongside colour and panchromatic photographs, pug zones and seepage areas were often not seen on the latter. The recognition of such features on colour infrared generally permitted their recognition on the other two film types.

Water, which reflects some green but very little red and no infrared radiation, is recorded blue-black to blue on colour infrared photographs, depending on the amount of green light reflected (Allum, 1970). Generally, the higher the moisture content of the pug zone or seepage area, the more black is the signature.

(vi) Drainage pattern. Drainage channels not in shadow are most easily recognized on colour infrared photographs. They are most difficult to recognize on colour photographs. However, when a drainage channel is in shadow at the time of photography, panchromatic film is the most suitable to use for its detection. In this situation, colour infrared is the least effective film type to use.

(vii) Rank of ease of interpretation. Table XIV shows the ease with which the author could interpret the various objects mentioned above using 1:18,000 vertical aerial photographs of the three film types being compared.

Table XIV - Rank of ease of interpretation.

Object	Colour	Colour infrared	Panchromatic
Alignments	2	1	2
Eroded surfaces	2	1	2
Erosion types	1-2	1	1-2
Vegetation types	1-2	1	3
Dead vegetation	3	1	4
Pug zones and seepage areas	2	1	3
Drainage pattern	2-3	2	2

- 1 easily recognizable and identifiable
- 2 recognizable and identifiable
- 3 recognizable and identifiable with some difficulty
- 4 recognition and identification uncertain

5.4 Variation of spectral signatures.

Spectral signatures on panchromatic and colour aerial photographs remained reasonably constant, irrespective of season of photography and batch of film used. However, colour balance varied to some extent on colour infrared photographs (see Fig. 33).

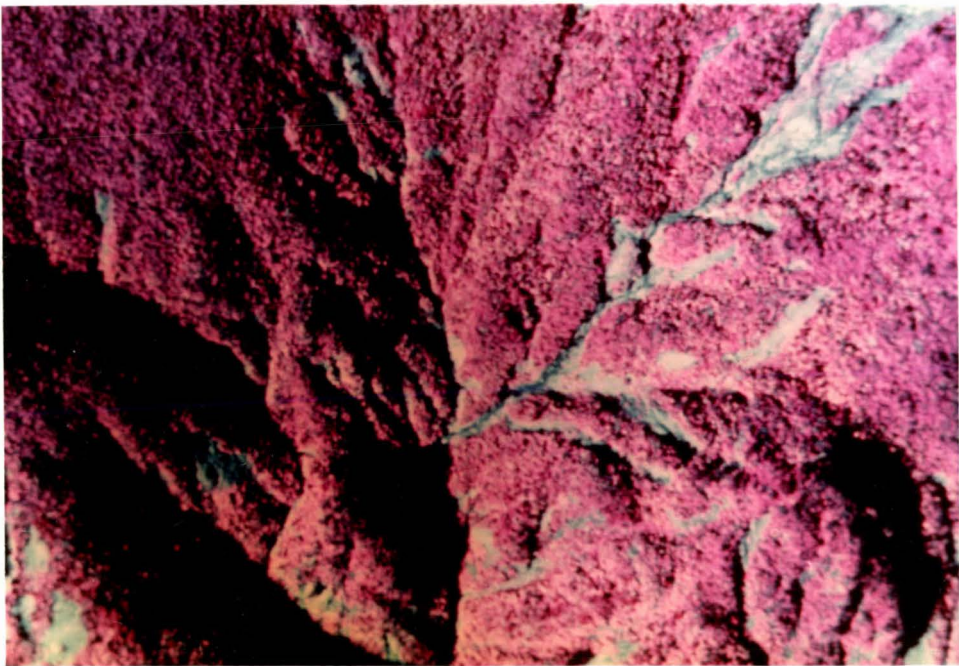
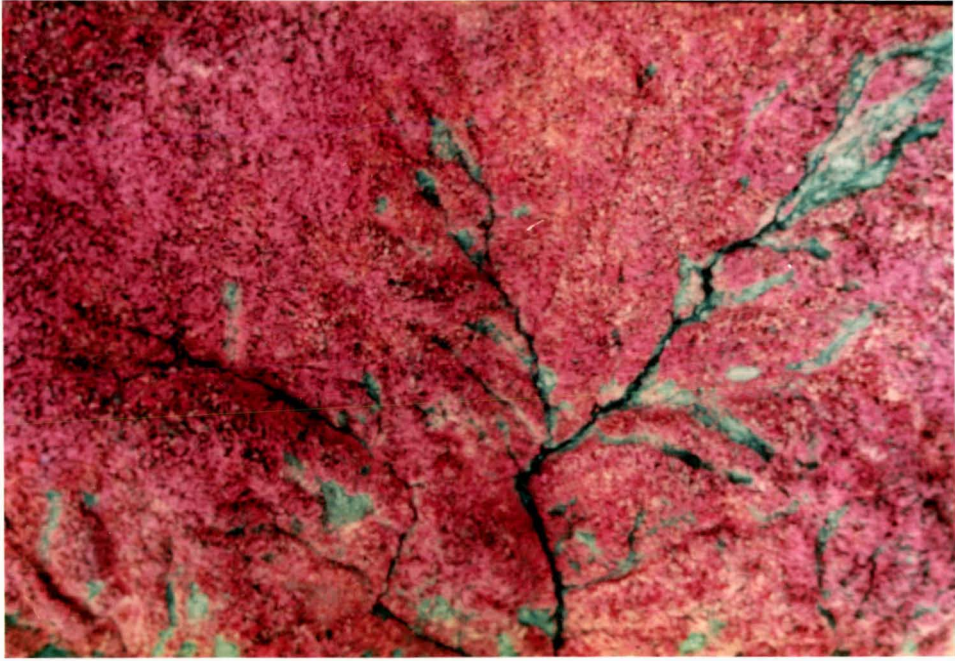
For this study, three batches of colour infrared film were used, and all gave slightly different signatures. The first batch was only one month from its expiry date when used, and each photograph had a blue appearance. Kodak Ektachrome Infrared films are somewhat sensitive to aging (Eastman Kodak Company, 1972). Aged film when exposed has a blue appearance. Signatures on the second and third batches were much the same, although the third batch gave a red-brown rendition of images reflecting infrared radiation. This is due to oversensitivity in the infrared emulsion layer (Eastman Kodak Company, 1972), and can be compensated for by using a Cyan-2 filter or storing (or aging) the film at room temperature before further storage in a freezer. Eastman Kodak Company (1972) give procedures and colour compensating filters that can be used so that colour adjustments can be made prior to aerial photography. This ensures that the colour balance of different films is standardised. In this study, colour evaluation was not done prior to aerial photography, but it is recommended before further use of this film type is undertaken.

Another factor which could have lead to the difference of signatures is exposure. Exposure readings were taken with a light meter sensitive to visible light only. Colour infrared film is sensitive to both visible and infrared light, and exposure may not have been exactly correct for the conditions. However, the exposed transparencies appeared to be within $\frac{1}{2}$ stop of correct exposure.

Spectral reflectance in the infrared region is greatly affected by such conditions as the season and water content of the soil (Fritz, 1967). Infrared aerial photographs were taken in summer, autumn, and winter, and the change in reflectance of infrared radiation from the canopy may have caused some of the shift in colour balance.

Reticulation of some infrared film occurred. This is due to either incorrect processing (E.D.Trask, New Zealand Aerial Mapping:

Fig. 33. Showing difference in colour balance of colour infrared film. Date of photography is June 6 1975 (top), and April 19 1975 (bottom). These two photographs of the same area also show the effect of shadow in this mountainous area. The top photograph was taken during cloudy conditions, and is considered to have correct colour balance. Scale is approximately 1:5,000.



pers. comm.) or to poor film storage (J.R. Clouston, Photographic Unit, Massey University; pers. comm.).

5.5 Cost comparison of aerial photography using each film type.

The photographic platform, film, and camera sizes used in this study would not be used as a method of aerial photographic survey for large areas of land. Thus comparison of costs involved in this study are not realistic. E.D.Trask (pers. comm.) has kindly given the following comparative costs (see Table XV) for vertical stereoscopic aerial photography of an area 16.1 km long by 12.1 km wide (area 19,500 ha), equal in size to the southern Ruahine Ranges.

Table XV - Comparative costs for vertical aerial photography, at two scales, using different film types, of an area totalling 19,500 ha.

Film type	Scale of photography	
	1:10,000	1:20,000
Panchromatic	\$1,595	\$1,011
Colour transparencies (reversal film)	\$2,060	\$1,151
Colour prints (negative film)	\$2,820	\$1,379
Colour transparencies (negative film)	\$3,352	\$1,539
Colour infrared transparencies (reversal film)	\$2,419	\$1,259
Multispectral I ² S	\$1,903	\$1,548

Points to note when comparing costs for this hypothetical situation are :

(i) An RMK 30/23 camera with a 304.8 mm lens (except for multispectral I²S) would be employed to give a 22.8 by 22.8 cm format. Multispectral images would have to be enlarged to this format size in a colour additive viewer.

(ii) Costs are based on current Lands and Survey scheduled rates and would be subject to any variation in these.

(iii) Figures in Table XV are a reasonable guide for a photographic survey of the stated area or larger, but a reduction in area or change in shape of an area can substantially affect costs.

(iv) As more than one flight may be required to expose more than one film type, costs involved if the various film types were exposed at the same time were not determined.

5.6 Conditions most suitable for aerial photography.

Climate conditions, time of day, and season of year are important factors partly controlling the quality of aerial photography, especially that of steep mountain areas.

Photographs taken during the winter months, even when the sun is high in a cloudless sky, show large areas of shadow within which very little detail is seen (see Figs. 32 and 33). Most detail in shadow is seen using panchromatic film. Colour is better than colour infrared in this regard. On June 30 1975 aerial photographs were taken a few days after a snow storm. As snow was still lying in shaded areas, some detail was seen, especially boundaries of eroded areas.

For the least shadow, the most suitable time of day and season of year for aerial photography is from 1100 to 1300 hours, during summer. However, the photographic flight on June 6 1975 was completed during high cloud, so that the sunlight was diffused allowing only weak shadows to be formed, and as a result all slopes could be seen on the photographs (see Figs. 31 and 33). Such a cloud cover in winter reduced the already weak illumination, necessitating wide aperture camera settings. Myers (1975) found that complete altostratus cloud cover was the most suitable weather condition for aerial photography for the mapping of rock outcrops beneath trees.

The optimum conditions for aerial photography in the southern Ruahine Ranges are considered to be a high cloud formation during summer which diffuses sunlight without seriously reducing total illumination.

5.7 Multispectral photography.

Spectral signatures of eroded surfaces are blue on colour infrared photographs owing to green light reflection. Multispectral

aerial photography, especially using ERTS (LANDSAT) band 4 (sensitive to 500 to 600 nm, the wavelength of green light) may well yield more information of eroded surfaces than the three film types compared in this study. It is considered that multispectral aerial photography should be compared with the other film types used in this study before any further aerial photography in the southern Ruahine Range is attempted.

5.8 Conclusions.

Of the three film types compared in this study, colour infrared is the most suitable to use when determining priorities for erosion control in the southern Ruahine Ranges. However, more information can be obtained by a photo-interpreter when more than one film type is used. Taking account of costs and capability of panchromatic and colour aerial photography, it is considered that colour infrared and panchromatic would be the most suitable combination of film types.

Multispectral aerial photography may well be more suitable than colour infrared, but to aid interpretation it may have to be used in conjunction with either panchromatic, colour, or colour infrared photography.

SECTION 6.PROCEDURES TO DETERMINE PRIORITIES FOR EROSION CONTROL IN THE
SOUTHERN RUAHINE RANGES.

In Sections 4 and 5 of this thesis the benefits of using sequential aerial photographs, various film types, and observations and measurements made in the field for evaluation of some factors causing erosion in the study area and southern Ruahine Ranges are illustrated.

Listed below are a number of salient procedures that should be undertaken so that priorities for erosion control in the southern Ruahine Ranges can be determined:

1. All sequential aerial photographs of the study area should be obtained. It is stressed that high quality panchromatic prints are necessary to yield the maximum amount of information for an interpreter. These photographs will provide an important record of mountain land conditions at various times dating back to 1946.
2. To obtain the maximum amount of essential and up-to-date information, vertical aerial photography using colour infrared, or preferably, colour infrared and panchromatic film should be undertaken. Multispectral aerial photography may be of more use than colour infrared and panchromatic photography. The scale of photography should be as large as possible, up to about 1:4,000.

Aerial photography should be undertaken during the summer months, if possible around midday when there is a high cloud cover. The author is aware of the practical problems of photography at such a precise time, but it is essential that the most amount of physical information is permanently recorded by this method of data acquisition.

3. A sound knowledge of ground conditions is essential. Familiarity with ground conditions is a prerequisite for detailed

photo-interpretation, the information from which will facilitate later field examinations.

It would be beneficial if personnel involved in these surveys had varied scientific backgrounds because of the wide range of casual factors.

The objective of such surveys should be to obtain the following information which relates to factors causing erosion, eroded and potentially erodible localities, erosion types, and erosion severity.

(a) The fault pattern as well as an understanding of the basement geology, emphasis being placed on interpretation of structure and identification of lithological units undergoing or susceptible to erosion.

(b) Information on vegetation types and communities and their condition. Condition in this instance refers to the position of species and communities with respect to indigenous forest succession, and whether they are healthy or declining.

(c) Information on herbivorous mammals, their population dynamics and feeding patterns. Establish, if possible, the exact cause and effect relationship between herbivorous mammals, vegetation condition, and erosion.

For b and c above, field personnel should have cognizance of previous indigenous vegetation and herbivorous mammal surveys.

(d) Effect of climatic elements on vegetation condition and erosion.

4. - When action for erosion control is begun, priority should be given to subcatchments on the basis of a system similar to that which is outlined below. For all areas requiring erosion control a numerical rating value could be established using the suggested rating values in Table XVI. Rating values were determined by the author after considering the many interacting erosion causing factors discussed in Section 4. The higher the total numerical rating value of an area, the higher is its priority for erosion control.

Table XVI - Rating values of factors determining priority for erosion control in the southern Ruahine Ranges.

Factor	Factor limits or severity	Value
Potential erosion	Extreme	8
	Very severe	7
	Severe	6
	Moderate	5
	Slight	4
Present erosion	Extreme	5
	Very severe	4
	Severe	3
	Moderate	2
	Slight	1
Fault density	High	7
	Medium	4
	Low	1
Lithology	Unstable	6
	Stable	3
Slope angle	>40°	6
	30 to 40°	4
	<30°	2
Vegetation	Poor or nil forest cover	7
	Reasonably intact forest cover	2
Altitude	> 900 m	7
	700 to 900 m	5
	< 700 m	1
Aspect	East-facing slopes	4
	North-facing slopes	3
	West-facing slopes	2
	South-facing slopes	1
Downstream protective value [*]	High	10
	Low	2

* Determined largely on a political basis, which is often difficult to forecast.

5. When the above information has been obtained and each subcatchment given a numerical rating value, such areas should be delineated on accurate maps. These maps should be of such a scale that they can be used by field personnel with relative ease and accuracy in terms of locating themselves and eroded slopes in the mountainous southern Ruahine Ranges.

Concluding statement.

The success of an erosion control scheme is strongly influenced by thorough planning before control works are initiated. While the costs of determining priorities for an erosion control scheme are substantial, prevention is far less costly than cure. Planning in the manner described in this thesis would appear urgent and very much in the national interest.

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A P P E N D I X IAERIAL PHOTOGRAPHS OF STUDY AREA - RUN AND PHOTOGRAPH NUMBERS

<u>Date</u>	<u>Run number</u>	<u>Photograph numbers</u>
9.10.46	527	57 - 62
	528	59 - 63
7.12.61	3025	9 - 11
26.1.66	3907	12 - 14
28.3.74	SN3721	I2 - I5
	SN3721	J5 - J7

A P P E N D I X II.GLOSSARY OF PLANT NAMES USED IN TEXT.

broadleaf	<u>Griselinia littoralis</u>
bush ricegrass	<u>Microlaena avenacea</u>
Californian thistle	<u>Cirsium arvense</u>
cedar	<u>Librocedrus bidwillii</u>
five-finger	<u>Neopanax arboreum</u>
foxglove	<u>Digitalis purpurea</u>
fuchsia	<u>Fuchsia exorticata</u>
Hall's totara	<u>Podocarpus hallii</u>
haumakaroa	<u>Neopanax simplex</u>
heketara	<u>Olearia rani</u>
hookgrass	<u>Uncinia spp.</u>
kamahi	<u>Weinmannia racemosa</u>
koromiko	<u>Hebe stricta</u>
leatherwood	<u>Olearia colensoi</u>
liverwort	<u>Marchantia spp.</u>
mahoe	<u>Meliccytus ramiflorus</u>
manuka	<u>Leptospermum scoparium</u>
matai	<u>Podocarpus spicatus</u>
miro	<u>Podocarpus ferrugineus</u>
mountain beech	<u>Nothofagus solandri</u>
peppertree	<u>Pseudowintera colorata</u>
pigeonwood	<u>Hedycarya arborea</u>
pink pine	<u>Dacrydium biforme</u>
putaputaweta	<u>Carpodetus serratus</u>
ragwort	<u>Senecio jacobaea</u>
rangiora	<u>Brachyglottis repanda</u>
rata	<u>Metrosideros robusta</u>
rautahi	<u>Carex geminata</u>
red beech	<u>Nothofagus fusca</u>
red tussock	<u>Chionochloa rubra</u>
rewarewa	<u>Knightia excelsa</u>
rimu	<u>Dacrydium cupressinum</u>
rushes	<u>Juncus spp.</u>
snowgrass tussock	<u>Chionochloa pallens</u>
supplejack	<u>Rhipogonum scandens</u>
sweet vernal	<u>Anthoxanthum odoratum</u>
tawa	<u>Beilschmiedia tawa</u>
titoki	<u>Alectryon excelsus</u>
toetoe	<u>Cortaderia fulvida</u>
tree ferns	<u>Dicksonia and Cyathea spp.</u>
tutu	<u>Coriaria arborea</u>
wineberry	<u>Aristotelia serrata</u>
Yorkshire fog	<u>Holcus lanatus</u>

A P P E N D I X III MINERALOGY OF FAULT PUG MATERIAL

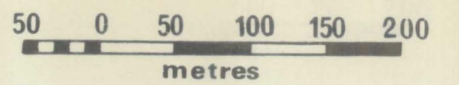
Sample location (N144)	Major minerals	Minor minerals	Percent total clay	Comments
358539	Kaolinite Chlorite	Mica	27.3	
353548	Mica Vermiculite Non-collapsable 1.2 nm mixed-layer material		17.0	
345555	Mica Chlorite Montmorillonite		21.0	No peak with Mg ²⁺ saturation. 1.83 nm peak with glycerol treatment.
357538	Montmorillonite Mica Kaolinite	Vermiculite	21.0	Montmorillonite more unstable than in N144/345555 sample. 1.57 nm peak with Mg ²⁺ saturation 1.80 nm peak with glycerol
368535	Mica Chlorite Kaolinite		19.0	Sampled on surface at base of slump A.
368535	Mica Chlorite Kaolinite		19.0	Sampled at 1 m depth at base of slump A.
383529	Mica Kaolinite	Chrolite Iron oxide	32.0	Crystalline Iron oxide not apparent in unheated Na ⁺ saturation, but small peak at 0.42 nm on heating. Probably due to Iron Oxide whose identity is uncertain. All spilite (red) fault pugs contained this mineral.

A P P E N D I X III (Continued)

379532	Mica Kaolinite	Iron oxide	20.0	As for N144/383529 sample.
371534	Collapsible mixed- layer material Vermiculite Kaolinite	Chlorite	23.0	With Na ⁺ saturation, mixed-layer material formed a peak at 1.2 - 1.3 nm. On heating a peak was formed at 0.9 - 1.0 nm.
365535	Kaolinite Mica Chlorite		40.0	
366532	Mica Kaolinite	Iron oxide Chlorite	55.0	Same as for N144/383529 sample. Sample from top of slump A.
369530	Kaolinite Mica	Iron oxide	15.0	Same as for N144/383529 sample.
371532	Kaolinite Mica	Iron oxide	16.6	Same as for N144/383529 sample. Red spilite pug.
371532	Kaolinite Mica Chlorite		14.6	Blue black (sandstone) pug from same fault as one immediately above.
400508	Kaolinite Mica	Chlorite	23.0	Sample from Mohaka Fault.



SCALE 1:5,000



KEY

- Stream channel bed
- Catchment boundary
- Soil boundary
- Soil symbol
- Erosion surface

SOIL LEGEND (also see text)

- SOILS OF THE FLAT - ROLLING LAND**
 - Takapari peaty loam
 - Dannevirke silt loam taxadjunct
- SOILS OF THE MODERATE TO MODERATE - STEEP SLOPES**
 - Ruahine stepland soils, mod. steep - steep phase
 - Takapari hill soils
 - Dannevirke hill soils
- SOILS OF THE STEEP TO VERY STEEP SLOPES**
 - Ruahine stepland soils
 - " " " , very steep phase
- SOILS OF THE VALLEY FLOOR**
 - recent soils

A P P E N D I X IV.SOIL PROFILE DESCRIPTIONS.

Ruaroa sandy loam. A typical profile has 25 cm of medium brown loose, structureless, coarse sandy loam. Beneath this there are alternating loose fine sand and medium stone horizons, which make up 30 cm of the profile. This changes to 22 cm of friable, medium brown silt loam, with a weakly developed nut structure. Many strong brown mottles are present. This overlies rounded sandstone terrace boulders and gravels, up to 30 cm in diameter.

Renata silt loam. A profile under peppertree shows 1 cm of litter overlying 13 cm of very dusky-red, friable silt loam, with strongly developed nut structure. This changes to 30 cm of dark brown friable silt loam with a weakly developed nut structure. At a depth of 43 cm, there is a 3/4 cm thick, discontinuous, dark reddish-brown iron pan; the result of downward movement and deposition of iron. The lower subsoil consists of 43 cm of yellowish-brown weathered rock with many strong brown mottles and many unweathered rock fragments.

Ramiha hill soils. A representative profile shows 20 cm of dark brown friable silt loam, with strongly developed nut structure. Rock fragments occur in places in the topsoil which overlies 38 cm of yellowish-brown friable silt loam, with moderately developed nut structure and many rock fragments and boulders. The underlying rock occurs at depths varying from 38 to 76 cm.

Renata hill soils. These soils consist of a thin layer of loess overlying rock, the rock being exposed on some slopes. On 24 to 28 degree slopes a typical profile has 18 cm of dark brown friable silt loam, with a weakly developed nut structure. This rests on 12 cm of dark yellowish-brown friable silt loam. Beneath this horizon is 40 cm of yellowish-brown mottled silt loam, with weakly developed block structure. Weathered rock occurs at depths varying between 50 to 70 cm. A discontinuous iron pan varying in thickness from 3/4 to 2 1/2 cm immediately above the bedrock is a characteristic of this soil.

Ruahine steepland and Ruahine steepland soils, very steep phase. Topsoils consist of 13 cm of dark greyish-brown silt loam, with a strongly developed nut structure and angular lithic fragments overlying bedrock. Soil profiles are generally shallow and stony, but deeper and often stone-free profiles occur in infilled gullies, these profiles being similar to Ramiha hill soils.

Rimutaka steepland and Rimutaka steepland soils, very steep phase. A representative profile consists of 2 cm of dark reddish-brown very friable silt loam, with a weakly developed fine nut structure, overlying 6 cm of dark brown mottled friable silt loam. This horizon overlies weathered bedrock.

Takapari peaty loam. A representative soil profile consists of 2 cm of dark reddish-brown slightly sticky peaty loam. This overlies 30 cm of very dark grey-brown sticky peaty silt loam. This rests on weathered bedrock.