**DEPARTMENT OF GEOGRAPHY DISCUSSION PAPER SERIES**

# *NATURAL SCIENCE STUDIES OF BURNABY AND BELCARRA MOUNTAINS*

*C.B. Crampton*

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# NATURAL SCIENCE STUDIES OF BURNABY AND BELCARRA MOUNTAINS

By

C.B. Crampton

DISCUSSION PAPER NO. 8

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# INTRODUCTION

Burnaby Mountain is a prominent landform, 1180 ft. (360 m.) at its summit, set within the Fraser Valley lowland, formed of sedimentary rocks which dip gently south, giving rise to a steep, north-facing escarpment and a gently inclined dipslope facing south (Fig. 1). On the other side of Burrard Inlet is Belcarra Mountain of contrasting character, 925 ft. (282 m.) at its summit, with a hummocky terrain arising from its formation of crystalline igneous and metamorphic rocks (Fig. 2). These two very different, neighbouring physical environments allow comparisons and contrasts of natural landscapes (Fig. 3). Based at Simon Fraser University atop Burnaby Mountain, research and class studies have been conducted since 1973.

Power and other lines cross both mountains, linking with industrial sites such as oil refineries, and urban areas around the footslopes. The drier, sandier terrain of Belcarra Mountain with its numerous rock outcrops supports mostly conifers, douglas fir, western hemlock and red cedar, whereas the more moist,. loamier terrain of Burnaby Mountain supports mostly hardwoods, broadleaf maple, vine maple, balsam poplar and red alder, with conifers occurring mostly on rocky, steep slopes. Krajina (1959) has assigned the Fraser lowland to the Coastal Douglas Fir Biogeoclimatic Zone, with a mediterranian to humid climate. The average of mean annual precipitation measurements since the construction of Simon Fraser University is about 80 in. (2032 mm.) across the summit of the mountain, with most precipitation occurring during the period November to February. In the valleylands the mean annual precipitation is only about 50 in. (1270 mm.). The normal summer cyclone track off the Pacific Ocean brings prevailing rain-bearing winds from the south and southeast and so slopes facing this direction tend to receive the most rainfall. The mean monthly temperatures vary between $2^{o}$ and $17^{o}$C. Long dry spells can often occur during July.

Larger mammals that can be seen on the mountains include the racoon, fox, coyote, the coast variety of the black-tailed deer, and the black bear on Belcarra Mountain, rarely on Burnaby Mountain. Bald eagles ocassionally ride the thermals rising from the concrete pavement of Simon Fraser University on Burnaby Mountain.

Throughout this study emphasis is placed upon the extraordinarily complex interaction that occurs between all elements of the landscape. Sometimes a simple approach is adopted whereby the interaction **as** discerned in the field between one factor of the landscape and another is described, for example between aspect and the distribution of particular flora and fauna. This approach will be extended by consideration of the synergy operating between, say, two factors acting together to influence a particular landscape element; for example the interaction between the underlying geology and the pH of the subsoil acting together to influence the distribution of forest cover type. This analysis of synergism is further developed to define the interaction between many factors acting as one. Cause and effect relationships are not assumed; instead it is considered that the analyses provide empirical relationships which help in the understanding of a landscape.

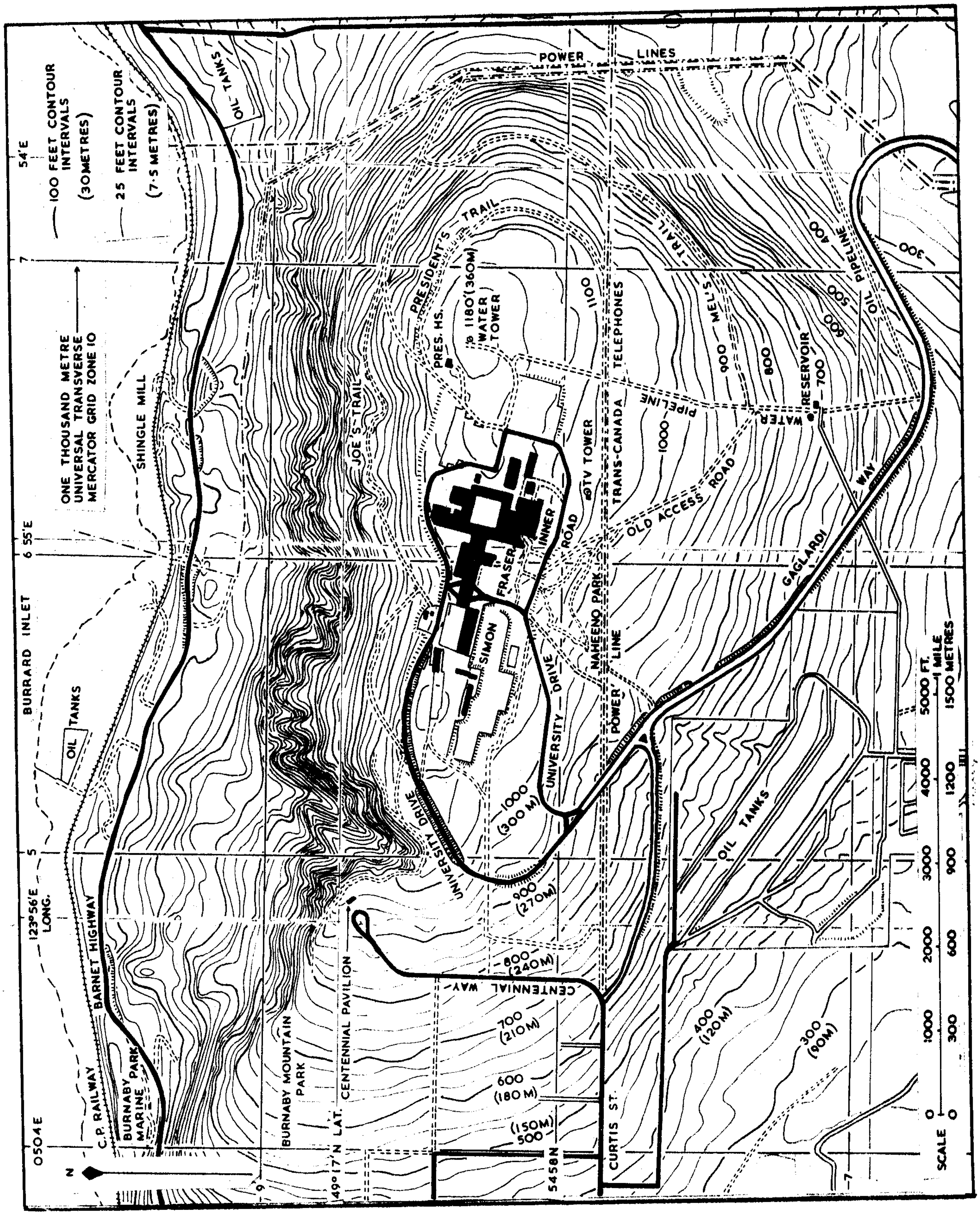

Fig. 1. Topographic map of Burnaby Mountain.

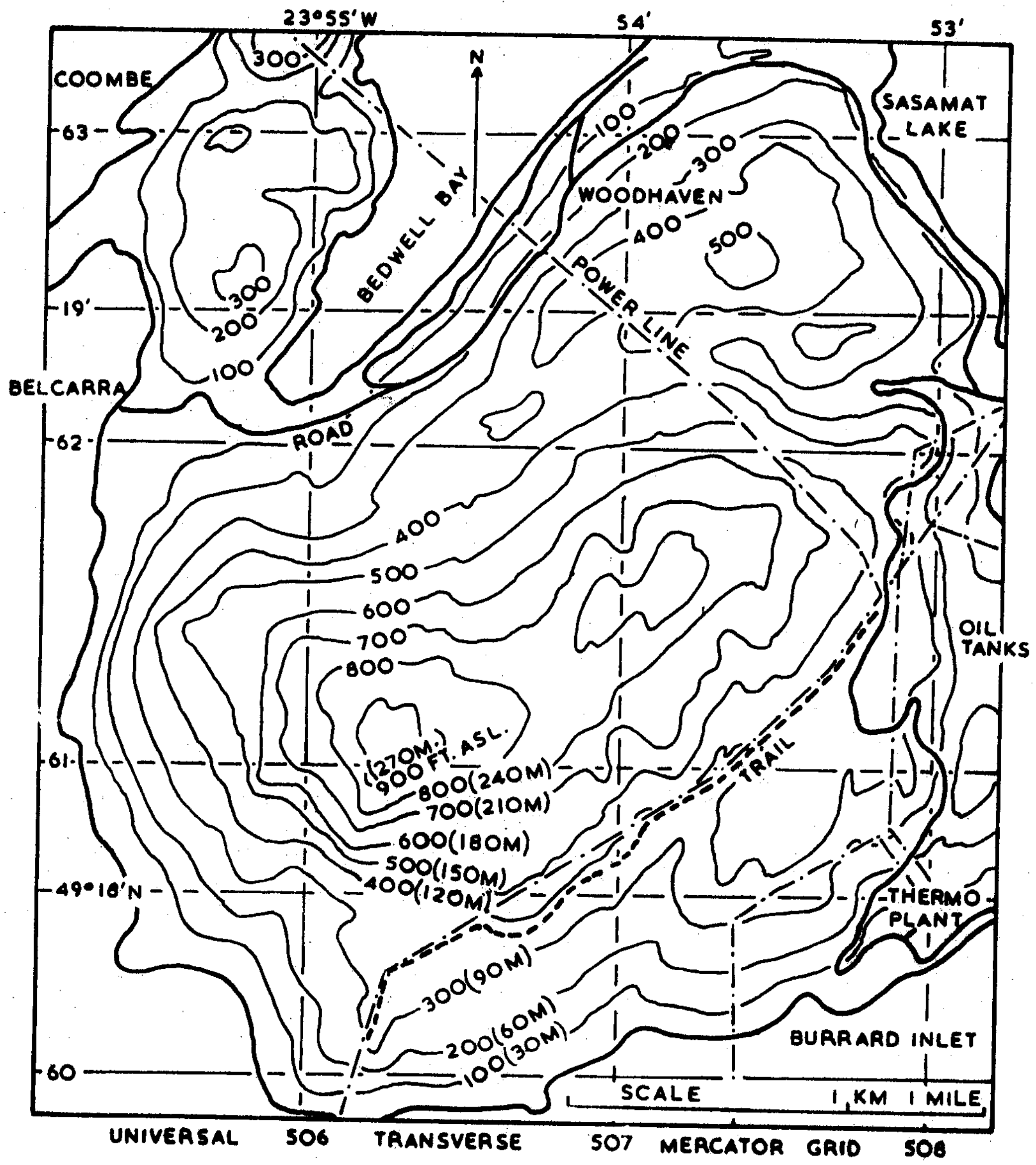

Fig. 2. Topographic map of Belcarra Mountain.

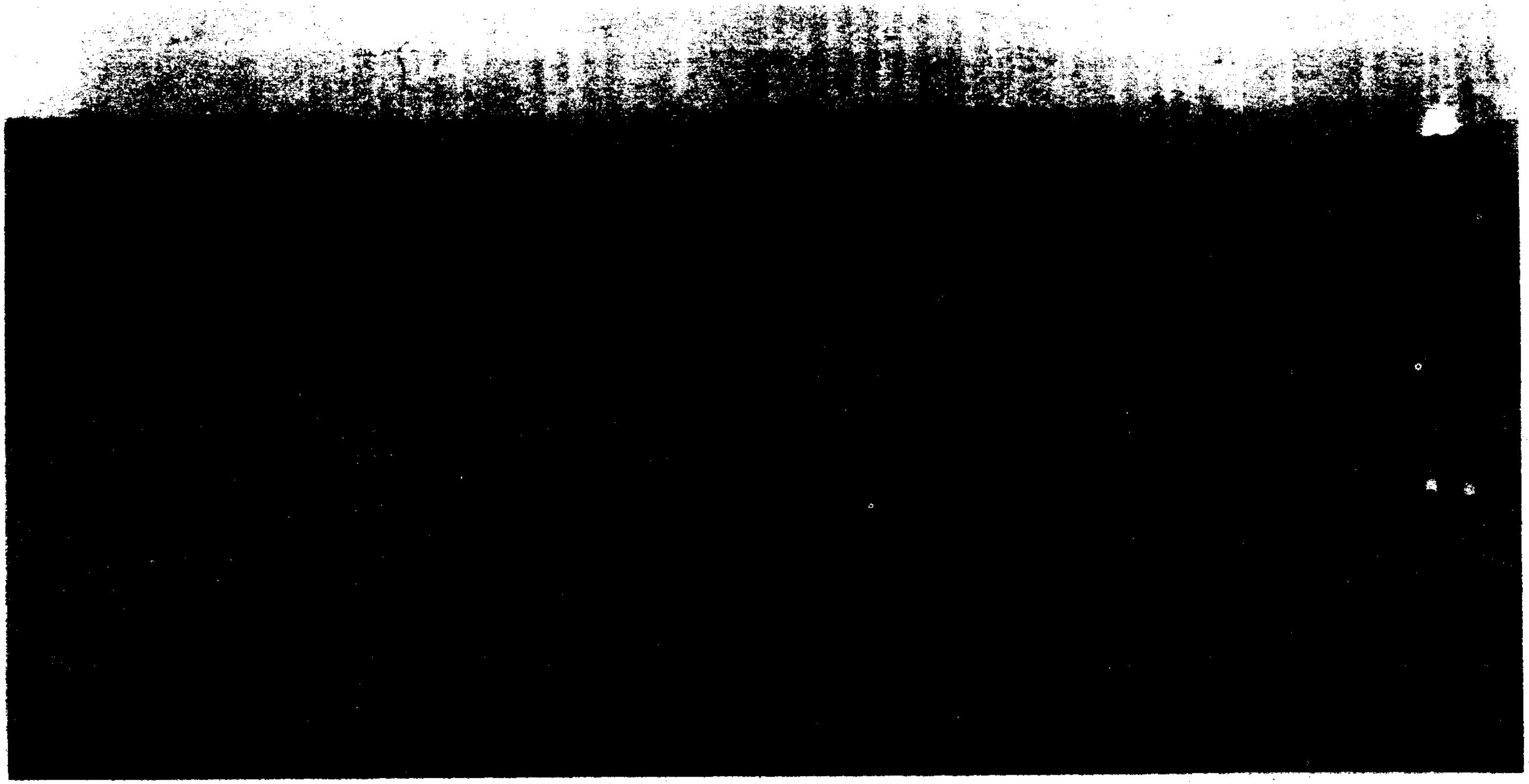

Fig. 3. View of Burnaby Mountain to the right, separated by the Burrard Inlet from Belcarra Mountain to the left, with the Indian Arm in the foreground of Belcarra Mountain, and Port Moody in the background.

It is never possible to collect enough information for a proper understanding of the local landscape, but this has to be accepted as a constraint upon any natural science study. For convenience, the study will be organized into the sections of microclimate, geology, soils and vegetation. Finally, all of the available information will be brought together within a terrain evaluation, which is an attempt to classify and map a surfeit of information in a manageable, usable form. This evaluation will involve a more intuitive visual analysis of the study-area.

# MICROCLIMATE OF A COASTAL MOUNTAIN

## Introduction

Soil, air temperatures close to the ground, and precipitation have been measured across Burnaby Mountain in order to gain some understanding of the microclimate of a mountain within the coastal zone of British Columbia. Since Burnaby and Belcarra Mountains are situated immediately either side of Burrard Inlet, this information from Burnaby Mountain is extrapolated to Belcarra Mountain.

## Local Temperature Changes at the Air-Ground Interface

### Soil Profile Temperature Gradients

Method

A temperature probe was used to measure the daytime soil temperatures at depths of 0, 10, 20, 30, 40 and 50 cm. below open grassland within the Centennial Park, and below adjoining forested land during the summer of 1978. Augering allowed the distribution of textures to be hand-estimated down through each profile, and the field interpretation of internal soil drainage (as distinct from site drainage) to be assessed. The temperature observations extended through the day, they were plotted, and balanced curves were drawn through the scatter in order to show the average change in soil temperature down through each profile (Fig. 4). Since changes of soil temperature with depth can be exponential (Oke, 1978; Geiger, 1973), each scatter was analysed for the best exponential or linear fit, and various statistics including the $r^2$-values have been given.

Results

During sunny weather, under grassland the soil temperatures decreased rapidly from the land surface down through the topmost 10 to 20 cm. of the profile (that is the lapse rate showed a strong negative gradient), and slowly down below these depths (there was a weaker gradient) (Fig. 4). As the day progressed, heat from the sun entered the soil profile and warmed, particularly, the topmost 20 cm., less so the soil below 20 cm., such that at a

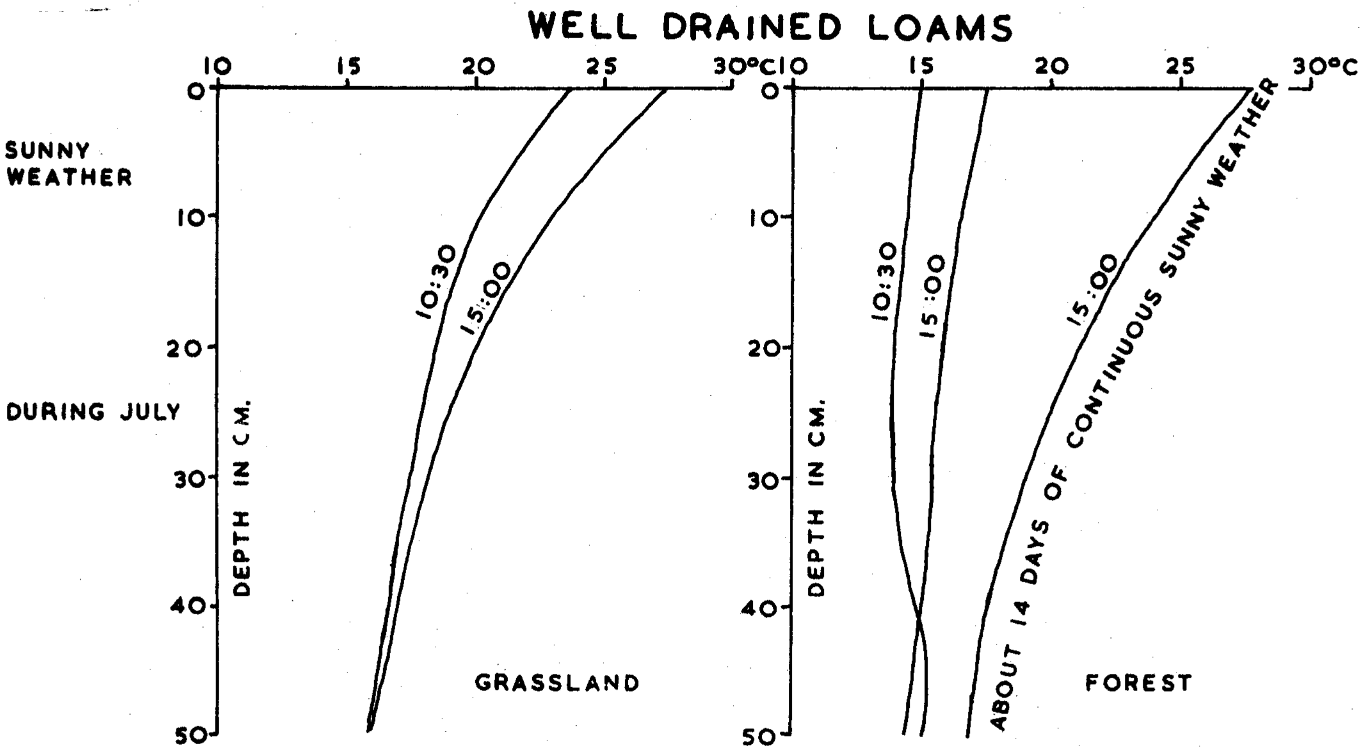

Fig. 4. Balanced curves for soil temperature gradients in profiles below grassland and forest without compaction. Scatter indicated by best linear or exponential fit. Grassland curves: 10:30, N = 60, M = 20.0, standard deviation = 2.15 $r^2$ = 0.68: 15:00, N = 102, M = 22.2, standard deviation = 4.07, $r^2$ = 0.59: 15:00, N = 41, M = 15.4, standard deviation = 4.11, $r^2$ = 0.52: 15:00, after about 14 days of continuous sunny weather, N = 54, M = 22.2, standard deviation = 3.78, $r^2$ = 0.58.

depth of 50 cm. there was no temperature difference between the mid-morning (10:30 hours) and mid-afternoon (15:00 hours) values.

Below the forest, during short periods of sunny weather the surface temperatures were distinctly cooler (at mid-morning 15°C compared with 24°C, and at mid-afternoon 17.5°C compared with 27.5°C) than below grassland. At mid-morning, in the profile below forest the temperature at a depth of 30 cm. and below was actually warmer than above, and there was a positive temperature gradient. As the day progressed, heat entering the profile eventually produced the normal negative gradient. If there was continuous sunny weather for around 14 days, as happened during July, the temperature gradient became very similar to that outside the forest.

## Interpretation

A forest canopy takes on many of the thermal characteristics of a grassland surface (Geiger, 1973), and shades the soil from much of the day's accumulating warmth, causing the soil to be distinctly cooler below forest than below open grassland. It follows from the evidence that a warming interface penetrated down into the soil profile during the day, followed by a cooling interface during the night. The occurrence of warmer morning temperatures below 30 cm. than above this depth, underneath a forest canopy, suggests the retention through the night of warmth that penetrated the subsoil during the previous day, the canopy reducing the radiation of heat out of the profile under clear skies at night. Since mid-afternoon temperatures at this depth are less than mid-morning temperatures, it would seem that this heat continues to disperse downwards during the day.

If there is continuous sunny weather for around 14 days, the temperature gradient becomes very similar to that outside the forest, under grassland. During short dry spells the forest canopy appears to insulate the underlying soil from the day's warmth, but if sunny, dry weather is maintained for more than a short while, the canopy wilts and seems to loose its insulating effect, and the soil surface warms as rapidly during the day as outside the canopy shade.

## Variations of Air and Soil Temperatures with Aspect

### Method

Eight stations were established at about 290 m. elevation around Burnaby Mountain, on approximately similarly forested slopes facing north, northeast, east, southeast, south, southwest, west and northwest. At each station the temperature was measured at a height of one metre above the ground, and at a depth of 5 cm. in the topsoil. The circuit of stations was traversed sequentially clockwise, starting at a different station each day, with the weather conditions being recorded, and the time at which the measurements were made. These measurements have been plotted, grouped by weather conditions, and balanced curves have been drawn for each distribution (Fig. 5).

### Results

Everywhere air and topsoil temperatures warmed during the day. On slopes facing in all directions, late afternoon temperatures one metre above the ground were consistently greater than the topsoil temperatures, on sunny days the difference being greatest on southwest- and west-facing slopes (7°C), and least on northeast- and east-facing slopes (4°C). The trend was similar on cloudy days, but less pronounced. The warmest air temperatures during late afternoon were achieved on southwest- and west-facing slopes, 24°C under sunny skies and 20°C under cloudy skies, while the lowest air temperatures were achieved on northwest-, through north-, to east-facing slopes, 22°C under sunny skies and 17°C under cloudy skies. During sunny days the early morning air temperatures were slightly greater on northeast- and east-facing slopes (18°C) than on other slopes.

Under sunny skies throughout the morning until midday the topsoils on northeast- and east-facing slopes were marginally warmer than all other slopes. From midday onwards southeast- and south-facing slope topsoils were slightly warmer than on all other slopes. The late afternoon topsoil temperatures on southwest- and west-facing slopes were the coolest around the mountain (only 14°C), contrasting with air temperatures on these slopes which were the highest around the mountain by late afternoon, helping to create the greatest differential between air and topsoil temperatures. Under cloudy skies the late afternoon topsoil temperatures varied little either side of 15°C, although on southwest- and west-facing slopes the topsoil was a little warmer (16°C).

### Interpretation

Bare ground normally responds to temperature changes more rapidly than the air (Geiger, 1973). Within the temperate zone the sun's rays are oblique, and so their effects penetrate only

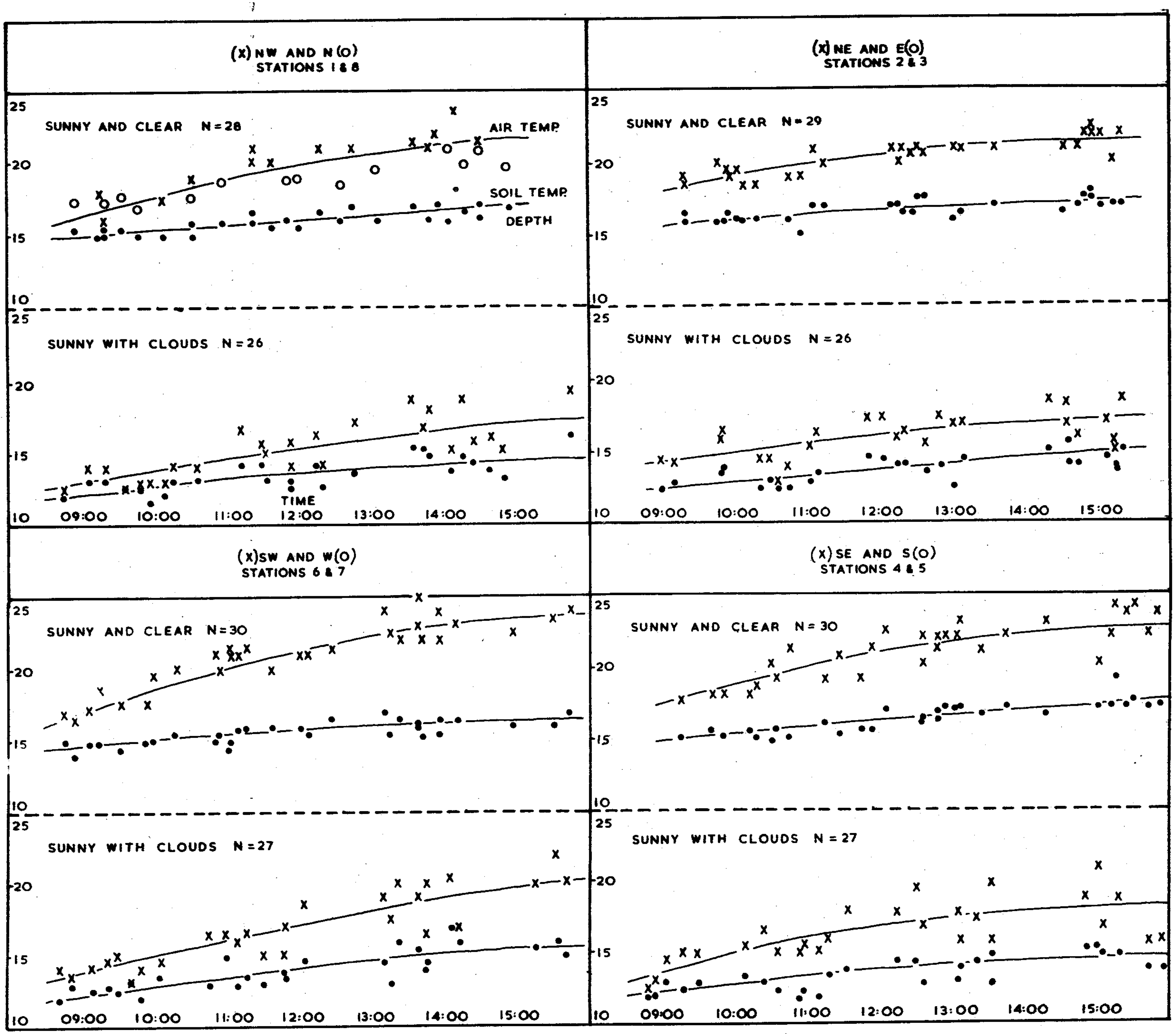

Fig. 5. Distribution of temperature measurements, and balanced curves for slopes of different aspect, grouped according to prevailing weather conditions.

partially into the stand, and the ground layer remains cooler and more moist for longer compared with bare ground. It is the forest canopy that takes on most of the characteristics of bare ground reactions to diurnal temperature changes. The periodic daily fluctuations of temperature are greatest in the canopy, they decrease downwards although they are still considerable within the stand, and they are minimal in the ground layer. In this way the forest gives the ground layer a protected, milder climate. Hence, the measured air temperatures within the forest stand on Burnaby Mountain were consistently greater than topsoil temperatures, although least on northeast- and east-facing slopes, and there were only small differences in topsoil temperatures around the mountain.

The measurements had been made during a period of alternating sunny and cloudy days. If there had been a long sunny, dry period, the topsoil would have been heated to a temperature comparable with the forest canopy as the insulating effect of the canopy, seemingly, broke down.

In summer the sun rises in the east-northeast rather than the east sky, and by evening it sets in the west-southwest rather than the west sky. Thus, air and topsoil morning temperatures on east-northeast slopes were greater than elsewhere at this time. By midday the sun is highest in the sky and its rays penetrate most effectively into the forest stand on south-southeast slopes, warming the soils to higher midday and afternoon temperatures than elsewhere. On slopes that receive the sun's radiation latest, those facing west-southwest, the forest canopy has already been warmed to some extent by indirect radiation. Thus, air temperatures are greater on west-southwest slopes than on all other slopes. But, these same slopes receive the sun's rays very obliquely during the whole day; even when shining opposite west-southwest slopes the sun is very low in the sky, and imparts less warmth to the ground layer on these slopes than on to other slopes. Hence, the measured afternoon ground temperatures on these slopes are the coolest around the mountain.

## Measurement of an Inversion Layer

### Method

Nine stations were established at 100 ft. (about 30 m.) intervals from bottom to top of the west-southwest slope of Burnaby Mountain, within clearings in the forest canopy. The mountain side could be divided into five sections; the gently inclined lower slope between stations 1, 2 and 3 (Fig. 6); a distinct break at station 3 divides the lower slope from a more steeply inclined slope between stations 3, 4 and 5; another distinct break in slope just below station 5 separates lower slopes from the steepest sections between stations 5, 6 and 7; the topslopes around stations 7 and 8 merge into the plateau top of the mountain, on which is situated station 9.

Throughout a 24-hour period from midday on the 29th to midday on the 30th July, and from midday on the 22nd to midday on the 23rd December, 1974, when the sky remained clear throughout each period, a traverse was made up the mountain every two hours, the air temperature being measured one metre above the ground at each of the stations, care being taken to shield the thermometer from the direct sun rays during the daytime.

Results - the Summer Inversion (Fig. 6)

The warmest temperatures were measured during the afternoon between 14:00 and 16:00 hours across the slope. After about 16:00 hours the air temperature around station 1 at the base of the mountainside dropped steadily from a peak of 29°C, but remained distinctly warmer than the mountain crest around station 9, especially at 20:00 hours as twilight developed when a temperature at the mountain base of 22°C contrasted with around 16°C across most of the remaining slope. At 18:00 hours during the late afternoon when the sun was moving into the southwest sky, its rays were striking most directly on the steepest slopes between stations 5 and 7, which slopes were distinctly warmer (27°C) than slopes above and below (around 23°C).

By 22:00 hours at night the temperature differential between the base and the crest of the mountainside no longer existed, both being around 17°C. Cooling was most intense around the break in slope between stations 3 and 4 where temperatures dropped to around 12°C. This cooling effect moved upslope and downslope as the night progressed, but the warmer base and crest could still be discerned at midnight (16°C. compared with around 13°C.). However, by 02:00 hours in the morning the whole mountainside was virtually at the same temperature of 13°C.

At 03:00 Hours in the morning a temperature inversion started to develop at the base of the mountainside, and a "lake" of cold air around 11°C accumulated, first at station 1 then 2 and 3, visible

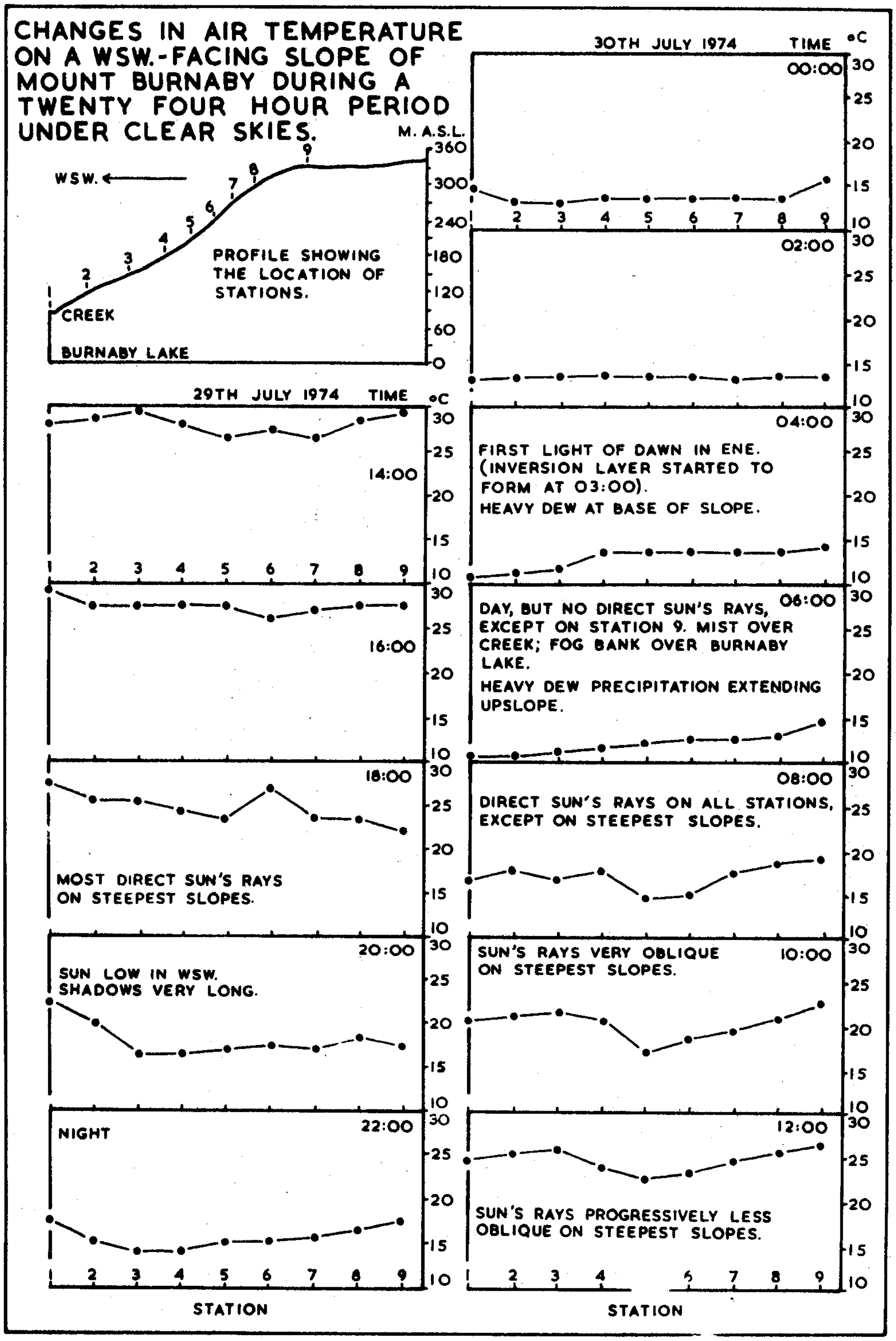

Fig. 6. Changes in air temperature one metre above the ground at selected stations across a west-southwest slope of Burnaby Mountain, during summer from 29th to 30th July, 1974 under clear skies.

in the form of dew on the ground. At 04:00 hours as the first light of dawn began to appear in the eastern sky, the temperature inversion was moving through station 3. By 06:00 hours in early morning daylight, except around station 9 at the crest of the mountain, all other stations had become cooler as the inversion interface moved upslope, and a heavy dew was precipitated on the ground vegetation at elevations up to 240 m., station 6. From 07:00 hours and later this temperature inversion rapidly dissipated.

The first direct, though very oblique sun's rays were falling on station 9 at the mountain crest by 06:00 hours. From 09:00 hours and later, station 9 temperatures were responding preferentially to this exposure, achieving the highest temperatures throughout the morning, until and including midday. Throughout the morning, temperatures everywhere on the mountain increased, but they increased most slowly around stations 5 and 6 on the steepest slopes of the mountainside where the sun's rays were consistently striking more obliquely than elsewhere as the sun moved around to the southern sky. This pocket of cooler air could still be discerned at midday where a temperature of 23°C contrasted with 27°C on the mountain crest. These steepest slopes had been warmest early evening, and were coolest throughout the morning.

Results - the Winter Inversion (Fig. 7).

The warmest temperature on the mountainside was achieved at the base of the slope around station 1, 12°C at 15:00 hours, later than in summer for the mountainside as a whole, but earlier than in summer for station 1. The afternoon temperature high on the steepest section of the mountainside, of 10°C at station 5, was also achieved at 15:00 hours, and earlier than in summer. As the temperatures declined during the late afternoon, the relative warmth at the base of the mountainside was not maintained after dusk at 17:00 hours. After 19:00 hours, station 1 was the coolest locality on the mountainside all through the night, until 09:00 hours in the morning. The temperature inversion was influencing station 2 by 21:00 hours, station 6 by 23:00 hours, and station 7 by 01:00 hours.

Around station 1 the temperature dropped below freezing at 23:00 hours (-1°C), and frost was precipitated. The temperature here remained below freezing point until about 08:00 hours, with maximum frost formation occurring at about 04:00 hours when the temperature was lowest and the relative humidity perceptibly high. Above station 1, from about 17:00 hours and onwards the temperatures did not vary greatly. Between 21:00 and 23:00 hours, when frost was forming at the base of the slope, the temperatures between stations 5 and 8 on the upper slope actually increased by a degree, and thereafter declined slowly until about 05:00 hours. Station 9 at the crest of the slope started to cool noticeably from about 00:00 hours until about 06:00 hours. From about 06:00 hours onwards temperatures at all localities on the mountainside started to equalize, rising in some places, falling in other places, until by 09:00 hours temperatures across the slope were around 2°C. From 11:00 hours onwards, temperatures everywhere were rising slowly.

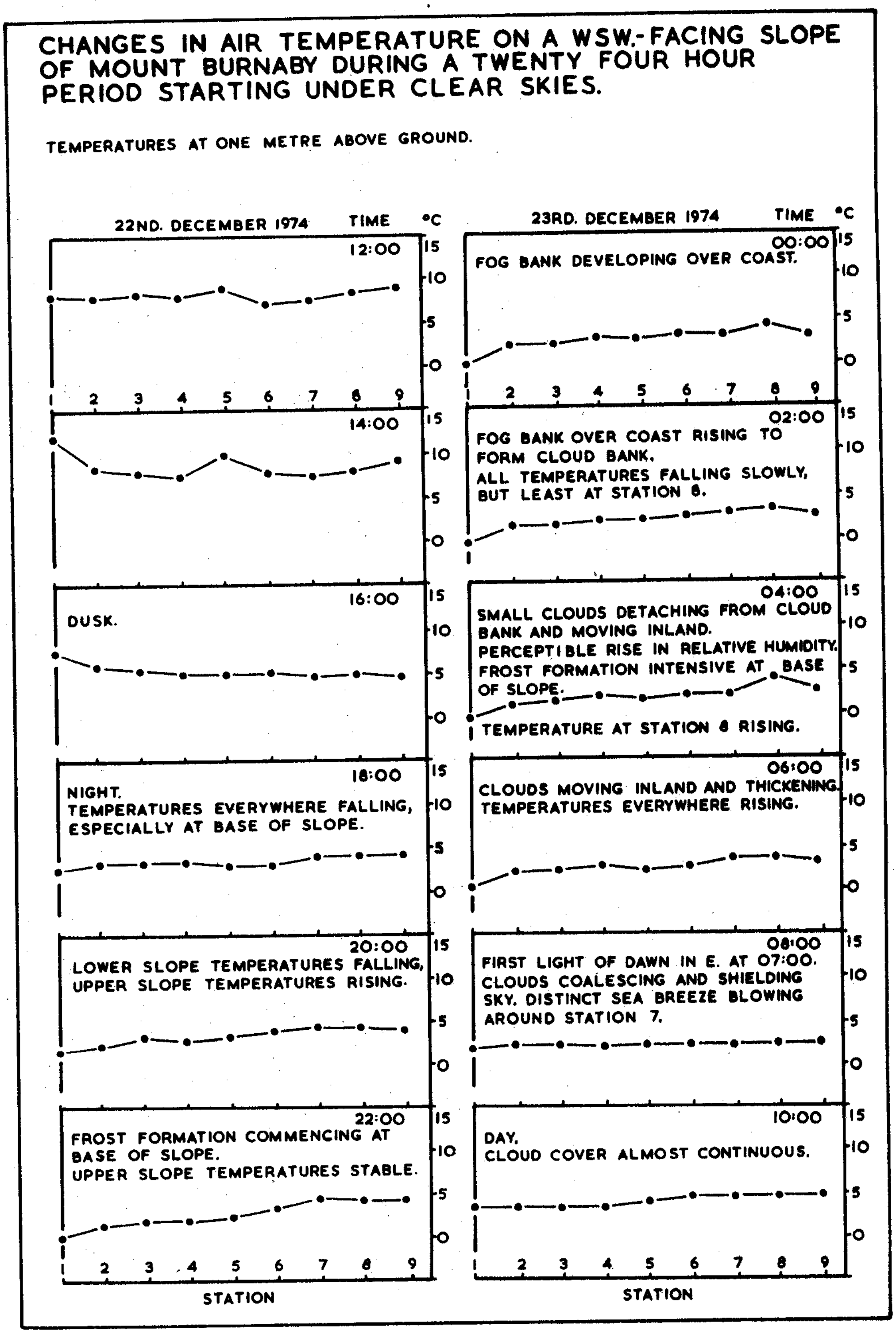

Fig. 7. Changes in air temperature one metre above the ground at selected stations across a west-southwest slope of Burnaby Mountain, during winter from 22nd to 23rd December, 1974, under clear skies.

At about 01:00 hours, two hours after frost formation at station 1, a fog bank developed over the adjoining lowland and water bodies, rising to form a cloud bank around 03:00 hours, with small clouds detaching from the main bank and moving inland at about 05:00 hours. These small clouds were thickening by 07:00 hours, when temperatures at the base of the slope were beginning to rise, and on the upper slope they were beginning to decline, thus tending to equalize the temperatures across the slope as the first dawn light appeared in the eastern sky at 08:00 hours. Individual clouds were coalescing by 09:00 hours, to form a cloud layer shielding the sky, and there was a distinct breeze from off the coast to be felt around station 7, when temperatures across the whole slope were similar. The cloud cover was virtually continuous at 11:00 hours, and did not start to disperse until about 13:00 hours.

Interpretation

Under clear skies with heat radiating from the land surface during the night, a summer inversion layer started to form at 03:00 hours. Geiger (1973) observed that the night inversion generally achieved a maximum height (up to 1000 metres in areas of great relief) just before sunrise, it was most intense one metre above ground, and after sunrise it was quickly destroyed. On Burnaby Mountain the maximum height of the inversion phenomenon was achieved two hours after the start of dawn, and in daylight. Beneath a forest the canopy takes on most characteristics associated with open ground, and the forest litter layer has a milder climate than that of the canopy (Geiger, 1973), and there is a flow of heat to the ground from above until midnight. Only after midnight does the forest floor start to radiate heat upwards. There may be a phase difference of four to six hours between the ground and the canopy. The stations on Burnaby Mountain were established in clearings, but the forest influence was sufficiently close to delay the onset of inversion, so that the maximum height of temperature inversion occurred after dawn.

During winter the temperature inversion started to form at about 20:00 hours, and increased in intensity until about 05:00 hours, after which it dissipated, four hours before dawn at 09:00 hours. The summer temperature inversion was a transient dawn feature, which started during late night as radiation under a clear sky produced sufficient cooling for the migration of relatively cold air down the slope, to pool at the bottom, and "fill" upslope. The winter temperature inversion was a more prominent phenomenon which started to form early in the night. Nitze (Geiger, 1973) demonstrated as early as 1936 that local air circulations are formed on a slope, air being pulled in from the reservoir of warmer air above the valley floor onto the midslope position, to replace cooled air migrating downslope. It is noteworthy that between 19:00 and 21:00 hours in winter the midslope temperatures actually rose a little, presumably because of incoming warmer air at about 275 m. replacing cooler air which was migrating downslope and pooling at the bottom. After 21:00 hours the midslope temperatures fell slightly, but they remained persistently greater than those at the base of the slope, where frost formed at about 23:00 hours.

At station 8 near the crest of the mountain the temperatures remained relatively stable after 23:00 hours, in contrast to the distinctly cooler temperatures at station 9 on the crest of the slope after 23:00 hours, which coolness, though it did not reach freezing point as at the base of the mountainside, was maintained until 05:00 hours. A layer of cool air is normally maintained on the hilltop since it is not dispersed so easily by migration downslope. The freezing temperatures at the base of the slope, and the cool air on the hilltop, define between them the so-called "thermal belt" where temperatures are warmer through the night. Baumgartner (reported by Geiger, 1973) recorded temperatures on the westsouthwest slope of Grosse Falkenstein in the Bavarian Forest, demonstrating both the presence of the thermal belt, and the warmer daytime temperatures at the base of the slope, similar to the findings on Burnaby Mountain, illustrating the more "continental" climate at the base of the slope (with daytime temperature "highs" and nighttime "lows"), in contrast to the more equitable climate characteristic of the thermal belt.

During summer, soon after the inversion layer started to form, at 06:00 hours fog developed over Burnaby Lake. During winter, between 01:00 and 05:00 hours when the inversion layer at the base of the slope was achieving its maximum development, a fog bank developed over local water bodies. When cold air flows out over **warmer water** the radiation balance is positive, but evaporation takes place in spite of the saturated state of the cold air off the land (Hofmann, 1956), which will produce "smoke" and eventually a fog bank. Over the lowland with its water bodies adjoining the mountain this fog thickened into a low cloud bank by 03:00 hours, which cloud rolled inland by 09:00 hours. This developing movement of cloud inland coincided with an increasing velocity of air circulation replenishing the cooling air migrating downslope from the midslope position, until at 09:00 hours a distinct breeze could be felt blowing onto the midslope position (Fig. 8).

This increasing movement of warm air during the morning eroded the temperature inversion at the base of the slope (from 07:00 hours onwards), it warmed and destroyed the layer of cold air on the hilltop, and eventually produced a remarkably even temperature at dawn (09:00 hours) from the base to the top of the mountainside. Thereafter, temperatures across the slope rose steadily. This self-destruction of the temperature inversion by circulating warm and cold air was frequently observed on the westsouthwest slope after clear winter nights, with the morning

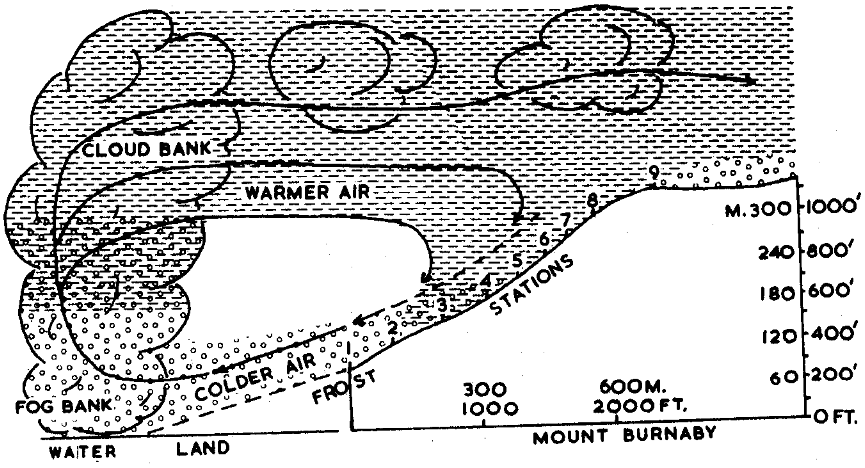

Fig. 8. Diagrammatic representation of winter air circulation between Mount Burnaby and the coast from 03:00 to 05:00 hours.

skies obscured by low cloud, which normally quickly dispersed as daytime temperatures rose. If clear skies developed during the night, and radiation from the land's surface occurred for a shorter period of time, the cloud bank over the coast failed to migrate inland sufficiently thickly and terminate the temperature inversion, which dispersed as in summer after dawn.

There was a strong relationship between air temperature changes during the day, and the steepness of the slope coupled with aspect. In summer the steepest slopes on this westsouthwest mountainside had been warmed during early evening when light from the setting sun impinged on these slopes more nearly at right angles compared with lesser slopes above and below, and they were coolest throughout the morning because these steeper slopes were shielded by the mountain from the rising sun. In winter these same slopes warmed earlier during the afternoon because the sun set earlier than in summer.

## Local Precipitation and Associated Phenomena

### Gumbel Analysis

Weather records have been kept at Simon Fraser University since its construction in 1966,* and although the period of years up to 1978 is small compared with the 50 years preferred for Gumbel (1954) Analysis of extreme events, an analysis does yield some tentative information. This form of analysis was devised to analyze characteristically non-cyclic and highly irregular events such as floods, rainstorms, droughts and

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* Now recorded by R.S. Sagar, Geography Department.

temperature variations.

## Interpretation of Results

The maximum monthly precipitation generally occurs during December and January. On average, a maximum monthly precipitation of 675 mm. can be expected once in every 20 years (Fig. 9), although for recurrence-intervals greater than the period of the records the error increases proportionately. Further interpreting this graph, 390 mm. is the mean maximum monthly precipitation (recurrence interval of 2.33 in Fig. 9), and 325 mm. is the most probable maximum monthly precipitation (recurrence interval of 1.6 in Fig. 9).

A Gumbel Analysis was also made of the minimum monthly precipitation, which generally occurs during July and August. No precipitation during a month can be expected, on average, once every nine years, a recurrence-interval within the period of the records. The most probable minimum monthly precipitation is 34 mm. The closely associated maximum monthly mean of mean daily temperatures generally occurs during August. On average, a maximum monthly mean of 22.5°C can be expected once in every 20 years. For these temperatures the mean value is 18°C and the most probable value is 17.3°C.

## Precipitation - Runoff Features

Because most of the annual precipitation falls during winter, except for a few streams on the southeast slope of Burnaby Mountain, most are dry during the summer. Fig. 10 shows streamflow measurements during a five-week period at a gauging station

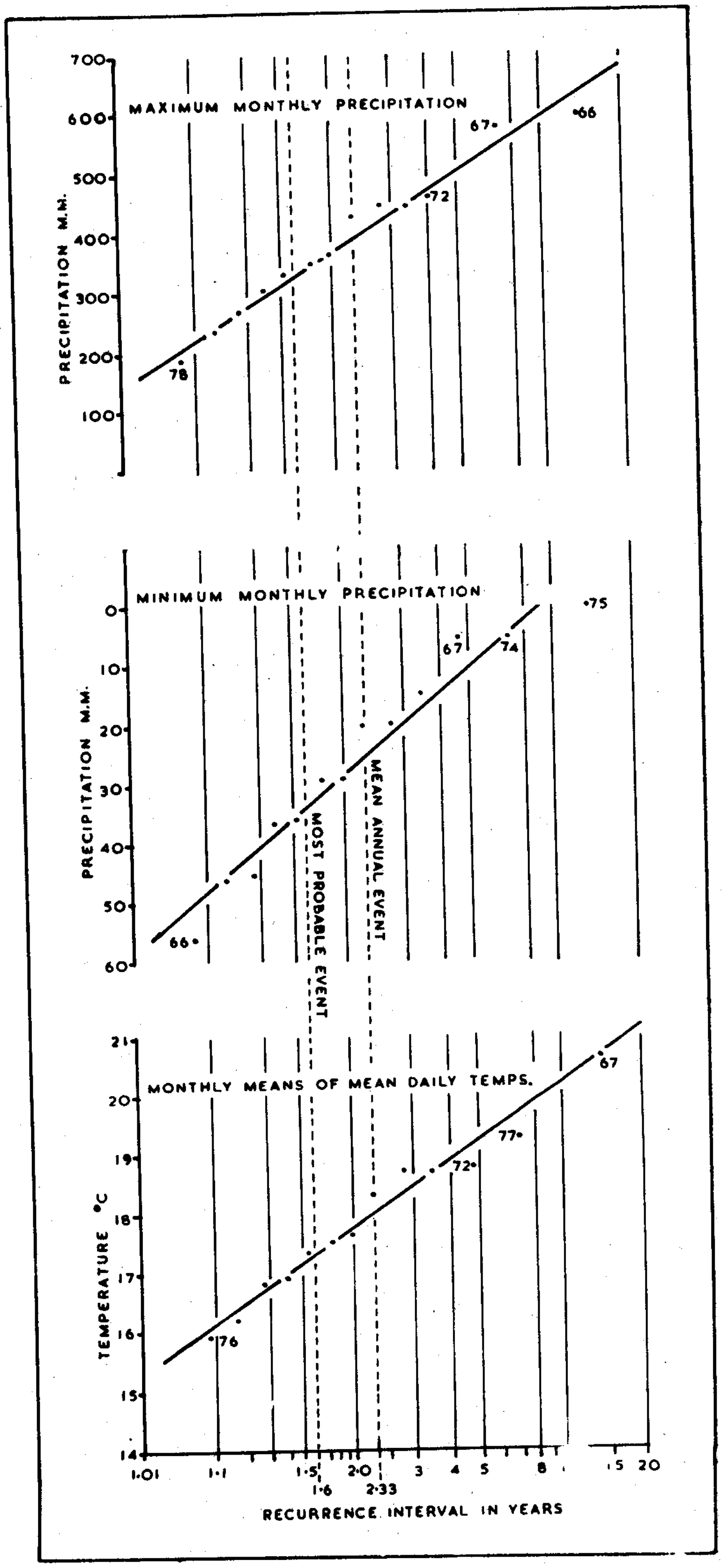

Fig. 9. Gumbel Analysis of precipitation and temperature measurements on Burnaby Mountain.

situated on the southwest slope of the mountain. Following a shower, there is an immediate response at the weir, and the decline in streamflow is fairly rapid after the shower. After prolonged winter rain a substantially greater reservoir of water accumulates in the substrate of the mountain, which can take over one and one-half weeks to drain, longer with subsequent showers.

## Local Wind Effects on Burnaby Mountain

A weather phenomenon which becomes more important in semi-urban areas is the effect of winds. Oke (1977) has described the wind effects associated particularly with high buildings, of the kind associated with the campus of Simon Fraser University on Burnaby Mountain where, because of its highly exposed situation, wind velocities can be very great.

The prevailing wind velocity is reduced by friction with the building tops, about a zone called the "canopy layer" approximately one quarter of the height of the buildings below the tops (Fig. 11). Where the wind at the canopy layer impinges upon an extensive flat surface of a building there is a narrow zone of more or less zero velocity called the "stagnation point" (Fig. 11). From this stagnation point the wind can rise over the building top, increasing the wind velocity across the top to greater than the velocity generally associated with air moving above the canopy layer. Also from this stagnation point the wind can form a downdraft, to impinge upon the ground and be forced to blow away from the wall.

Wind striking an extensive building surface near a corner will be deflected around the corner, increasing the wind velocity

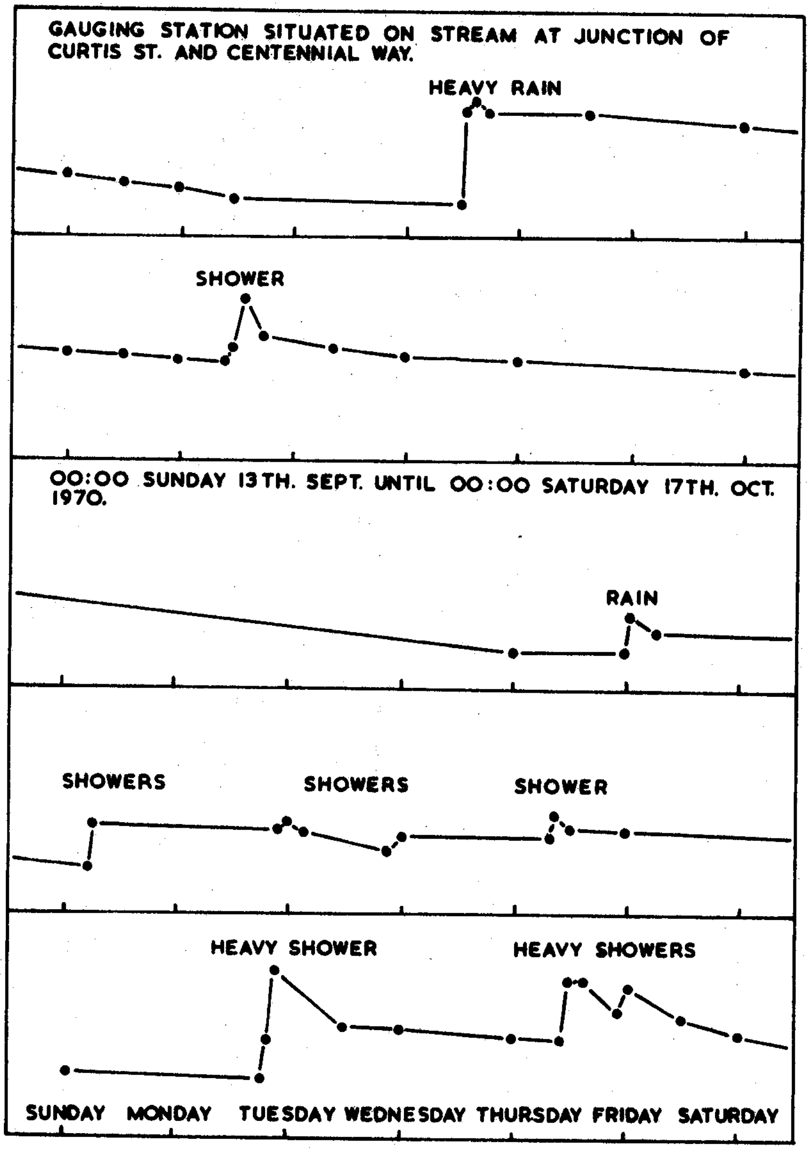

Fig. 10. Streamflow over a weir on the mid-southwest slope of Burnaby Mountain, based on observations by D. Mark, from 13th September to 17th October, 1970.

along the end wall of the building in the same way that the wind velocity is increased across the building top. This "corner stream" (Fig. 11), and the downdraft, greatly increase the "through-flow" (Fig. 11) of wind passing through a mall or passage-way, sometimes to considerable velocities. A similar effect can be produced between close-set buildings, called "jetting" (Fig. 11).

The wind accelerated across the building top fans out, downwards on the lee side, producing a pressure gradient declining downwards, which produces a back-eddie of air within a "vortex-flow" (Fig. 11), and a negative pressure just below the building top, which can be sufficiently strong during gusting to pluck out windows. With prevailing cyclonic winds from the south and southeast, arising from the route generally followed by cyclones striking this section of the Pacific coast, low clouds, or steam and smoke from the boilers of the Library, can often be seen swirling within this vortex-flow on the northern side of the building.

### Interpretation

Across campus building tops the wind is accelerated to a velocity greater than that prevailing within the air flow well above the buildings. A similar effect can be created by wind blowing over an escarpment such as that of Burnaby Mountain, creating powerful gusts across the plateau top.

A mall is generally created to provide a pleasant meeting place or crossing area, which it often is, but an extremely

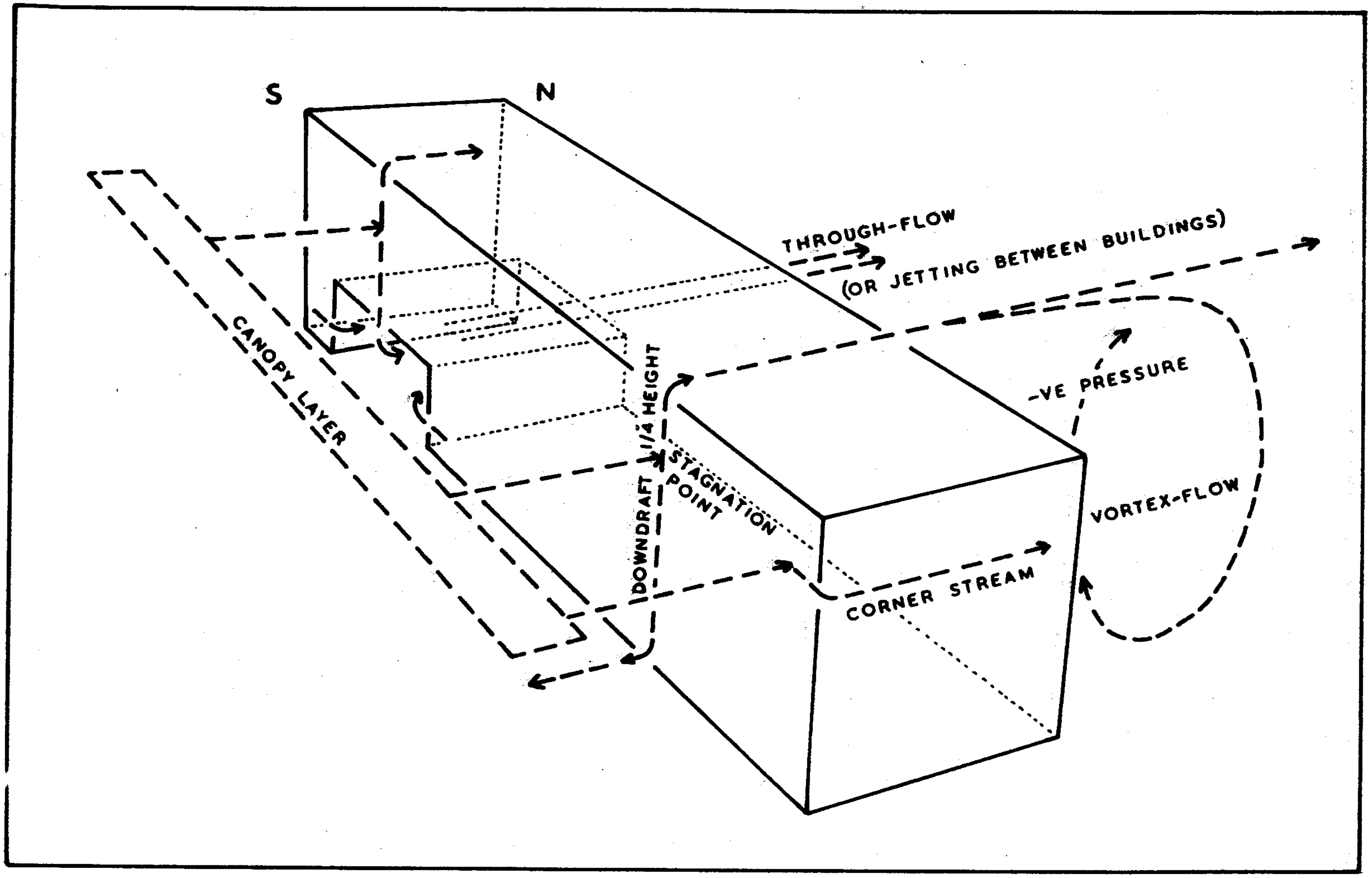

Fig. 11. Wind flow over, around and through a building according to Oke (1977).

hostile environment may be produced by the local configuration of buildings when a wind is funneled through a constriction. If the wind is cold the chill factor can be very unpleasant. The campus mall alongside the Library is a most pleasant meeting place when the weather is fine and sunny, but it can produce severe chilling when there is a winter wind, sending people scurrying into adjoining buildings. This was not the intended effect, but it has caused the relocation of ceremonial occasions off-campus, and it has helped stunt the growth of trees planted in concrete boxes within the mall. Low clouds carried by strong winds can be seen channeled through the underpass below the Rotunda, freezing people waiting for buses, the clouds fanning out once again as the velocity is reduced on the other side of the building. Only the hardiest pines seem to survive this through-flow.

The cool, north-facing aspect of one of the major wall surfaces of the Library, together with vortex-eddies, will help create a very special microclimate at this location, which will affect the vegetation, particularly any exotic species planted. Vortex-eddies can be seen on a grand scale in swirling clouds on the lee side of mountain ridges, bringing a gentler, cloudy eddie back up the slope, partly through the trees, an ephemeral effect that can hold attention.

## Summary and some Interactions

During sunny weather, under grassland the soil profile warms rapidly near the surface, and more slowly at greater depths. Profile surface temperatures are distinctly cooler beneath a forest canopy throughout a sunny day compared with grassland. The canopy helps to insulate the soil from the sun's heat, and to reduce radiation of the accumulated heat back into the air during the night under clear skies. During early morning the subsoil is actually warmer than the topsoil. If dry, sunny weather is maintained for about two weeks the canopy appears to loose its insulating effect, and the topsoil warms to similar temperatures inside and outside the forest.

On slopes facing in all directions, air temperatures are greater than topsoil temperatures beneath the forest canopy, the difference being about 4°C on slopes facing around northeast, and about 7° on slopes facing around southwest during a sunny day. Because they have been warmed throughout the whole day, the greatest air temperatures are achieved during the afternoon on westsouthwest slopes. Since the sun's rays always strike the forest canopy on these slopes very obliquely, the soils remain cooler than on all other slopes throughout the day. The sun's rays penetrate a forest stand most effectively when the sun is highest in the sky around midday shining on southsoutheast slopes, warming the topsoils to higher midday and afternoon temperatures than elsewhere. The eastnortheast slopes are warmed by the morning sun to higher morning air and topsoil temperatures than other slopes.

The insulating effect of a forest canopy delays the onset of a summer inversion layer near the ground surface to just before dawn, and it achieves its maximum elevation on the slope two hours after dawn, after which it quickly dissipates. During winter the cold air starts to pool at the base of the slope during the more usual time of early night, when frost forms. The warmer thermal belt occurs below cooler air over the mountain crest and above freezing air collecting over the lower half of the slope. Cold currents sinking downslope draw in air along the thermal belts bringing fog over the mountain. This fog stops radiation under clear night skies essential for the development of an inversion layer, which is rapidly eroded, eventually equalizing temperatures across the slope.

Steep slopes on the southwest side of the mountain warm to higher temperatures than other slopes during late afternoon and evening because they are at a higher angle to the sun's rays. Conversely, these steep slopes remain in the shade for longer, and are therefore cooler than other slopes during the morning when the sun is rising in the eastern sky.

The maximum monthly precipitation generally occurs during December and January, and the minimum during July and August. These two months are also normally characterized by the maximum daily temperatures. A maximum monthly precipitation of 675 mm. can be expected, on average, once in every 20 years, an amount of precipitation about twice the mean maximum monthly precipitation of 325 mm. No precipitation during a summer month can be expected, on average, once in every 9 years.

Burnaby Mountain is an isolated prominence in the Lower Mainland of British Columbia, and the catchment area is small. After rain, runoff is rapid, a surge of water sweeping down all streams draining the mountain. After showers, many streams quickly run dry. Only on the south side of the mountain are there streams that carry a trickle of water during a dry summer.

A mountain raises the wind to increase the velocity across its top. In a similar way, wind gusts are accelerated around Building corners and through underpasses or malls, locally creating severe environments for people and plants. On the lee side of buildings or ridges, vortex-eddies are associated with backflows of ground air movement.

## Aspect and Radial Growth of Hemlock

Using stumps about one metre high of felled trees at selected sites around Burnaby Mountain at an elevation of about 275 m., the radial growth with direction was measured for hemlock. Scalar plans were drawn, and related to aspect (Fig. 12).

The tree situated on the slope facing westsouthwest showed distinct preferential growth in the direction faced by the slope, with moderate growth south and southeast, declining to the least growth in the direction facing northeast and north, which is consistent with the differential warming effect of the sun within the forest stand around the mountain, greatest on southwest slopes and least on northeast slopes. The tree situated on the southeast slope had been partially shielded from the maximum warming effect of the air by the sun during late afternoon when the sun was in the southwest sky, and the maximum radial growth occurred on the side facing south. The tree situated on the north-facing escarpment received the sun's warmth only when the sun was very low in the western sky; at all other times during the day the mountain blocked the direct sun's rays. Radial growth is not great compared with the other two trees, but it is maximal in the direction facing westsouthwest where it received some of the sun's warmth late in the day.

Fig. 3 shows the steep, north-facing scarp of Burnaby Mountain deep in shadows. Only the lower footslopes, particularly the extension of the footslopes formed by the rock slide, is receiving patchy sunlight. On a warm summer's day, the chill in temperature and the increase in dampness can be felt quite distinctly when walking off the plateau top of the mountain and onto the north slope down Joe's Trail. The most pleasant time for walking along Joe's Trail is during late afternoon and evening when the sun's oblique rays warm the more prominent spurs separating the deeply incised ravines on the north face.

## The Effects of Aspect on Certain Plants and Insects

Observations were made within a 400-metre grid pattern established across the study-area, in this case Burnaby Mountain. The vegetation mantle and associated insect distribution is extremely complex and continuous, and so data gathering has to be grossly limited by species and site. Attempted accuracy is too time-consuming for routine work, and might still be inadequate because of a host of unavoidable environmental interactions (Randall, 1978). Therefore, percentage cover estimates for swordfern and bracken, and counts per square half metre of carefully dismembered litter layer for the Micryphantida white spider and the red ant, have been averaged by grid square, and the means contoured across the mountain (Fig. 13), to suggest

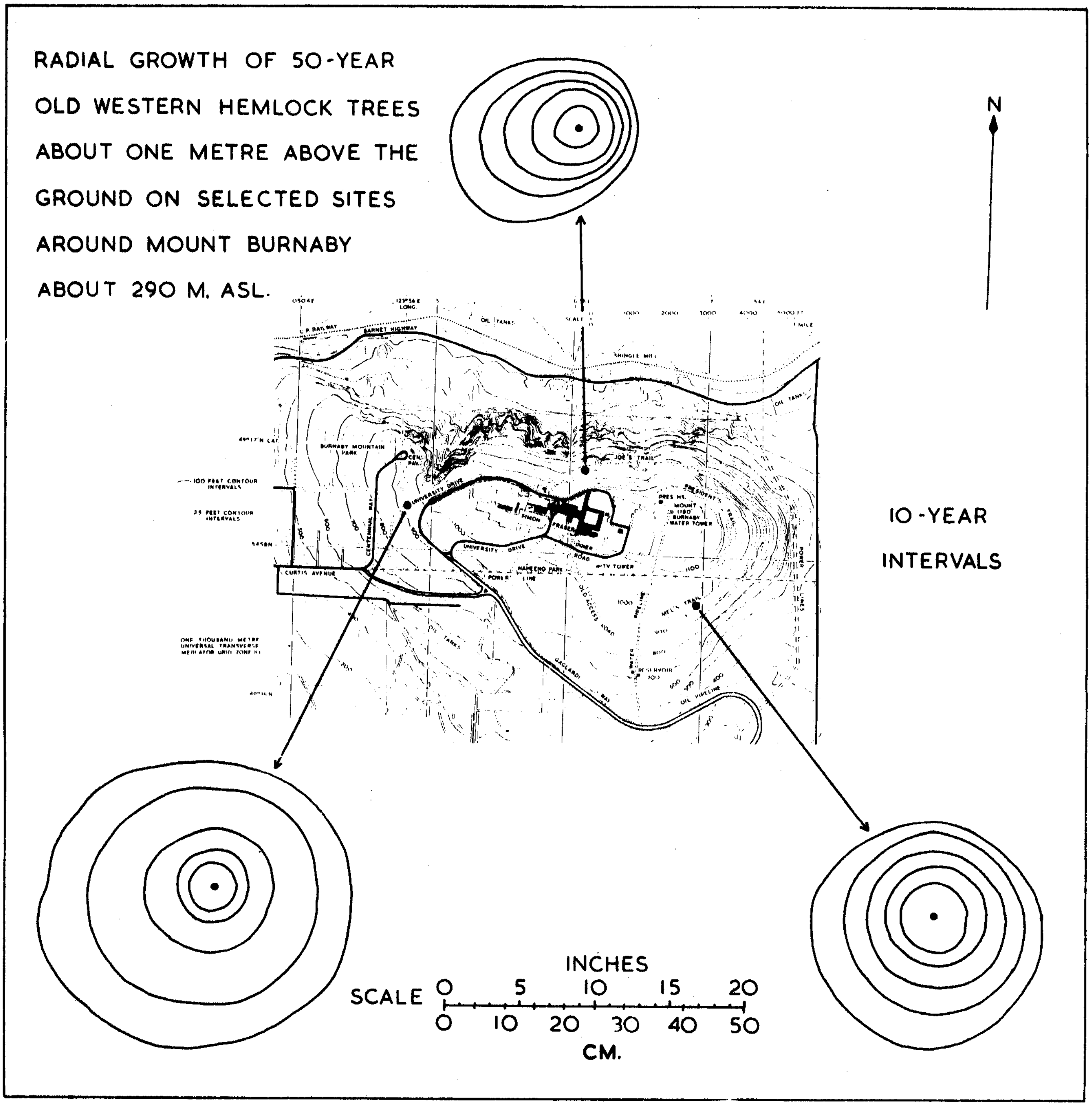

Fig. 12. Radial growth of selected 50-year old western hemlock trees about one metre above the ground on three sites facing NNW, SE. and WSW., situated about 275 m. A.S.L. on Burnaby Mountain.

tentative distributions.

The ground flora and fauna will be strongly influenced by forest air temperatures, and the richest variety of species can be observed on southern slopes. However, certain plants such as swordfern compete most effectively with other species on north-facing slopes, despite the relatively cool air compared with other slopes. After long sunny periods the sun's heat can penetrate the forest canopy on southeast, through south, to southwest slopes and dry the topsoils. The more continuously moist topsoils on north-facing slopes shielded from much of the day's sun might offer some advantage to certain species.

Bracken appears to compete with other plants most effectively on southeast-facing slopes, extending onto south-facing and more gentle slopes at progressively higher elevations, tending to be most widespread where the soil litter layer is warmest during the day, as distinct from air temperatures.

The Micryphantida white spider which lives within the litter layer is most abundant on south-, but particularly southwest-facing slopes. Like most other creatures living in litter, the spider becomes difficult to find on cool and wet days. The forest red ant forages for its food mostly on the surface, and appears more dependent on surface soil temperatures, in that it is most abundant on the warmest southeast-facing slope soils at lower elevations, through south-facing at progressively higher and more gentle slopes, like the distribution of bracken.

## The Inversion Layer and Phenological Effects

Nine stations were established at 100 ft. (30 m.) intervals

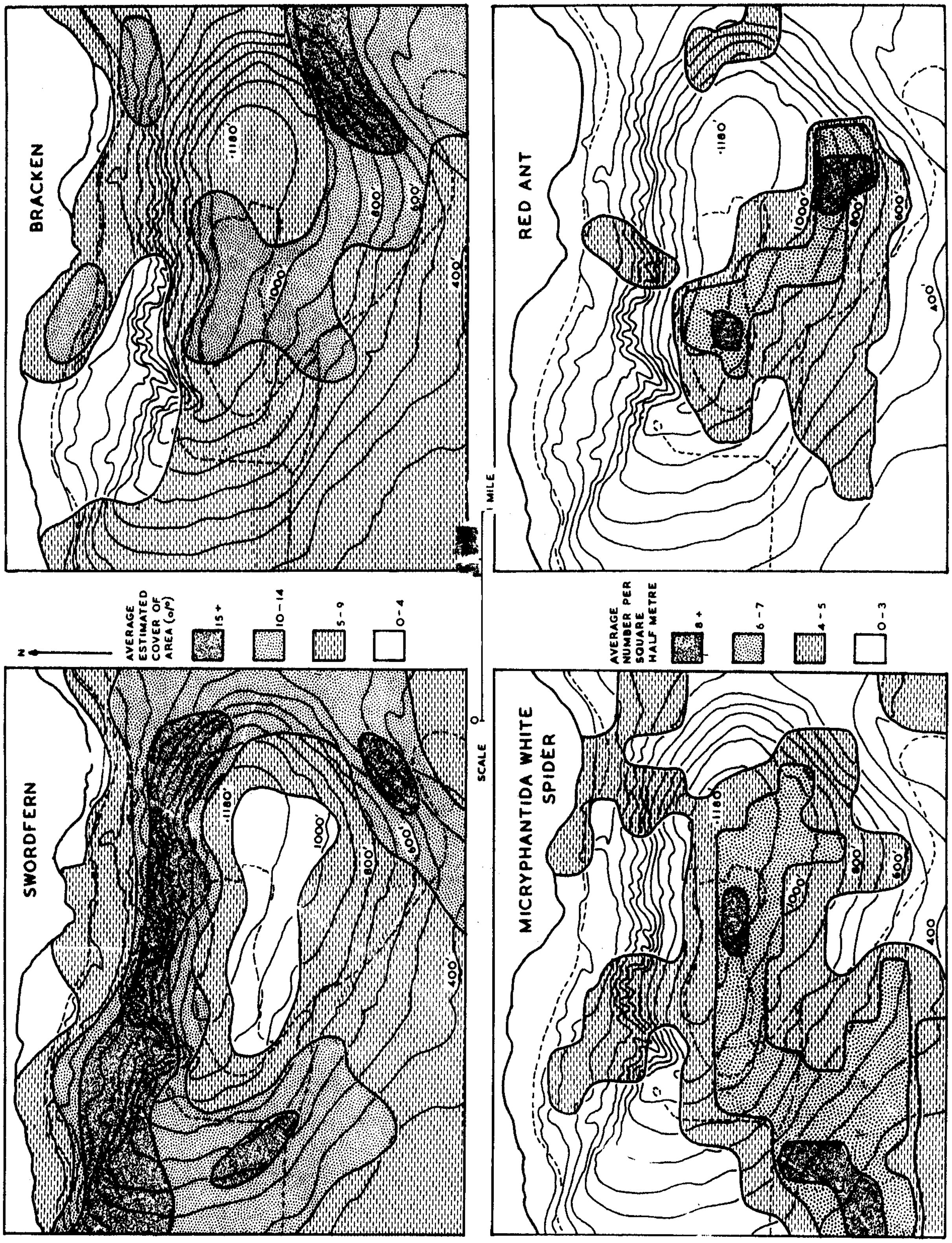

Fig. 13. Distribution of swordfern and bracken, based on averaged percentage cover estimates (N = 440), and of the Micryphantida white spider and red ant, based on averaged counts/square half-metre (N = 260).

from bottom to top of the westsouthwest slope of Burnaby Mountain, at the same localities established for measuring the inversion layer. An additional nine stations were established at the same intervals from bottom to top of the eastnortheast slope of Burnaby Mountain (Fig. 14). Repeated snowfalls occurred during January and February of 1975. On the westsouthwest slope there was a rapid response to warming, and by 27th February snow patches remained only in the closed forest because of the way it insulates the forest floor from the prevailing weather. However, at this time a thick, continuous cover of snow remained on the eastnortheast slope. By the 6th March the snow had melted on the westsouthwest slope, but still remained in patches on the upper eastnortheast slope, which patches did not all melt until the 24th March. Hence, there was an 18-day differential for snow-melt between westsouthwest and eastnortheast slopes this early in the year.

Phenology concerns the occurrence of certain important seasonal events in the annual cycle for plants. For example, bud-burst for indian plum (Fig. 14) occurred first at an elevation of about 550 ft. (168 m.) on the westsouthwest slope, on the 25th February. This locality is just above the most intense lows associated with the late winter and summer temperature inversions. A wave of bud-burst for this species then spread downhill to the base of the westsouthwest slope, and uphill at about the same rate to an elevation of about 850 ft. (260 m.). At this time, seven days after first bud-burst, the bud-burst of indian plum occurred on the eastnortheast slope at about the same elevation of 800 ft. (245 m.), 250 ft. (76 m.) higher on the eastnortheast slope than first bud-burst on the westsouthwest slope. The wave of bud-burst continued to spread uphill on both westsouthwest and eastnortheast slopes, reaching the plateau top 16 days after bud-burst of indian plum first occurred on the mountain. The wave of bud-burst also spread down the eastnortheast slope at the same rate, reaching the base of this slope 18 days after first bud-burst on the mountain.

Since first bud-burst occurred higher on the eastnortheast slope than first bud-burst on the westsouthwest slope, the implication is that the intense temperature inversion lows reach higher on the eastnortheast slope; presumably the associated thermal belt is also higher on the eastnortheast slope than on the opposite slope. Compared with the westsouthwest

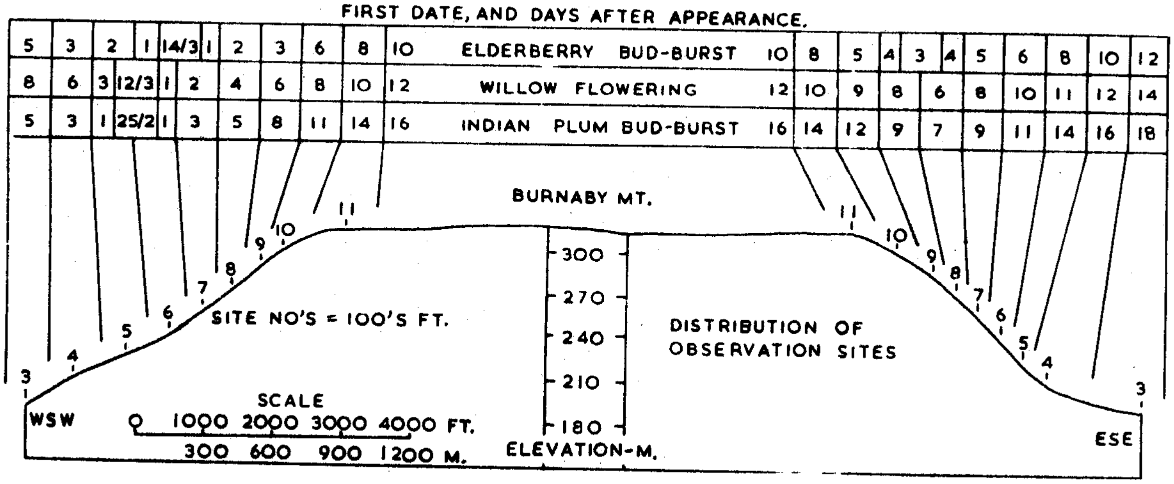

Fig. 14. Stations for phenological observations, WSW to ENE across Burnaby Mountain. The day and month of the first observation of a particular growth stage is given numerically, and all other observations of this stage are expressed as "days after" first observation.

slope, the seven-day later first bud-burst of indian plum on the eastnortheast slope also presumably reflects the cooler air temperatures on this slope.

Flowering of scouler willow started on the 12th March at an elevation of 550 ft. (168 m.) on the westsouthwest slope, and the subsequent wave of flowering across the mountain followed a pattern remarkably similar to that of indian plum bud-burst, with similar implications regarding the height to which the temperature inversion lows pool on westsouthwest and eastnortheast slopes, with the latter slopes being distinctly cooler. However, first scouler willow flowering occurred 15 days after first indian plum bud-burst. First willow flowering on the eastnortheast slope occurred at 800 ft. (245 m.) only six days after first flowering lower on the westsouthwest slope, and the last location at which flowering occurred, at the base of the eastnortheast slope, was only 14 days after first willow flowering on the mountain.

This shorter time span for the completion of a particular plant stage across the mountain was more pronounced for red elderberry for which bud-burst first occurred on the 14th March at 650 ft. (198 m.) on the westsouthwest slope; it first occurred on the eastnortheast slope three days later at 850 ft. (260 m.), and the cycle of bud-burst was complete 12 days later at the base of the eastnortheast slope.

Bud-burst for salmonberry and red alder started on the 18th March, but at this later date of inception the pattern of events was much less regular. It would appear that temperature inversion lows, sufficiently intense to produce frost at the base in this region, affect only those plants that undergo bud-burst or flowering early in the year. The earliest bud-burst during late February of indian plum apparently reacted most severely to differential temperatures across the mountain. By late March, the change from a mid-winter temperature inversion to a summer inversion has proceeded sufficiently far for there to be much less effect on plants. By the 9th April the flowering of indian plum (as distinct from leafing) occurred virtually simultaneously across all slopes; the bud-burst of scouler willow (as distinct from earlier flowering) occurred more or less simultaneously across all slopes on the 11th April, and the flowering of red elderberry occurred across all slopes on 8th May.

# GEOLOGY

## Stratigraphical and Structural Geology of Burnaby Mountain

A structural basin called by Newcomb et al. (1949) the Whatcom Basin, apparently began to form across northwest Washington and southwest British Columbia during the Middle Eocene, and it intermittently subsided during the Oligocene and Miocene, accompanied by concomittant deposition associated with a great Fraser River delta. Burnaby Mountain is formed of these sediments situated on the north side of the palaeo-delta, locally called the Kitsilano Formation. Roddick (1965) described an ill-defined outcrop of these Tertiary rocks on the mountain. The total thickness of this formation is uncertain, though it is at least 2660 ft. (810 m.) below Burnaby Mountain (Johnston, 1923). The regional dip is southwards. Drilling during the 1920's in Burnaby around the southern footslopes of the mountain tapped a considerable quantity of gas, but at the time little use could be made of it and it was allowed to dissipate. During the 1920's a George Green mined low-grade coal from an outcrop still to be seen high on the escarpment near the Centennial Pavilion (Fig. 18).

The mountain consists of mostly sandstone, some conglomerates and a little shale (Fig. 15), approximately of Eocene age. It is the conglomerates that are most competent. Thick conglomerate bands cap the mountain (Fig. 16), producing the plateau top and giving rise to a steep scarp along the upper north- and northeast-facing slopes (Fig. 3). Generally, these geologically young conglomerates are uncemented and individual pebbles can be easily prised out of the rock. However, excavations during 1977 for an extension to the Classroom Complex had to penetrate a thick, cemented conglomerate band which was hard enough to delay the work, and which required explosives to move. Below the plateau top cementation of the conglomerate bands is very local, but the rocks are firm enough to form a sequence of steps in the landscape where they crop out on the gently inclined south-facing dipslope. Because of the landform it produces, the outcrop of each conglomerate band was most useful during mapping of the mountain (Crampton, 1977).

The strata dip at an angle of about $6^{\circ}$ on a bearing of $181^{\circ}$ (Fig. 17), except on the northern escarpment where surface creep down the steep slope has buckled the strata locally, giving them a dip at a high angle to the north. The conglomerate bands tend to occur in groups, illustrated in the section (Fig. 18) described from the ravine below the Centennial Pavilion. C2 consists of three major conglomerate bands, separated principally by sandstones, but also by a little shale and lignite. This group of conglomerates produces a steepening of the escarpment face. The softer sandstones are important in the succession above C2, separating the latter from the higher group of conglomerates, C1, capping the mountain. Two other groups of conglomerates, C3 and C4, crop out below C2, each separated from the other by mostly softer sandstones. The basal exposure produces a cliff locally alongside the Barnet Highway.

These lowermost conglomerates consist of pebbles mostly of crystalline igneous rock origin (80% of pebble assemblage), as distinct from a 50% content of this rock type higher in the

Fig. 15. (Upper) conglomerate over sandstone, over shale; part of Kitsilano Formation forming Burnaby Mountain. (Lower) dark, fine-grained, crystalline dyke, through light, coarse-grained, crystalline granulitic diorite of Twin Island Group metamorphics and associated igneous rocks forming Belcarra Mountain.

mountain. The sediment source became less rich in igneous rocks with the passage of time. The earlier provenance consisted mostly of igneous rocks, but it slowly gave way to one with some sedimentary rocks, locally uplifted and exposed to erosion.

The greenish, frequently cross-bedded sandstones which constitute a major part of the succession are soft enough to be grubbed out with the hands in some places. These sandstones give rise to less steep slopes around the mountain, that is the more gently inclined platforms above each of the steps produced by the conglomerate outcrops. Although shales are not important in the total thickness of the succession, because they are impervious to water they guide water pooling within overlying porous sandstones downwards in the direction of the southerly dip. The dipslope of the mountain is more steeply inclined than the dip of the strata and so shale bands bring the water back to the surface along a spring line.

Because of the clastic nature of the sediments, few fossils have been found in them. However, locally in the finer-textured shales (for example, exposed during excavations for the Library foundations), plant fossils have been found which suggest that at the time of deposition the climate was warm and temperate (Hopkins, 1969; Rouse, 1962). Some of the species identified now occur only in Asia, suggesting a land bridge across the Bering Strait. Other species now occur only in eastern Canada, suggesting that the Rockies were hills during Eocene times.*

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* Personal Communication, R.W. Mathewes, Biological Sciences.

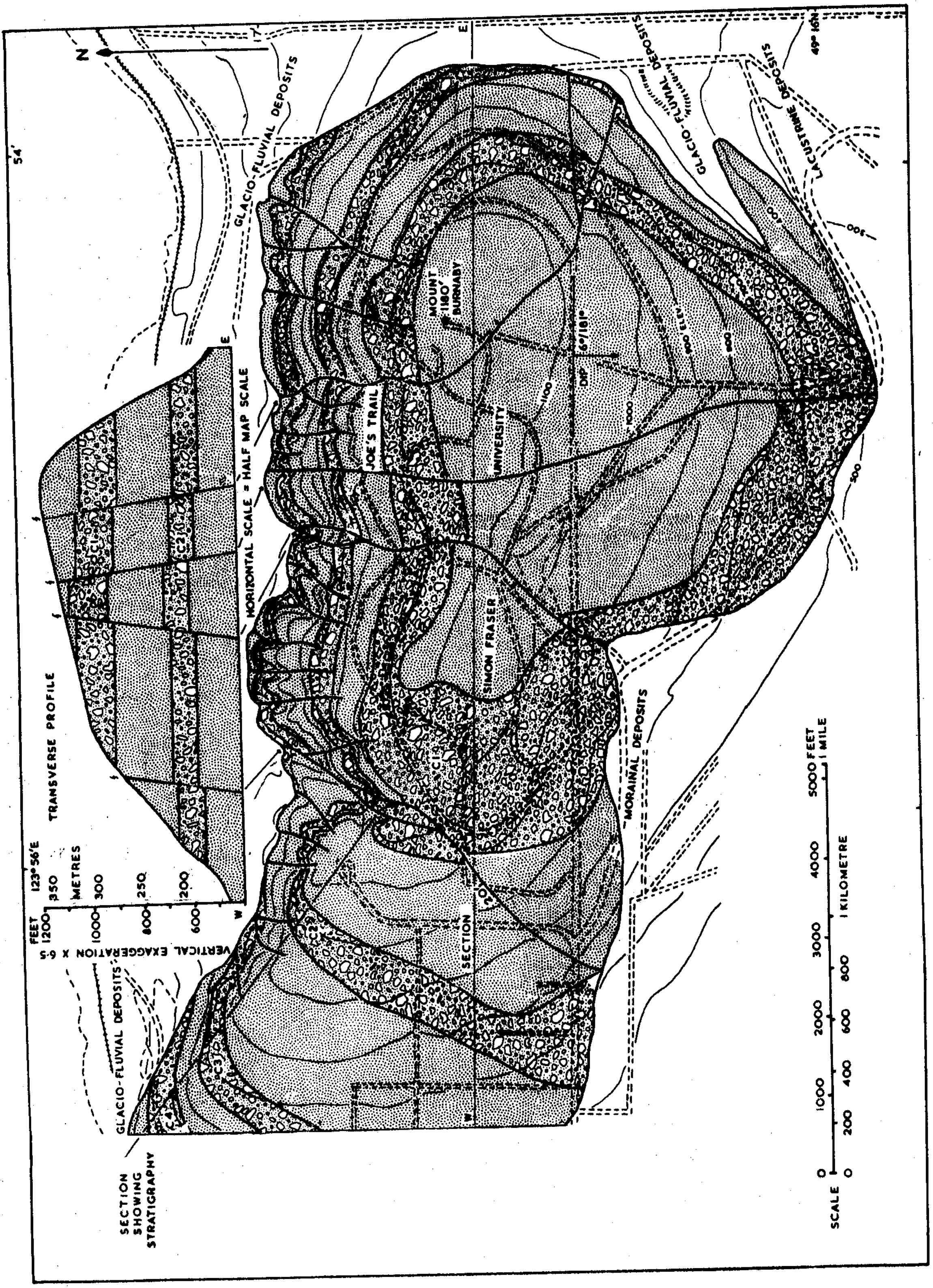


Fig. 16. Geology of Burnaby Mountain, with transverse profile.

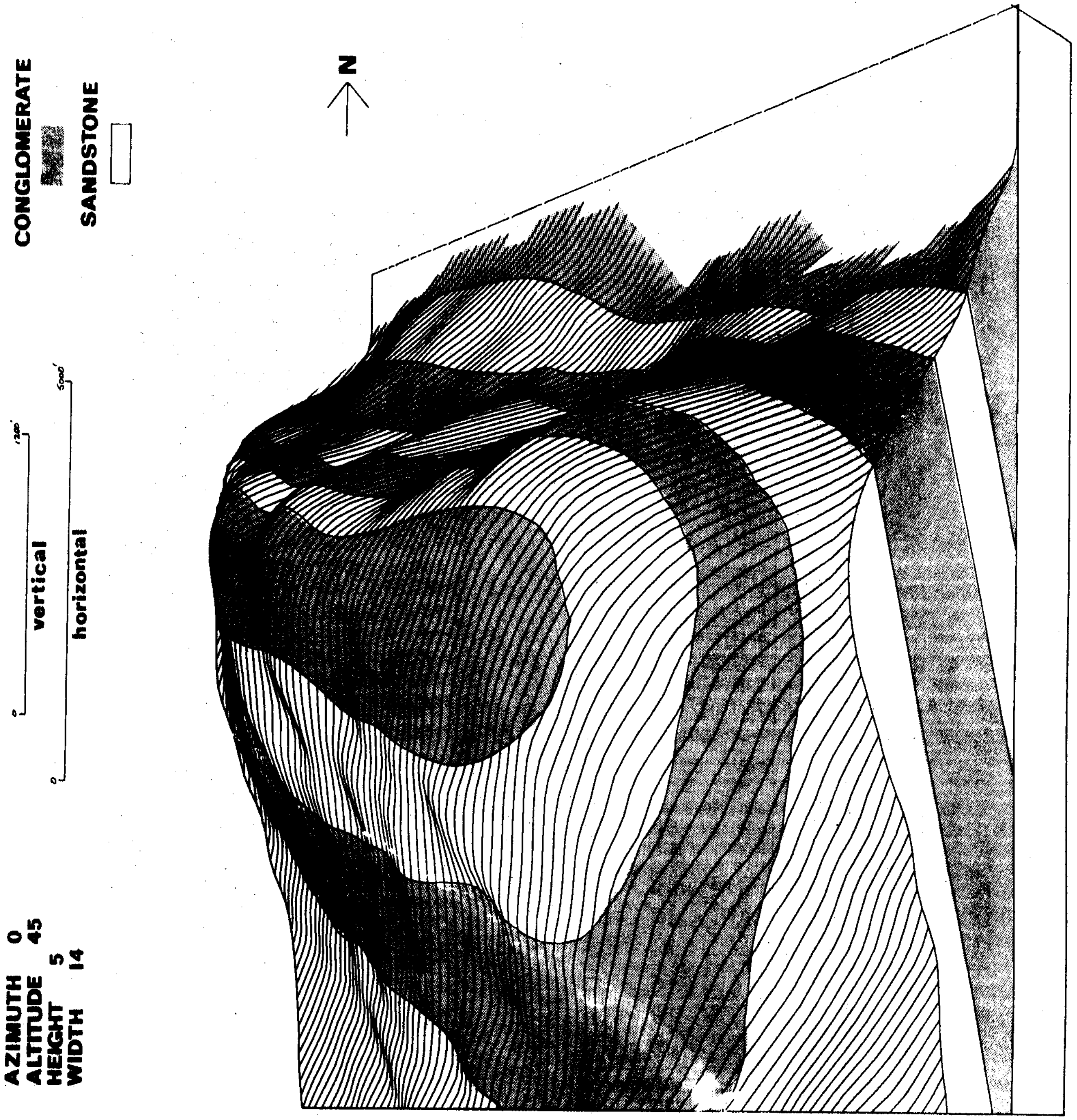


Fig. 17. Symvu projection of the geology of Burnaby Mountain.

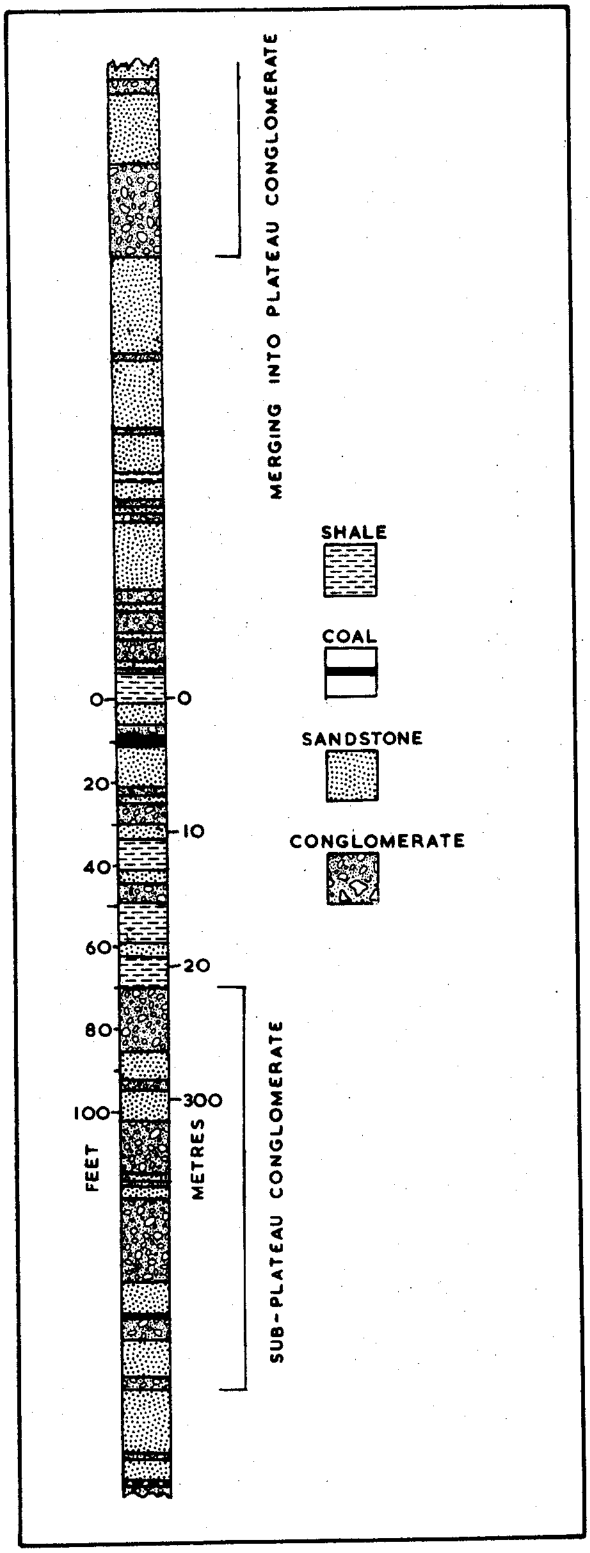


Fig. 18. Stratigraphy in the ravine below the Centennial Pavilion, from the plateau conglomerate beds, and through the sub-plateau conglomerates.

Four major, dip-slip, normal faults dissect the mountain, the two on the west side downthrown to the west, and the two on the east side downthrown to the east (Fig. 16), the whole structure appearing to be one of collapse about the centre. The bifurcating fault system occupying the double-headed ravine below the Centennial Pavilion can be traced across Burnaby Mountain in distinct troughs where differential erosion has removed the gouge or rock rubble generated by past fault movement. The section shown in Fig. 18 is situated on one side of the eastern branch of this fault system, and is displaced 20 ft. (6 m.) from the other side. It is impossible to measure the amount of throw associated with the other major faults, although the up-buckling and down-buckling of the strata on either side of the fault zone indicates the upthrown and downthrown sides.

Differential erosion by an intermittent stream within a ravine on the north slope marks the outcrop of the major fault passing beneath the Library (Fig. 16). When the foundations of this building were being laid water flowed through the fault zone causing much trouble, until it was filled with concrete. The fault zone below the Centennial Pavilion contains calcareous deposits, presumably laid by percolating water. Because of the excessive precipitation over the mountain, much water within each of the approximately 15 ft. (4.5 m.) wide, major fault zones ensures water-soaked gouge for most of the year. This would allow any fault movement to occur by creep rather than sudden movements (Bolt et al., 1975). The northern escarpment is cut by many small ravines, dissecting the scarp into spurs

(Figs. 1 and 34), presumably produced by minor faults, although this was confirmed for only a few.

## Foreset Bedding Exposed by Joe's Trail

### Analyses

The cutting of Joe's Trail exposed unattenuated foreset-type beds on the north-facing escarpment. Fracturing down the escarpment has slightly disturbed the beds. The orientation of this bedding indicates that the current responsible for its deposition came from the eastsoutheast (Fig. 19). This direction is more or less the same as for the present Fraser River current, although the Burnaby Mountain sediments would have been laid down on the north side of the, then, much larger delta during early Eocene times. The section on Joe's Trail consists of interbedded conglomerates and sandstones over a sandy shale band. Because this band contains the finest material of the section, it is assumed that during deposition it was laid in sluggish water moving across a nearly flat surface. In short, it is assumed that the sandy shale band represents the original horizontal surface on which the foreset beds were deposited. The foreset slope subtends a maximum angle of 11° with the sandy shale band. The whole section has now been tilted northnorthwest. Also, minor fracturing of the beds has occurred locally (Fig. 19), although insufficient to obscure the stratigraphy.

Analysis of the particle size distribution for the sandy shale band was undertaken with the settling tube. Using Folk and Ward's (1957) formulae, the sediment was calculated to be fine sand, well sorted, positively skewed and very leptokurtic,

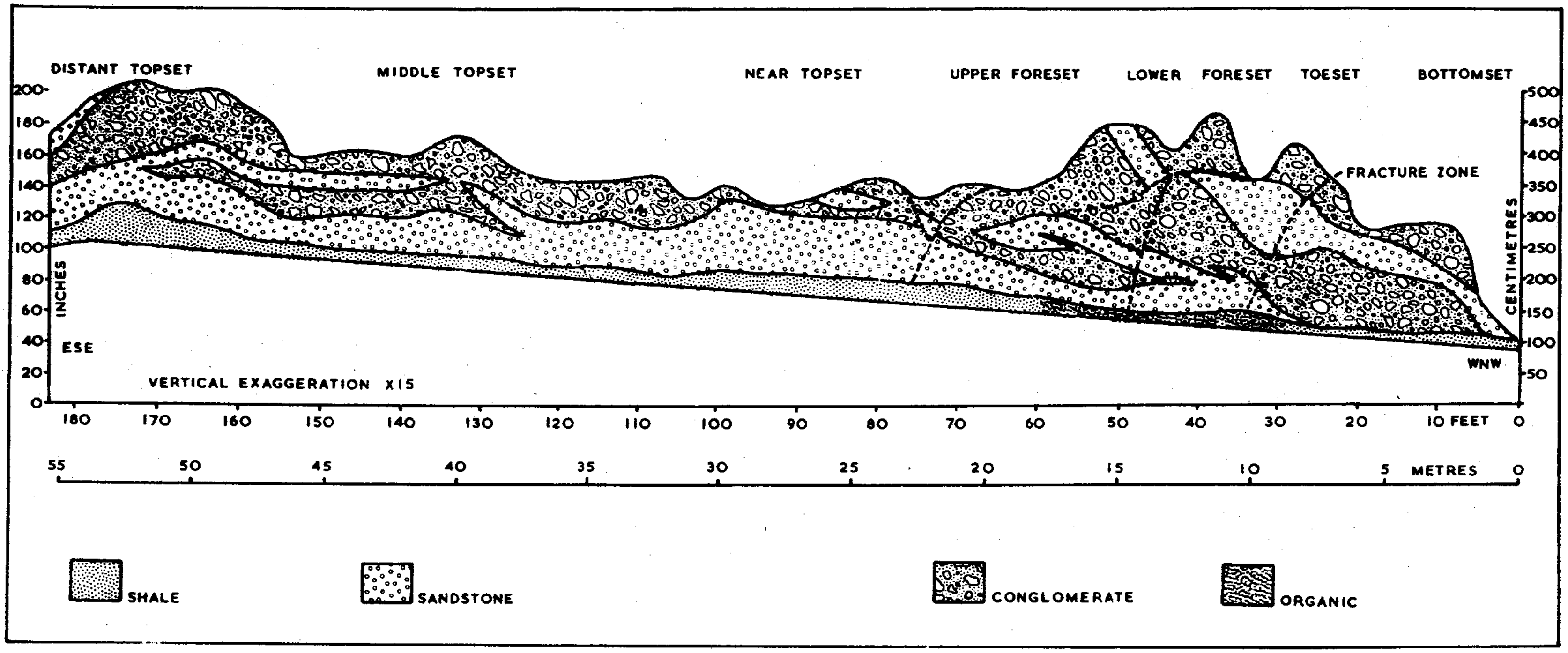


Fig. 19. Scale profile of the foreset beds on Joe's Trail.

suggestive of wind-blown material (Friedman, 1961). Today's deltas may be associated with areas of dune sand.

Many analyses by sieving were conducted by Geography 318 classes on each of eight samples collected from selected sites in the sandstone band immediately above the sandy shale band, and the averages are plotted (Fig. 20). Pebbles were extracted from ten selected sites within the conglomerate band above the sandstone, and the dimensions of each pebble measured with reference to a triaxial ellipsoid (Krumbein and Sloss, 1963). Based on the maximum dimension, the pebbles were arranged in size classes. Mean grain size was calculated for the sandstone and conglomerate sample sites, and sorting, skewness and kurtosis for the sandstone sites. On the Wentworth Scale the sandstone varies from medium to coarse sand, and the conglomerate from pebbles to cobbles (Fig. 20).

For convenience, the foreset beds have been divided into sections, from the bottomset where the foreset beds merge with the sandy shale band (Fig. 19), up and over the foreset beds through the toeset where the bottomset merges into the foreset slope, which slope has been divided into the lower and upper foreset sections, to the near-topset position where the foreset slope merges into the flatter topset. The near-topset has been divided by the middle topset section from the so-called distant-topset furthest from the foreset slope. From the middle topset to the toeset both conglomerates and sandstone bands show the same trends. There is a decrease in grain size across the topset towards the crest of the foreset slope, from cobbles to pebbles

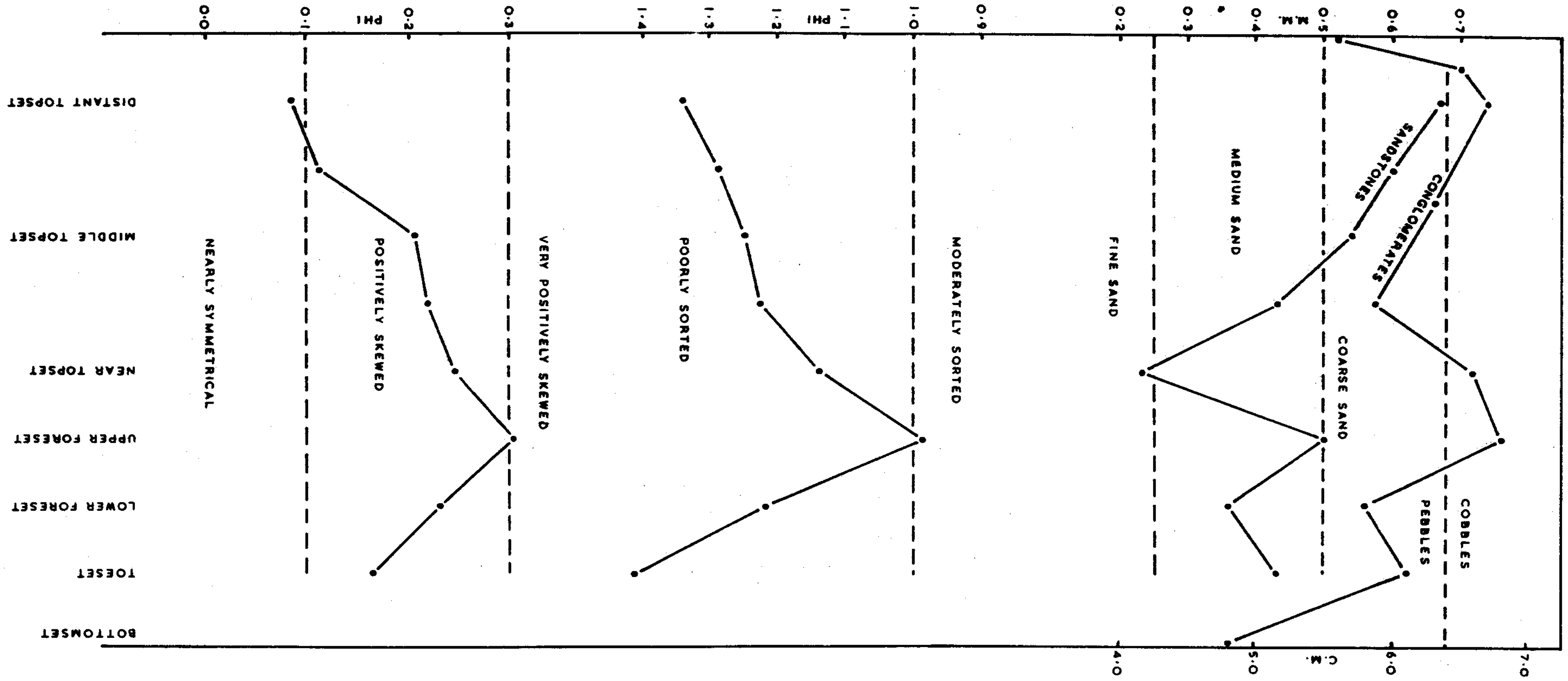


Fig. 20. Distributions of mean grain size for sandstones and conglomerates across the foreset beds on Joe's Trail, and of sorting and skewing.

and from coarse to fine sand (Fig. 20). On the upper foreset slope there is a pronounced increase in grain size, to cobbles and coarse sand. On the middle foreset there is a return to finer grained material, pebbles and medium sand, and on the toeset, once again an increase in grain size, albeit not so pronounced as on the upper foreset slope. The sandstone band wedges out sharply against the sandy shale band at the toeset. On the bottomset the conglomeratic band contains the smallest pebbles of the foreset beds and it, also, wedges out against the sandy shale band. On the distant topset there is a similar, though not so pronounced decrease in pebble size.

The sandstone samples are generally poorly sorted, although across the topset the sorting improves towards the near-topset position, achieving moderately sorted status on the upper foreset position, below which the sorting degrades rapidly to the toeset where it achieves the poorest sorting on the foreset beds. Skewness shows a similar trend across the foreset beds, being nearly symmetrical on the distant topset position, grading through positively skewed, to very positively skewed on the upper foreset position, below which the skewness degrades rapidly to the toeset.

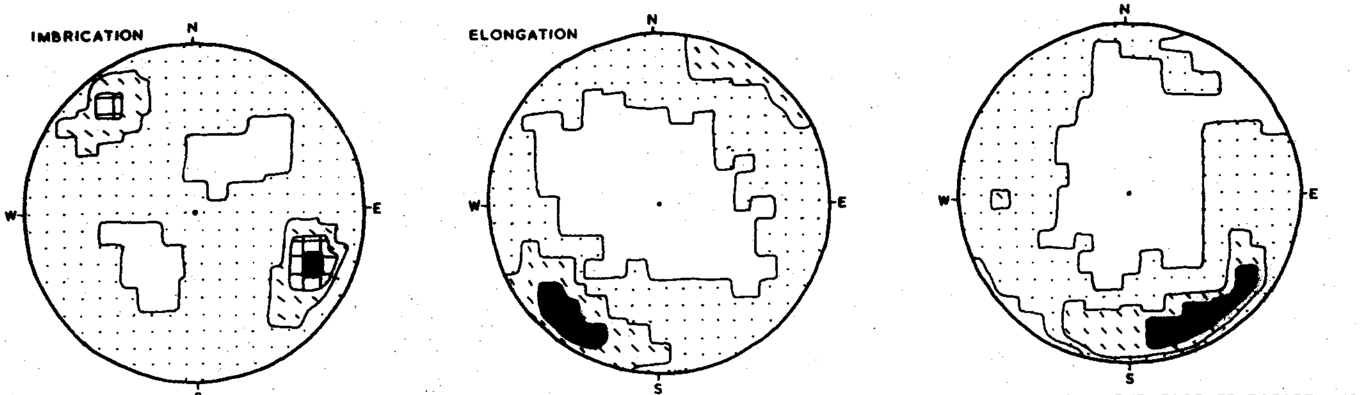
Using the simple classification of pebble shape based on the triaxial measurements described by Krumbein and Sloss (1963), 357 spheroids, rollers (or rods), blades and disks were split open and their origin identified in terms of igneous, metamorphic or volcanic. With six degrees of freedom a Chi-square test was significant at better than the 0.025 level, for a distribution of pebble shapes of mostly spheroids as igneous crystalline rocks, rods and blades as metamorphic rocks, and disks as volcanic rocks. Coarsely jointed igneous rocks apparently often break down with erosion into spherical pebbles, frequently cleaved metamorphic rocks often break down into elongated pebbles, while layered lavas often break down into flattened pebbles. The nearest source of rock types of this nature is the Coast Range, locally represented by Belcarra Mountain on the other side of Burrard Inlet.

Dip and bearing orientation measurements were made by students of Geography 318 of the flatter surface, and of the elongation of many pebbles in the foreset beds, which measurements were plotted and contoured on the Lambert Equal-Area Projection (Fig. 21). A common inclination of pebble flat surfaces, imbrication, on the topset is downwards to the southeast at an angle of around 26$^{\circ}$, forming the primary maximum. There is a secondary maximum of pebble flat surfaces dipping around 23$^{\circ}$ to the northwest. The scatter of some pebble flat surfaces at low inclinations to the horizontal around the periphery of the Lambert Projection represents a so-called "girdle" distribution more or less within the horizontal plane. The scatter of some pebble flat surfaces at high angles through the centre of the projection represents a girdle oriented more or less vertically. "Crossed girdles" have been described in other fields of study (e.g. Crampton, 1958). An examination of the orientation of specific pebble shapes shows that it is the disks which mostly give rise to the primary maximum, and the vertical girdle and secondary maximum.

On the foreset slope there is a very pronounced preferred orientation of pebble flat surfaces dipping at a low angle into the slope.

The horizontal girdle of elongation measurements from the topset contains a pronounced concentration of pebble elongations directed at a low angle to the southwest. On the foreset slope pebble elongations show an equally pronounced concentration dipping at a low angle to the southeast within a more or less horizontal girdle (Fig. 21). An examination of the orientation of specific pebble shapes shows that it is the disks that first take up a particular elongation orientation, but that it is the rods that eventually show the best preferred orientation of elongation. Because of their poor elongation and flattening, the spheroids take up the various preferred orientations least perfectly. A preferred orientation of pebble elongation or flattened surface is least developed on the most distant topset position.

The distribution of the four pebble shapes across the foreset beds is shown in Fig. 22. Spheroids are most abundant in the pebble assemblage on the distant topset position (30%); the proportion within the assemblage declines to a minimum on the upper foreset (13%), below which site the proportion within the assemblage increases once again to a secondary concentration on the bottomset (22%). The percentage of rods in the assemblage is maximal on the distant topset (32%), and the percentage declines steadily across the foreset beds down to the bottomset (16%). The percentage of blades is minimal on the distant topset, and increases steadily across the foreset beds to a



600 PEBBLES FROM ACROSS THE TOPSET.
CONTOURS 1, 4, 6 AND 8% PER 1% AREA.

1000 PEBBLES FROM THE TOPSET.
CONTOURS 1, 4 AND 8% PER 1% AREA.

1000 PEBBLES FROM THE FORESET, TOESET AND
CONTOURS 1, 4 AND 6% PER 1% AREA.

Fig. 21. Lambert stereographic equal-area projection, showing the contoured distribution of pebble elongation and imbrication across the foreset beds on Joe's Trail, presented in the geographical horizontal.

maximum (25%) on the bottomset. The percentage of disks increases from the distant topset (81%) to the upper foreset position where they are very abundant (49%), below which the percentage within the pebble assemblage declines (37% on the bottomset). There is a matching relationship between the proportions of rods and blades, as there is between the proportions of spheroids and disks across the foreset beds.

The mean sphericity and sphericity standard deviation were calculated according to Krumbein and Sloss (1963). The mean sphericity of the pebble assemblage is minimal (the assemblage is least spheroidal in character) on the upper foreset where there are most disks, and where the spread of sphericity values for pebbles in the assemblage (the sphericity standard deviation) is greatest (0.13). Conversely, the mean sphericity is greatest on the distant topset (0.69), and to a lesser extent on the bottomset (0.66) where there are most spheroids in the pebble assemblage. The sphericity standard deviation is least on the bottomset (0.05), implying that there is the smallest range of sphericity values for pebbles in the assemblage here.

## Interpretation

In the laboratory (Johansson, 1963) and in the field (e.g. Krumbein and Sloss, 1963), it has been widely reported that pebbles with flat surfaces dip up-current. It is generally considered that the angle of dip (the imbrication) approximately reflects the velocity of the current. A southeasterly imbrication at an angle of 26° (Fig. 21) on the topset is consistent with

|  | Distant Topset | Middle Topset | Near Topset | Upper Foreset | Lower Foreset | Toeset | Bottomset |
|---|---|---|---|---|---|---|---|
| % Spheroids | 30 | 22 | 19 | 13 | 18 | 20 | 22 |
| % Rods | 32 | 24 | 22 | 18 | 17 | 16 | 16 |
| % Blades | 7 | 18 | 20 | 20 | 25 | 25 | 25 |
| % Disks | 31 | 36 | 39 | 49 | 40 | 39 | 37 |
| Mean Sphericity | 0.69 | 0.68 | 0.67 | 0.53 | 0.60 | 0.63 | 0.66 |
| Sphericity Standard Deviation | 0.10 | 0.11 | 0.12 | 0.13 | 0.12 | 0.11 | 0.05 |

Fig. 22. Distribution of pebble shapes, mean sphericity and sphericity standard deviation for the assemblage at each conglomeratic site sampled across the foreset beds.

the orientation of the foreset beds (Fig. 19) by implying that a strong current from the southeast deposited these beds on Joe's Trail.

Flume work has revealed that flattened pebbles on the topset initially imbricate up-current but, as sand is eroded from beneath the up-current side of the pebble causing it to tilt, the pebble eventually rolls over so that its more flattened surface dips down-current (as in the secondary maximum oriented towards the northwest in Fig. 21). Flume work also shows this to be a temporary position as erosion beneath the up-current side of the rod causes it to continue to roll, until it occupies an orthodox attitude once again, dipping up-current. Three revolutions have been observed as the pebbles migrate against the current, until they become buried in the sand. This process would explain the vertical girdle distribution in Fig. 21.

In laboratory work Jopling (1965) observed a slight decrease in sand grain size across the topset towards the crest of the foreset slope. The pronounced decrease in sand grain and pebble size across the topset towards the crest of the foreset slope on Joe's Trail arose because the larger grains and pebbles were preferentially worked out of the sediment, presumably according to Bagnold's (1954) Theory of Dispersive Pressures as the current agitated the topset sediment, to make it a surface of erosion. These larger sand grains and pebbles were carried over the crest to be deposited on the upper foreset (Fig. 20). Concomittant with this process, the intensity of sorting improved across the topset (Fig. 20), achieving its maximum with the accumulation of large sand grains on the upper foreset. Also, there was an increase in positive skewing (Fig. 20), that is there was an increasing spread of the particle size range towards smaller particles, as the preferential winnowing out of larger grains from the topset sediment proceeded up to a limiting size determined by the current velocity. This material accumulated on the upper foreset where it was more positively skewed than anywhere else on the foreset beds.

Both Jopling (1965) and Johansson (1963) reported a flume accumulation of larger sand grains or pebbles on the upper foreset slope, as on the upper foreset of Joe's Trail (Fig. 20), as long as the angle of the slope did not exceed 20°. When the angle of slope exceeded this value during flume work, some sliding under gravity occurred down the foreset slope, and when the angle of slope was about 30° all of the coarse material originally on the upper foreset slumped downslope to accumulate on the toeset. Since coarse material had accumulated at the top and bottom (toeset) of the foreset slope on Joe's Trail (Fig. 20), the original angle of slope was probably greater than it is now (11°), possibly greater than 20°, though less than 30° by comparison with flume work. This would imply that compaction of the sediments on Joe's Trail has occurred since the sediments were deposited about 60 million years ago, compaction probably within the more compressible sandstones. However, any such compaction was **inadequate** to harden these geologically young sediments which are relatively soft to this day, except where local cementation has occurred.

The preferred orientation of pebble elongation transverse to the direction of current flow across the topset on Joe's Trail (Fig. 21), particularly for rods, is consistent with laboratory flume work by Johansson (1963). He also noticed that smaller disks first adopted a new orientation because saltation lifted them above bed friction. Johansson found that gravity sliding down the foreset slope produced a reorientation of pebble elongation such that there was a preferred orientation downslope. A downslope preferred orientation of pebble elongation on Joe's Trail (Fig. 21) suggests that some sliding down the foreset slope under gravity did occur, to produce the secondary accumulation of coarse grains and pebbles on the toeset. The convolutions between sand and pebble strata on the foreset beds (Fig. 19) could only have been produced by the sliding of successive, irregular tongues of different sediments.

Compared with a disk of similar volume, a spheroid has a distinctly smaller surface area. Therefore, the current will move spheroids least effectively and disks most effectively (by saltation; Johansson, 1963) across the topset, producing a decreasing proportion of spheroids in the pebble assemblage (Fig. 22), and an increasing proportion of disks towards the crest of the foreset slope. Because of their relatively great surface area, frictional forces tend to produce stacking of the flattened disks on the foreset slope (Johansson, 1963), where they become imbricated into the slope. Therefore, the sphericity standard deviation is greatest on the foreset slope (Fig. 22). Spheroids do not stack so readily but, because of their relatively small surface area, they tend to roll down the slope and accumulate at the base (Fig. 22). The smallest sphericity standard deviation across the foreset beds is associated with the bottomset, which suggests that in addition to many spheroids in the pebble assemblage at this position, the rods, blades and disks present must also be more spheroidal in character than elsewhere on the foreset beds.

By analogy with Jopling's (1965) flume work, the angular contact between the conglomerate with the sandy shale band at the toeset (Fig. 19)implies erosion of the toeset by a back-current created as a powerful main current swept over the crest of the foreset slope. In Jopling's (1965) flume work, beyond the influence of any back-current, only the finest material was deposited on the bottomset. The smallest pebbles have accumulated on the bottomset of Joe's Trail (Fig. 20). The deposition of comparable material occurs only on the most distant topset position, which may be the transition to a bottomset of other foreset beds. The described preferred orientation characteristic of a topset is least well shown at this distant location.

## Surficial Deposits on Burnaby and Belcarra Mountains

A mantle of till (or boulder clay) covers much of Burnaby Mountain and the footslopes of Belcarra Mountain, thin at higher elevations and thick at lower elevations. A most characteristic feature of the till on Burnaby Mountain is the erratics, large crystalline boulders derived from igneous rocks of the Coast

Range, which extends into the study-area as Belcarra Mountain, opposite sedimentary Burnaby Mountain. Presumably, these erratics were carried onto Burnaby Mountain by the most recent ice sheet advance, the Wisconsin which, at one time, must have completely overtopped the mountain.

Near the land surface the till is often compacted and hard, associated with a medium platy structure. Many pedologists in Canada think that this compaction and associated structure arose during the last ice sheet advance because of the immense weight of ice pressing on a till mantle deposited by melting of the previous ice sheet across the area. Others (e.g. Fitzpatrick, 1956; Crampton, 1965) believe that sometimes this hardened, often brittle subsoil could have arisen from a confining pressure exerted by freezing within the subsoil during the cold, dry conditions which prevailed after the ice sheets had melted back, and the land was no longer protected from permafrost development by an ice cover. If this hard surficial layer is apparently uncemented and slakes when wetted it is called a fragipan, but if apparently cemented it is called a Duric horizon (McKeague and Sprout, 1975). This layer often impedes the downward percolation of water to produce waterlogging at the surface (see Fera Gleysol, p. 75B).

Outwash streams pouring from the thawing periphery of the melting ice sheet laid coarse-textured glacio-fluvial deposits on lower slopes of Burnaby Mountain (allowing the working of gravel deposits on the southeast and northern footslopes, Fig. 16), and of Belcarra Mountain (Fig. 25). Crossbedding (attentuated foreset beds) (Fig. 23) and interlayered sand

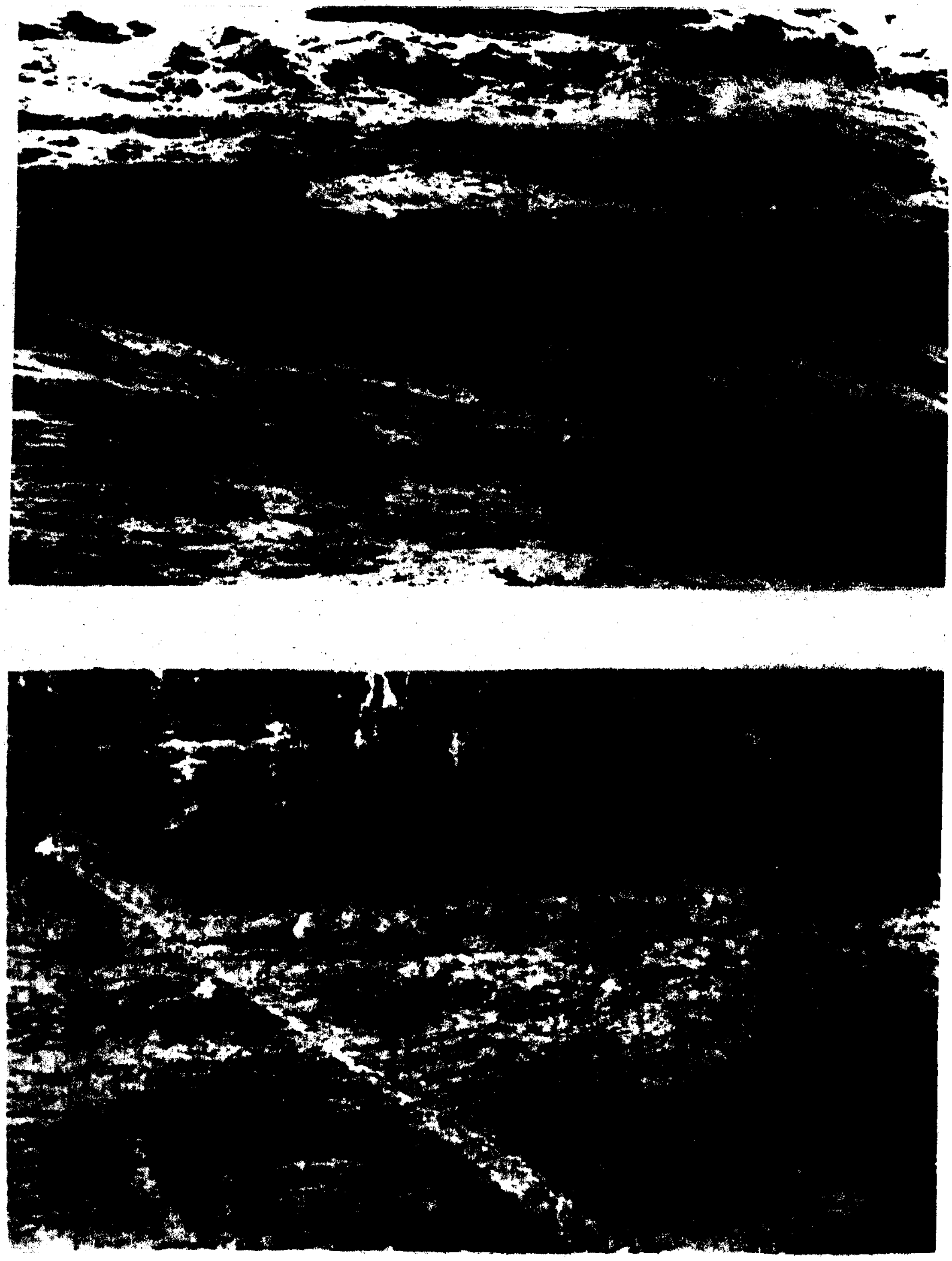


Fig. 23. (Upper) cross-bedded, glacio-fluvial sands on southeast footslopes of Burnaby Mountain. (Lower) varved, glacio-lacustrine silts lower on southeast footslopes.

and pebble beds can be seen in these deposits, very similar in appearance to those of the Eocene beds forming the core of Burnaby Mountain. However, the glacio-fluvial deposits are very much younger (about 10,000 years old) compared with the Eocene rocks (about 60 million years old), and although the Eocene rocks are geologically young, they are marginally, but noticeably harder than the glacio-fluvial deposits because of subsequent burial and compaction. The glacio-fluvial deposits are completely loose and unconsolidated.

During the melt-back of ice sheets, temporary glacial lakes were often impounded between the ice margin and mountainsides. In these lakes varves or lacustrine deposits were laid down. On the southeast footslopes of Burnaby Mountain the thinly layered rhythmites alternate from thicker, lighter laminae of fine sand representing deposition from swollen outwash rivers, to thinner, darker laminae of silt representing periods of diminished river flow (Fulton, 1965). When the ice margin melted back still further and allowed the lake to drain away, the exposed varves periodically dried and cracked within a surficial hexagonal pattern extending down into the sediment as irregular columns. Later rains carried surface material into these cracks, filling them with a deposit having a grayer, finer texture than the surrounding material (Fig. 23). Similar varved deposits occur in the valleylands around Belcarra Mountain.

At the foot of the cliffs below the Centennial Pavilion there is a hummocky land mass (Fig. 1 and 3). This landmass consists of blocks of sedimentary rock brought down from the north-facing slope by rotational slides at some time in the past (Armstrong, 1956). The originally, more or less horizontal strata are now inclined at high angles, sometimes vertically, and are locally shattered into a chaotic assemblage of blocks which have slumped downslope to form pressure ridges. Tall, mature timber now on the landmass indicates that it has stabilized. Locally, the movement must have been close to a flow, similar to that reported in relatively unconsolidated Tertiary and younger rocks elsewhere (Piteau, 1977). A transverse profile northwest - southeast through Burnaby Mountain helps summarize the hardrock and surficial geology (Fig. 24).

## Geology of Belcarra Mountain

Hornblende diorite, hornblende being the dominant mafic mineral in the rock, gives rise to the highland of Belcarra Park (Fig. 25). Varietal changes occur in the rock forming this local batholith, and hornblende-biotite granodiorite occurs southwest of Sasamat Lake. Metamorphosed sediments of the Twin Island Group (probably of Mesozoic age), granulites, amphibolites, micaceous quartzites, phyllites, gneisses, schists, minor conglomerates and lime-silicate rocks crop out to the west of Bedwell Bay (Fig. 25). In contrast to the coarsely crystalline diorites forming the core of Belcarra Mountain, except for the conglomerates, most of the metamorphosed sediments are finely crystalline. They are tightly folded, which makes the delineation of faults difficult. The local presence

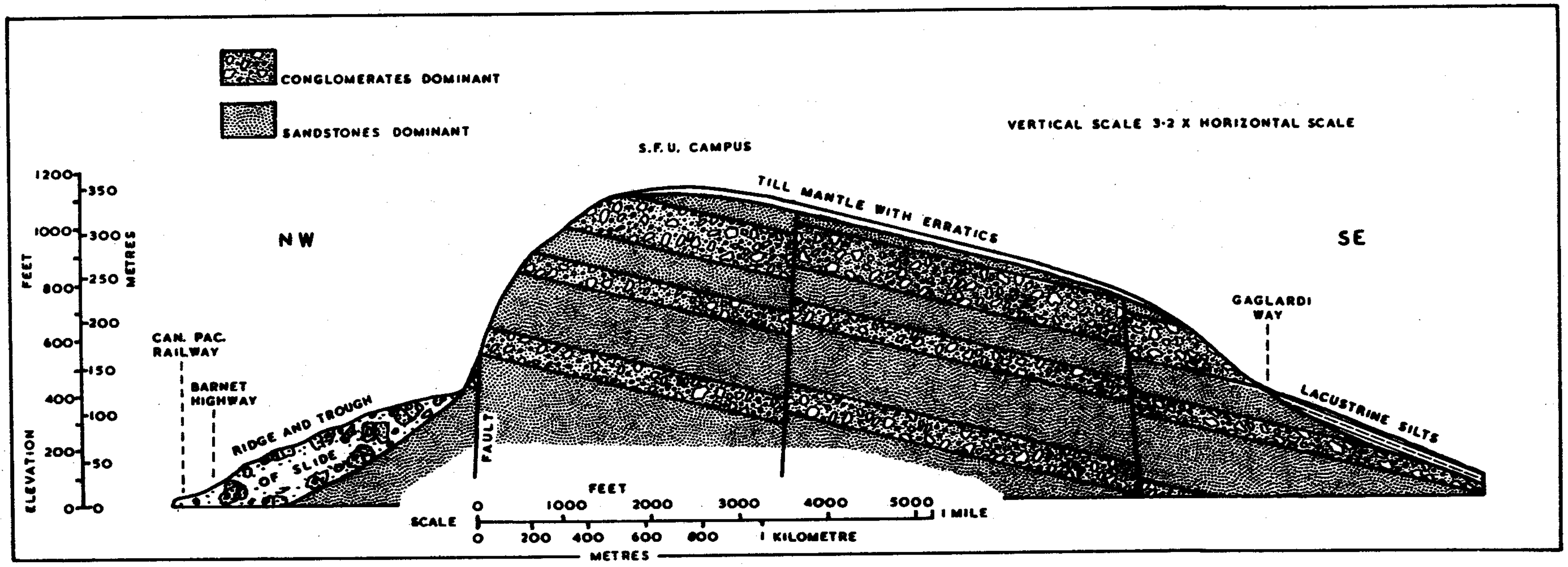


Fig. 24. Transverse profile northwest - southeast through Burnaby Mountain.

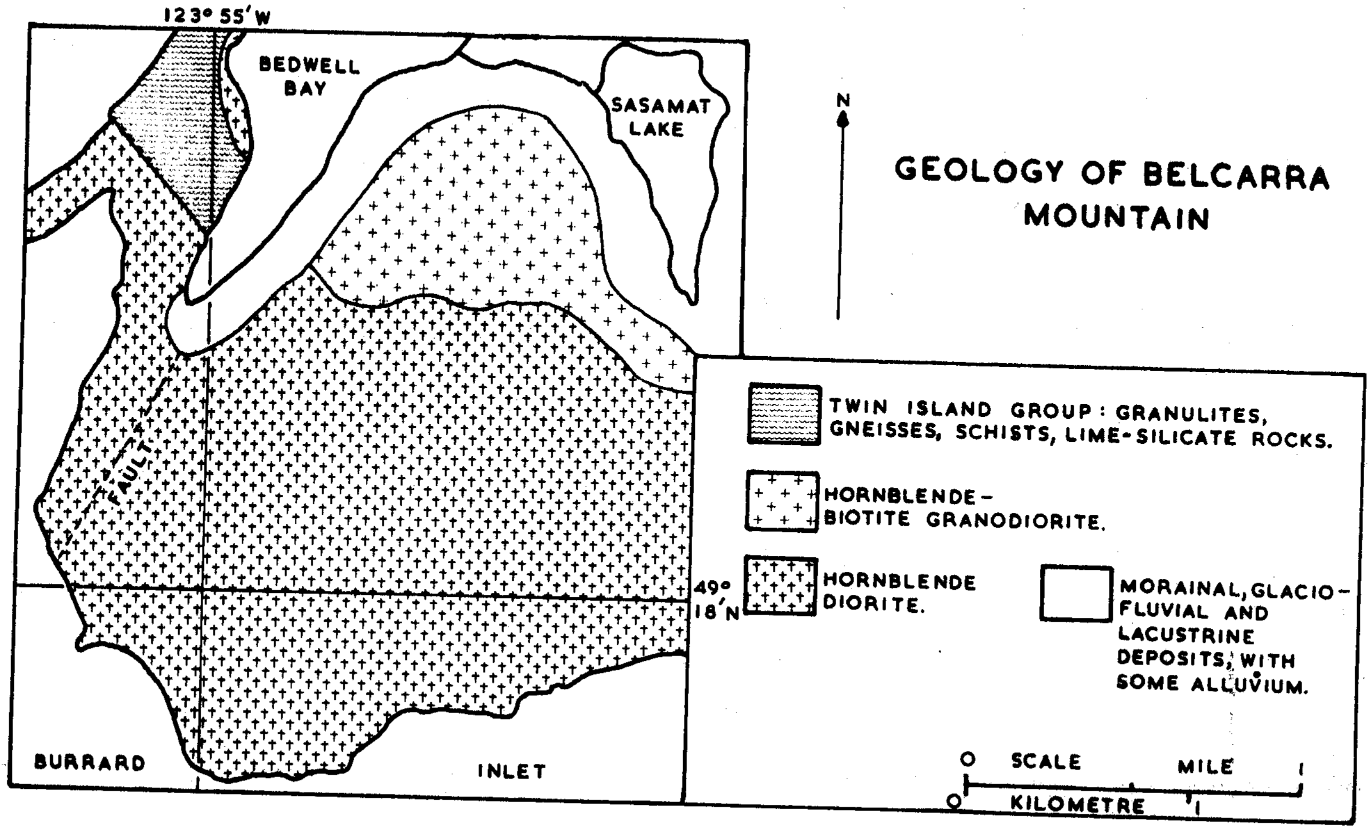


Fig. 25. Geology of Belcarra Mountain.

of calcareous-siliceous rocks can hold ore bodies (Roddick, 1965), and a small mining operation once existed on the nearby Twin Islands.

## Summary and some Interactions

Sedimentary, Eocene sandstones and conglomerates, dipping at a low angle to the south, form the prominent north-facing escarpment of Burnaby Mountain. These sediments were laid down on the north side of the Fraser River delta by currents coming from the southeast. Foreset beds developed seaward as locally sediment slumped over the advancing slope. The strata are today only partially consolidated, but irregularly cemented conglomerates form the plateau on which is situated Simon Fraser University. The mountain has collapsed either side of a sequence of faults, downthrowing to the east and west.

Outwash deposits and varves occur locally on the footslopes. A mantle of till with erratics covers Burnaby Mountain. These erratics, and many pebbles in the underlying conglomerates, are coarsely crystalline rocks similar to those of the Coast Range, represented in the study-area by Belcarra Mountain on the other side of Burrard Inlet. Belcarra Mountain is formed principally of diorites, although metamorphic rocks crop out in the northwest.

## Analysis of Synergism and the Influence of Underlying Strata on Selected Vegetation

### Introduction

Synergism is a concept that describes the interaction of factors with a combined effect much greater than if each factor was acting separately (Crampton*). Just as factors can combine to enhance the total effect, it follows that they can also combine to reduce the total effect below that produced by the factors acting separately, a process called antagonism. Synergism and antagonism have been invoked chiefly in the fields of insecticides (Wilkinson, 1976), pharmacology (Goodman and Gilman, 1970) and ecology (e.g. Kellman, 1975). The more

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* Crampton, C.B. 1979. Soil landscape studies in the Lower Fraser River Valley. Discussion Paper No. 6, Dept. of Geography, Simon Fraser University.

important synergistic and antagonistic interactions between parent material factors over their full range of effects on selected vegetation in the study-area have been examined.

## Method

From 1974 until 1978 systematic surveys of soil and site characteristics were undertaken across Burnaby and Belcarra Mountains within the framework of a 400-metre grid established across the area. At least eight percentage cover estimates were made of selected plant species (and forest cover), at different undisturbed places by different teams (some students of Geography 317), within each of the 521 grid squares, and averaged to give one value of the dependent variable for each grid square. This averaging was an attempt to offset the very approximate nature of cover estimates (Randall, 1978)

Factors used as the independent variables in the analysis were each divided into three classes; parent material, e.g. granitic (on Belcarra Mountain), sedimentary (on Burnaby Mountain), and till; elevation; aspect; slope; internal profile drainage (as distinct from the site drainage); texture; and the pH of the A, B and C horizons. Estimates such as drainage and texture were averaged by grid square as for percentage cover estimates.

A 20% random sample was removed from the total population and was not used in the analysis, but constituted data for checking the effectiveness of the analysis. Thus, information from 417 localities was used for the analysis and 104 localities for the check. It was possible to create 36 different two-variable combinations from the nine single independent variables of the input. The analytical population was used to design a model, identifying and ranking the most important two-variable, synergistically interacting systems influencing the vegetation (Crampton, 1980).

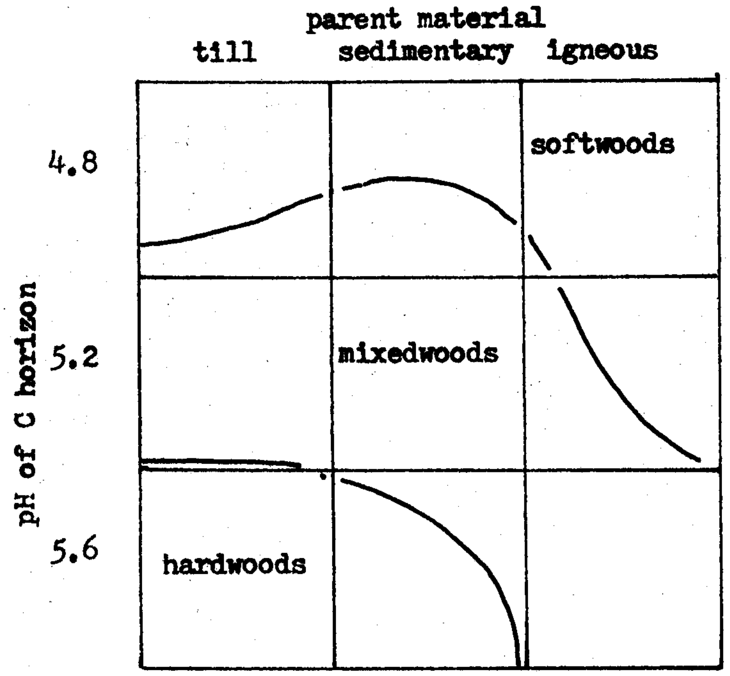
For analyzing synergism all the independent variables were classified into the same arbitrary number of three categories. The categorization of synergistically interacting variables was accomplished in the following manner. For each possible combination of two independent variables a two-dimensional, 3 x 3 matrix was constructed to embrace all possible combinations of categories for these two variables. Within this matrix the dependent variable for a grid square was recorded in the appropriate cell representing the particular combination of categories associated with the site. After all values for the dependent variable had been included within the matrix, the mean for each cell was calculated.

This matrix is intended as a mathematical analog of an experienced person's judgement when attempting to evaluate the synergistic interactions which permeate the natural world (Crampton, 1979). Field surveyors regularly perceive two-variable synergistic interactions within the landscape they are examining, although there is a limit to the amount of data that can be consciously comprehended.

Cell means were then ranked and divided into three classes, each class containing those particular combinations of categories for the two independent variables involved in one interaction which could be equated with that class of the dependent variable. The minimum standard deviation about the ranked category means was used to identify the most effective synergistic systems, those systems for which the categories are the most closely clustered about whole numbers.

## Results

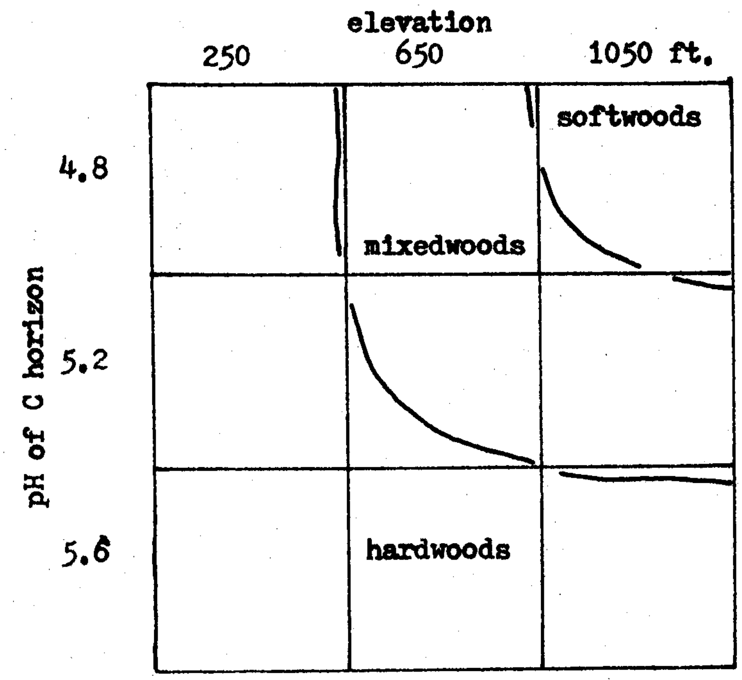
The model set up by the analysis was checked against the independent sample, and the $r^2$-value used as a measure of the validity of the two-variable surrogates (each acting for two synergistically interacting independent variables), influencing forest cover type (and the distribution of red elderberry) on Burnaby and Belcarra Mountains. The interaction between parent material and the pH of the C horizon contributed most to the analysis of forest cover type, and it is illustrated by contouring cell means of the matrix within an interaction diagram (Fig. 26). The parent material and pH value of the C horizon associated with a particular site can be traced on the interaction diagram, and the forest cover to be expected at that site extrapolated. Checking the analytical model for forest cover yielded an $r^2$ value of 0.60, and for red edlerberry distribution 0.58. These check $r^2$ values for interacting paired variables were greater than those for single variables used as input into regression (for forest cover $r^2 = 0.41$; for red elderberry $r^2 = 0.37$). A comparison of these $r^2$ values demonstrated that the combined effect of two interacting variables was greater than if each variable was acting separately, confirming the involvement of synergism (or its counterpart, antagonism) within the interaction.



First

**Softwoods are mostly associated with relatively low pH values in the C horizon, especially over till and sedimentary rocks. Hardwoods are associated with relatively high pH values in the C horizon over till and sedimentary rocks.**

$r^2$ check = 0.60



Second

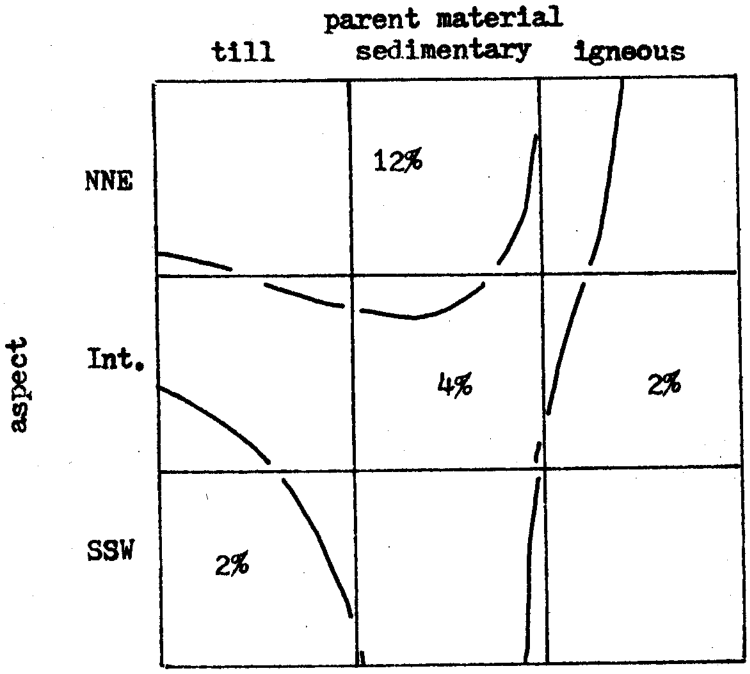
**Softwoods are associated with relatively acid C horizons at high elevations. Hardwoods and mixedwoods show a somewhat diffuse distribution.**

Fig. 26. Interaction diagrams for the two most important interactions influencing forest cover type.

The interaction between elevation and the pH of the C horizon was the second most important combination of variables influencing the forest cover type (Fig. 26). Other interactions involving, in order of importance, aspect, drainage and texture made very small contributions to the $r^2$ of the check, and so attention has been concentrated upon the first two interactions.

The pH of the C horizon is influenced by the nature of the underlying rock, the parent material. On the coarsely crystalline igneous rocks of Belcarra Mountain the C horizon is considerably more acid than the C horizon on sedimentary rocks of Burnaby Mountain. There is much collinearity between C horizon acidity and parent material, emphasizing the absence of true independence between the so-called independent variables normally expected for regression analysis when involving environmental factors.

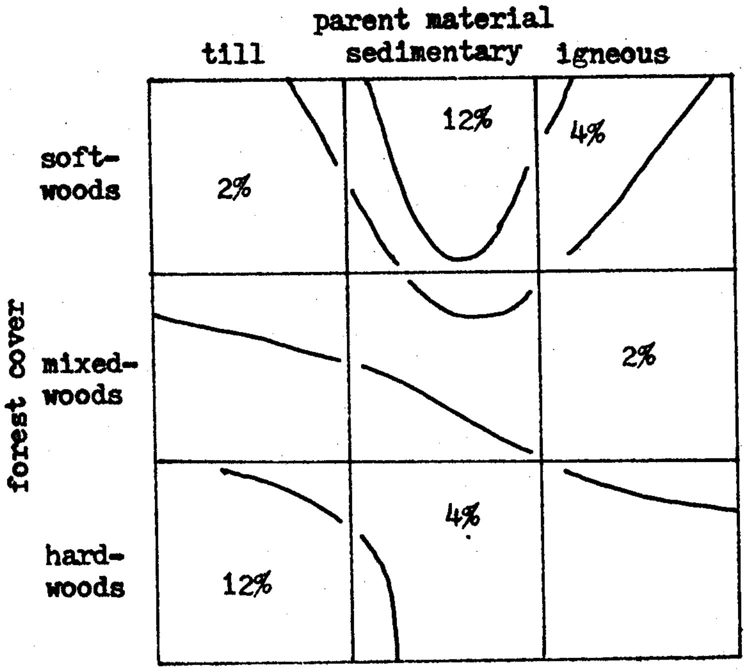
In the study-area softwoods are mostly associated with relatively low pH values in the C horizon, especially for sites over the sedimentary rocks of Burnaby Mountain and over till on lower slopes of both Belcarra and Burnaby Mountains (Fig. 26). On crystalline igneous rocks forming higher land of Belcarra Mountain softwoods appear to dominate the forest cover through a wider range of pH values in the C horizon, although still somewhat acid. Hardwoods are mostly associated with relatively high pH values in the C horizon, especially on the sedimentary rocks of Burnaby Mountain, but also over till on the lower slopes of Belcarra and Burnaby Mountains. The second most important interaction confirms the preferred associated of softwoods with low pH values in the C horizon, but in this case



First

**Maximum cover of elderberry on till and sedimentary rocks with NNE aspect. Minimum cover over igneous rocks, whatever aspect; also on till with SSW aspect.**

**$r^2$ check = 0.58**



Second

**Bimodal distribution; maximum cover on sedimentary rocks under softwoods, and on till under hardwoods.**

Fig. 27. Interaction diagrams for the two most important interactions influencing the distrbution of red elderberry.

at high elevations. On these heights hardwoods dominate the forest cover where the pH values in the C horizon are closer to neutrality. Hardwoods tend to grow on acid sites only at low elevations.

The most important interaction influencing the distribution of red elderberry is between parent material and aspect. The maximum cover of elderberry is associated with the north-facing escarpment of Burnaby Mountain formed of sedimentary rocks. Elderberry also occurs extensively on lower slope tills. This is the synergistic effect between parent material and aspect. The minimum cover of elderberry occurs over igneous rocks of Belcarra Mountain, whatever aspect, and on lower slope tills facing near south, the antagonistic effect. The second most important interaction influencing the distribution of red elderberry is between parent material (again, emphasizing its importance within synergistic interactions) and forest cover type (Fig. 27). The distribution is bimodal, a type sometimes observed elsewhere (Kellman, 1975). The maximum cover of red elderberry is associated with two different environments, one below softwoods over sedimentary rocks of Burnaby Mountain and the other below hardwoods on lower slope tills. On these tills the minimum cover of red elderberry occurs below softwoods.

# SOILS

## Distribution

The parent material to the soils on the jointed, crystalline diorites of Belcarra Mountain is generally sandy and acid, whereas the parent material to the soils on the sedimentary Burnaby Mountain is generally loamy and near neutral. On both mountains there is a general catenary sequence from better drained soils on the mountain top down to less well drained soils on the footslopes (Fig. 28). Thus, on Belcarra Mountain the soils range from very well drained, sandy Orthic Humo-Ferric Podzols (Clayton et el., 1977) at higher elevations to imperfectly drained, loamy Gleyed Eutric Brunisols at lower elevations (Fig. 29), whereas on Burnaby Mountain they range from well drained Eluviated Dystric Brunisols, slightly podzolized soils, on top, to clayey Fera and Rego Gleysols (Fig. 28) on flat or gently inclined lands at the base of the slopes.

Podzols occur very locally on Burnaby Mountain, but are much more extensive on Belcarra Mountain, sometimes possessing a thin iron pan or Bhfc horizon within Placic Ferro-Humic Podzols. Well drained Orthic Dystric Brunisols, in which there is no leached eluvial horizon, occur on both mountains, but are more extensive on Belcarra Mountain where the parent material is more acid. Orthic Eutric Brunisols, characterized by near-neutral parent material, are far more extensive on Burnaby Mountain. Locally, both of these Brunisolic soils possess very thick organic horizons, when they are called Orthic Sombric or Melanic Brunisols, respectively. Some

| Orthic Humo-Ferric Podzol | Orthic Dystric Brunisol | Orthic Eutric Brunisol | Fera Gleysol |
|---|---|---|---|
| 0 -13 cm. L/F/H<br>Forest litter,over brown fibrous,over black mor, with abundant charcoal. pH 4.3; narrow boundary. | 0 -10 cm. L/F/H<br>Loose forest litter,over brown fibrous,over black humified organic matter. pH 4.7; narrow boundary. | 0 -10 cm. L/F/H<br>Thick forest litter,over thin brown fibrous,over black humified org. mat. pH 5.0;merging boundary. | 0 -18 cm. 0<br>Matted forest litter, over thick black organic matter. pH 4.4; merging boundary. |
| 13-23 cm. Ae<br>Dark gray (5YR 4/1), loose loamy sand with few roots. pH 4.5;narrow undulating boundary. | 10-18 cm. Ah<br>Dark brown (7.5YR 3/2), friable,fine granular sandy loam with roots. pH 5.0;merging boundary. | 10-18 cm. Ah<br>Brown (7.5YR 4/4), friable,fine granular loam with many roots. pH 5.2;merging boundary. | 18-26 cm. Ah<br>Brown (10YR 4/3), slightly sticky,fine prismatic sandy clay loam with many roots. pH 4.8; narrow boundary. |
| 32-51 cm. Bfh<br>Yellowish red (5YR 4/6), friable,medium blocky sandy loam with very few roots. pH 5.0; merging boundary. | 18-43 cm. Bm<br>Reddish brown (5YR 4/4), medium blocky sandy loam with some roots. pH 5.2; merging boundary. | 18-43 cm. Bm<br>Dark yellowish brown (10YR 4/4),friable medium granular loam with many roots. pH 5.8; merging boundary. | 26-51 cm. Bgf<br>Light gray (2.5YR 7/2), with many,medium size, prominent, strong brown (7.5YR 5/8) mottles, plastic, medium platy clay with a few roots along structure cracks. pH 4.8; narrow boundary. |
| 51+ C<br>Yellowish brown (10YR 5/6),friable, medium blocky sandy loam with no roots. pH 5.4. | 43+ C<br>Yellowish brown (10YR 5/6),friable, medium blocky sandy loam with few roots. pH 5.5. | 43+ C<br>Dark yellowish brown (10YR 4/4),friable, medium blocky sandy loam with many roots. pH 6.0. | 51+ Cgxj<br>Light gray (2.5YR 7/2), slightly sticky,medium platy clay with no roots. pH 5.8. |

Munsell soil colour notation used. Horizon symbolization according to Clayton et al. (1977).

Profile descriptions of four selected soils, varying from an excessively well drained, acid Podzol, through well drained, increasingly more loamy, decreasingly acid, better structured, more deeply rooted Orthic Dystric and Orthic Eutric Brunisols, to a poorly drained, moderately acid, clayey (impeding percolation of water), sticky and plastic, platy-structured, ochreously mottled Fera Gleysol, on Burnaby and Belcarra Mountains. Examples of an Eluviated Dystric Brunisol and Gleyed Eutric Brunisol are given on p. 116.

examples of different profiles are shown.

On mid-slope benches of Burnaby Mountain, normally floored by shale outcrops, there are imperfectly drained Gleyed Eutric Brunisols. Faint mottling in the Bmg horizon of these soils is indicative of imperfect drainage, aeration of the subsoil being a process that is discontinuous in both time and space. These soils are extensive on till-covered footslopes of Burnaby Mountain, and occur in local, moist pockets on till-covered footslopes of Belcarra Mountain. On the lower footslopes of Burnaby Mountain there are Fera Gleysols (with ochreously mottled Bgf horizons produced where air can periodically penetrate the subsoil and oxidize the iron) and Rego Gleysols which are thoroughly waterlogged (Fig. 28).

Lithic Regosols, shallow, immature soils are extensive on the steep, north-facing escarpment of Burnaby Mountain where downslope movement inhibits any tendency for profile layering to develop. These soils, with a thicker organic horizon, and sometimes called Folisols, are extensive on the hummocky rock slopes characteristic of terrain like Belcarra Mountain (Fig. 30). Soil profile development is slow on hard, igneous rocks. Clear-felling over most of Belcarra Mountain between 1905 and 1920 exposed these Folisols to erosion and, where this has occurred, subsequent soil development and revegetation has been very slow. A Folisol originates mostly from the forest canopy, and the Rhacomitrium mosses which pioneer a site denuded of soil contribute new soil

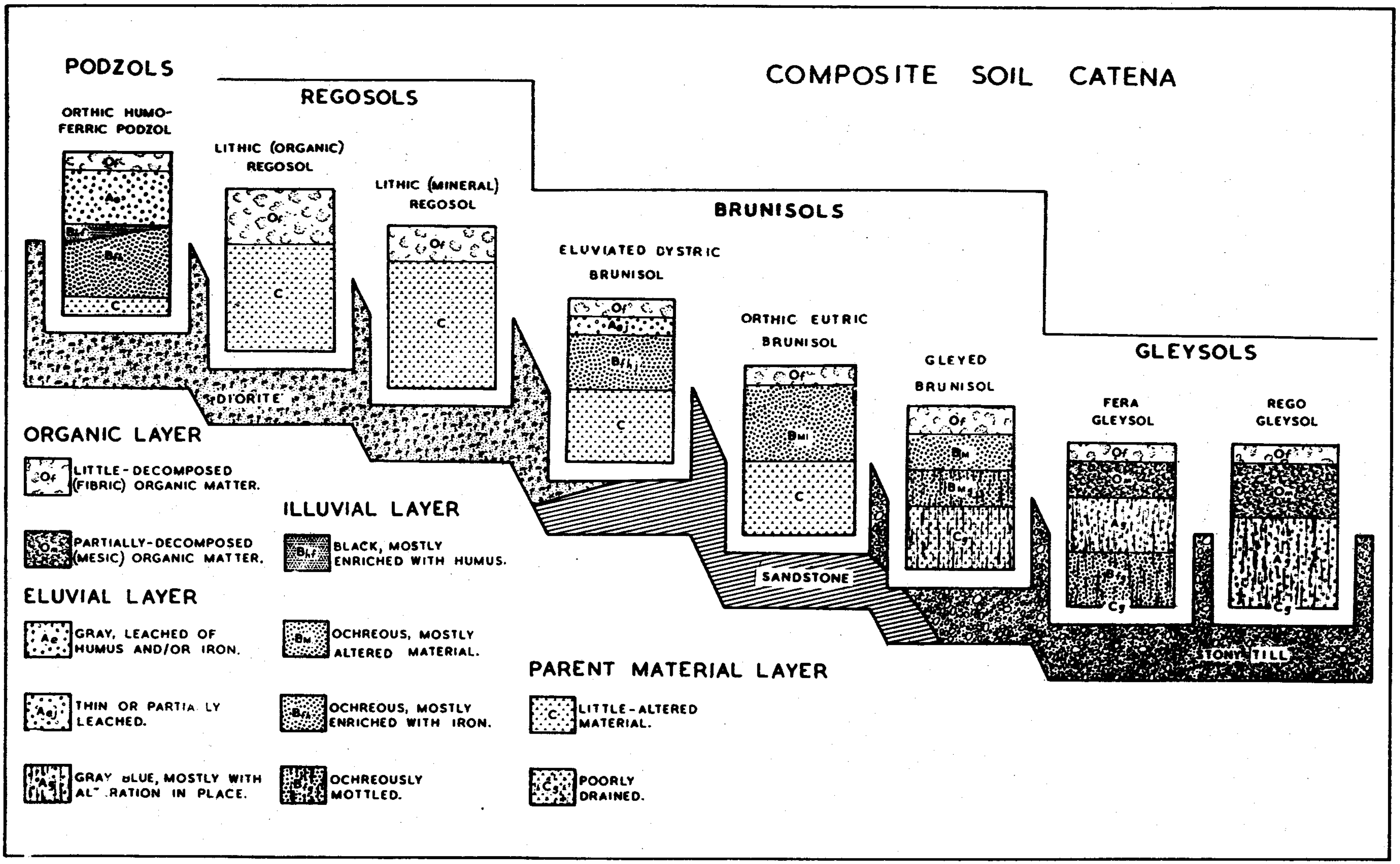


Fig. 28. Composite soil catena on Belcarra (to the left) and Burnaby (to the right) Mountains, illustrating typical soil profile layering.

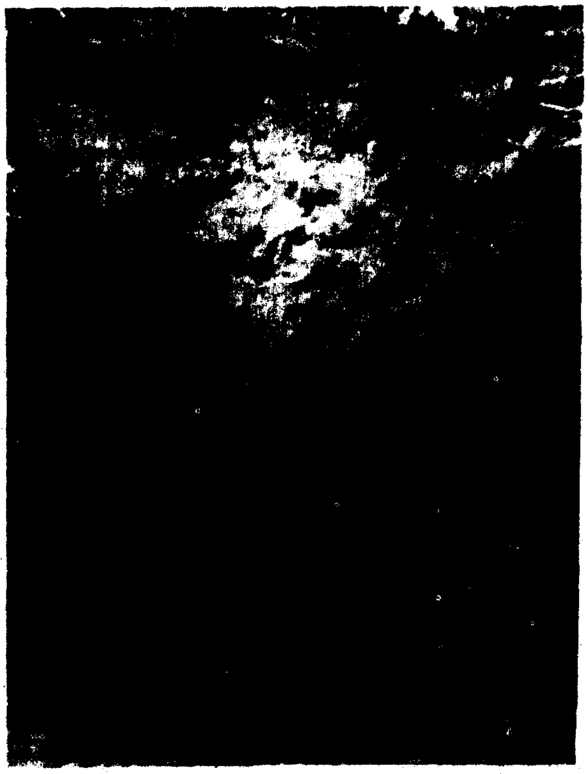


Fig. 29B. Orthic Humo-Ferric Podzol on Belcarra Mountain.

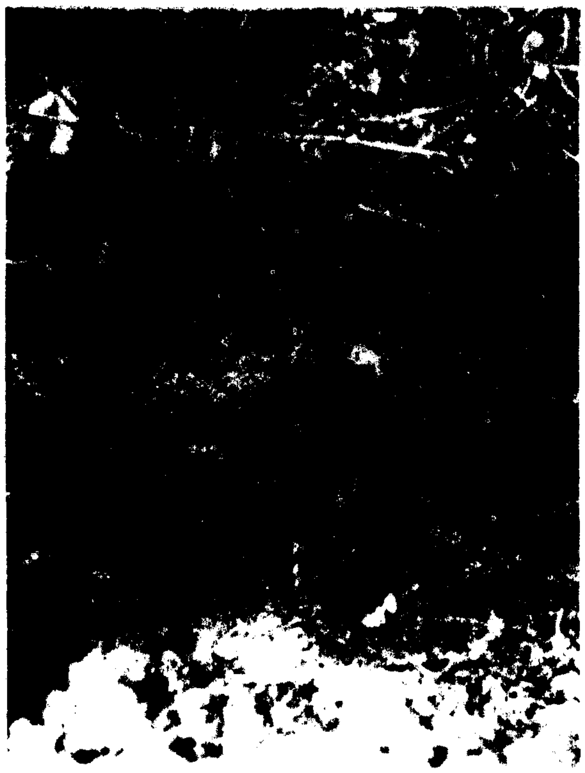


Fig. 29B. Gleyed Eutric Brunisol on Burnaby Mountain.

material extremely slowly (Fig. 30). An organic horizon over grus (weathered, coarse sandy crystalline rock) may be found under some moss polsters 50 years after clear-felling. Salal and red huckleberry subsequently take hold, while stunted trees may take 100 years to become established.

## Modeling the Distribution of Soil Drainage on Burnaby Mountain

### Introduction

Hills and Boissoneau (1960) and Crampton (1970) have observed a rise in the water table to wet the soils after clear-felling of certain species. Conversely, planting particular species appears to extract more water than, for example, grassland (Rutter and Fourt, 1965), producing a lowering of the water table and the evolution of less well drained soils into better drained soils (Hinson *et al.*, 1967; Crampton, 1970). Voronkov and Sokolova (1951) and Johnston and Maginnis (1960) have described reduced water flows from forested catchments, compared with deforested catchments of similar physiography and size. Just as the soil as part of site conditions influences tree growth, so forest growth influences the soil drainage.

### Analysis of Synergism

During 1976 a systematic survey had been undertaken within the 400-metre grid established across the mountain, recording soil and site characteristics such as internal profile drainage (which became the dependent variable), texture, slope, elevation, aspect, forest cover type, measurements such

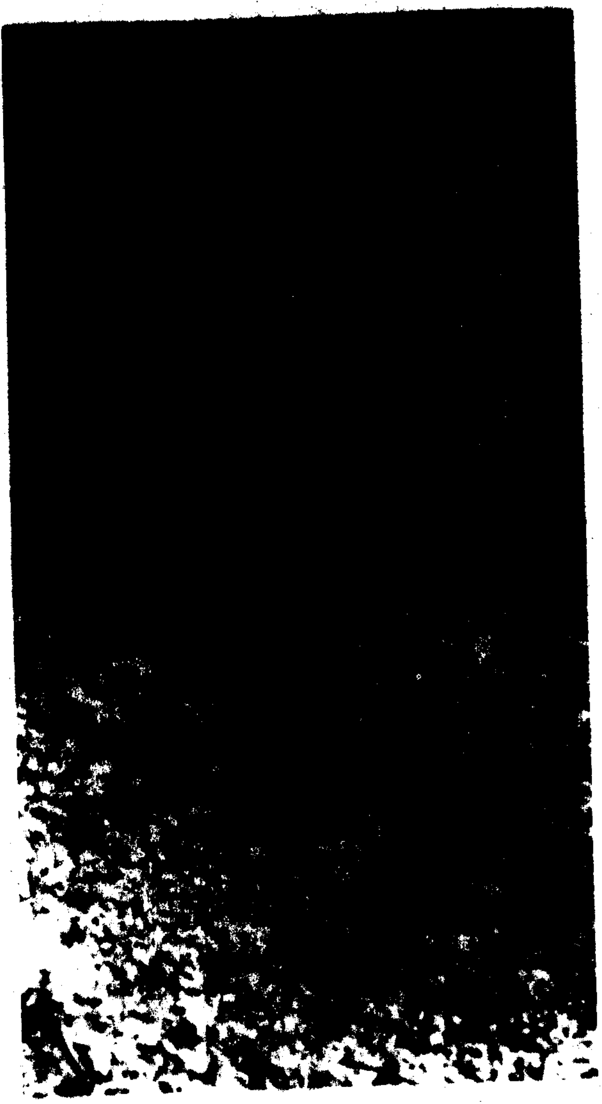


Fig. 30. (Above) logged site 50 years after clear-felling, on Belcarra Mountain with Rhacomitrium and other mosses as pioneer species. (Below) immature, very shallow Folisol (see cent for scale) beneath a Rhacomitrium canescens polster.

measurements such as the tree height, diameter and age of selected trees and the basal area per acre from which was calculated the standing volume per unit area. These latter factors became the six independent variables for the analysis.

As with analysis of two-variable synergistic interactions (p. ), a 20% random samples was extracted from the original population of 600 and used to check the effectiveness of the analysis. Thus, there were 480 sites for the analysis and 120 for the check.

Instead of the input into the analysis being two-variable interactions, all six were considered as one interacting surrogate which became the single independent variable. This procedure takes full advantage of the multiplicative effects of synergistically interacting variables rather than the more usually analyzed additive effects.

The dependent variable, drainage, was divided on a numerical scale of 1 (excessively well drained) to 8 (very poorly drained). All the independent variables were classified into the same arbitrary number of six categories. If there is to be any precision in the definition of a surrogate acting for several individual variables, each surrogate class should consist of a different combination of variable classes. For two variables interacting together, each classified into six classes, there would be 36 possible classes for the surrogate; if the surrogate represented three variables there would be 216 possible classes, for four variables, 1296 possible classes, and so on. Depending, in part, on the population, analysis of such expanding surrogates could eventually exceed the capacity of a computer. Such a great number of classes for a particular surrogate must be reclassified into the arbitrary six classes if the analysis is to be manageable.

The same procedure was adopted as with two-variable combinations for constructing an analytical model matrix. For an interaction embracing all six independent variables a six dimensional, 6 x 6 x 6 x 6 x 6 x 6 matrix was constructed to include all possible combinations of categories for these six variables. Within this matrix the observed drainage for each site was recorded in the appropriate cell representing the particular combination of categories associated with the site.

Although almost every site was unique when defined in terms of six factors, there was a clustering of observations about cells representing particular category combinations, suggesting a naturally occurring collinearity between variables within the matrix as an unavoidable corollary of the preferred relationship between dependent and independent variables being sought in the analysis. This preferred association of particular category combinations can, in simple cases, be observed in the field. For example, low-lying, flat, relatively clayey soils are often poorly drained, whereas on high slopes where the soils are relatively sandy there is generally good drainage.

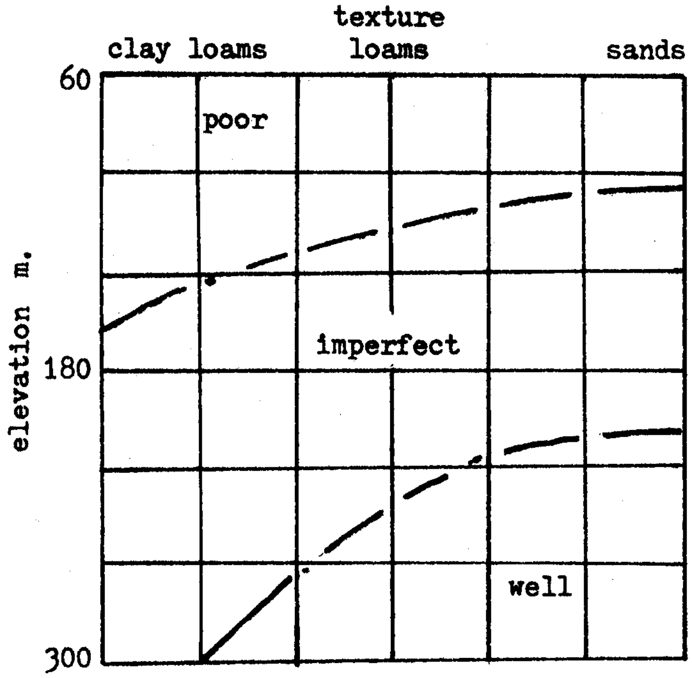
In each cell of the matrix the values for the dependent variable were averaged. Cell means were ranked and divided into six classes of internal profile drainage, each class containing those specific combinations of categories for the six independent variables involved in the interaction which could be equated with that class of the dependent variable. If the standard deviations about the ranked category means for each variable involved in the synergistic interaction are related, then the relative importance of the individual variables within the interaction can be assessed.

Because almost every site is unique, to predict drainage from the analysis for another site (e.g. in the check sample), the mean drainage of closely similar analytical sites (as determined by the least sum of differences between variable categories) was used. Sites in the check sample have played no part in the analysis, giving the check its essential independent character. Using these check sites, the actual drainage observed was regressed with the drainage predicted by the most similar analytical sites, yielding an $r^2$ of 0.65. This value confirms the usefulness of an analysis based on one six-variable interaction. Since the $r^2$ for an orthodox multiple regression of six separate independent variables was miserably small. The final output consisted of the prediction of drainage for a selected range of interacting variable combinations, using the same method as for the check.

## Results

As part of a complex, six-variable interaction, most well drained soils are sandy and occur on high, steeper slopes often facing north to northeast, whereas most imperfectly and poorly drained soils are loams or clay loams, respectively, and generally occur on the lower, more gently inclined footslopes, often the southwest-facing dipslope of the mountain. These results are generally consistent with field survey experience, although more precisely defined in terms of site characteristics. The forest cover also influences internal soil drainage, well drained soils tending to occur beneath softwoods and poorly drained soils below hardwoods. These relationships of drainage with forest cover were only vaguely sensed during the field survey, presumably because they were not simple, but were complex interactions with other factors. A most interesting result is that soil drainage is strongly influenced by the volume of timber per unit area, but only in interaction with the other site factors. The better drained soils tend to occur beneath large stands of timber, whereas the less well drained woils tend to be associated with small volumes of timber per unit area.

Because a six-variable interaction is difficult to illustrate adequately, selected two-variable interacting systems have been extracted from the whole analysed interaction (Fig. 31).



Distribution of internal soil drainage according to selected two-variable interactions extracted from the whole six-variable interacting system.

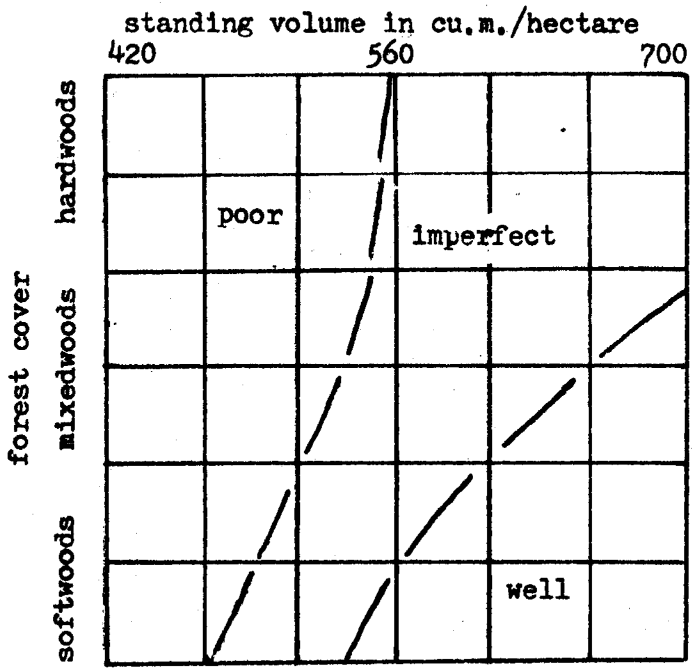


Fig. 31. Interaction diagrams for selected two-variable interacting systems extracted from the whole analysed interaction.

## Discussion

That part of the total interaction between forest cover and standing volume per unit area, as they affect soil drainage (Fig. 31), was apparent primarily as the result of the analysis. Presumably, large stands of timber, particularly conifers, extract great amounts of water from the soil to meet the demands of transpiration during the often dry mid-summer. This extraction of water is additional to the normal water loss by percolation through the soil profile and porous sandstones which often occur below. Hence, the soils are better drained and show the morphological characteristics of better drainage below high forest than is usually associated with their textures (e.g. loams to clay loams) and site factors (e.g. gentle slopes), within the prevailing climate (2030 mm. mean annual precipitation). Clear-felling across the mountain would undoubtely produce severe waterlogging in the soils, and greater run-off into the local streams draining the catchment, probably associated with greater erosion commonly observed during forestry operations.

## The Concept of the Limiting Factor

This concept is normally applied to agriculture and forestry yields (Brady, 1974), but can be extended to other environments. A soil profile might be suitable in every other way for a productive forest except that there is a limiting horizon, say a clayey subsoil through which water percolates very slowly. The preceeding analysis suggests that good drainage on Burnaby Mountain is dependent upon a favourable combination of particular environmental characteristics of the factors, aspect, elevation, slope, texture, standing volume and forest cover type. A change in character of any one of these factors can lead to a deterioration of internal profile drainage. The factor which is least optimal will largely determine the level of internal drainage. The "Principle of Limiting Factors" states that the level of drainage can be no better than that allowed by the most limiting of the essential factors influencing internal drainage.

There has been no corresponding work on the concept of the "optimizing factor", primarily because it is considered that internal drainage, for example, can be no better than that allowed by the limiting factor, whatever the quality of the optimizing factor. Thus, as an optimizing factor a heavily transpiring forest encourages good drainage, but the presence of a clayey subsoil supports a perched water table and, as the limiting factor, will tend to produce poor drainage regardless of the forest. However, if the concept of the limiting (or optimizing) factor is further extended to involve synergism, the "absolute" effects of single factors become ameliorated by the relative effects of several other interacting factors.

Hence, there is a range of good and bad effects (in terms of soil drainage) by different factors depending on the precise nature of the interactions. In this context, limiting and optimizing factors both have relevance since the delineating factors act together. The limiting factor is that one tending to produce poor drainage (say, a clayey subsoil) whereas the optimizing factor is that one tending to produce good drainage (say, a heavily transpiring forest), and the internal profile drainage is a compromise between the two "pressures" exerted within a complex interaction involving many factors.

Using all the sites within each 400-metre square of the grid superimposed across Burnaby Mountain, the mean category of each variable involved within the interaction was correlated with the analytical output of predictions for selected environments. The variable within the interaction tending more than any other to produce poor drainage was identified as the limiting factor within a grid square, and the variable tending more than any other to produce good drainage was identified as the optimizing factor.

The distribution of limiting and optimizing factors across Burnaby Mountain is shown in Fig. 32. Across the plateau top of the mountain, and part of the southerly dipslope, texture (clay content) is the chief limiting factor tending to encourage poor drainage whereas (high) elevation is the chief optimizing factor tending to encourage the formation of good drainage. The compromise between these two pressures is the extensive occurrence of moderately well drained Orthi Eutric Brunisols and imperfectly drained Gleyed Eutric Brunisols.

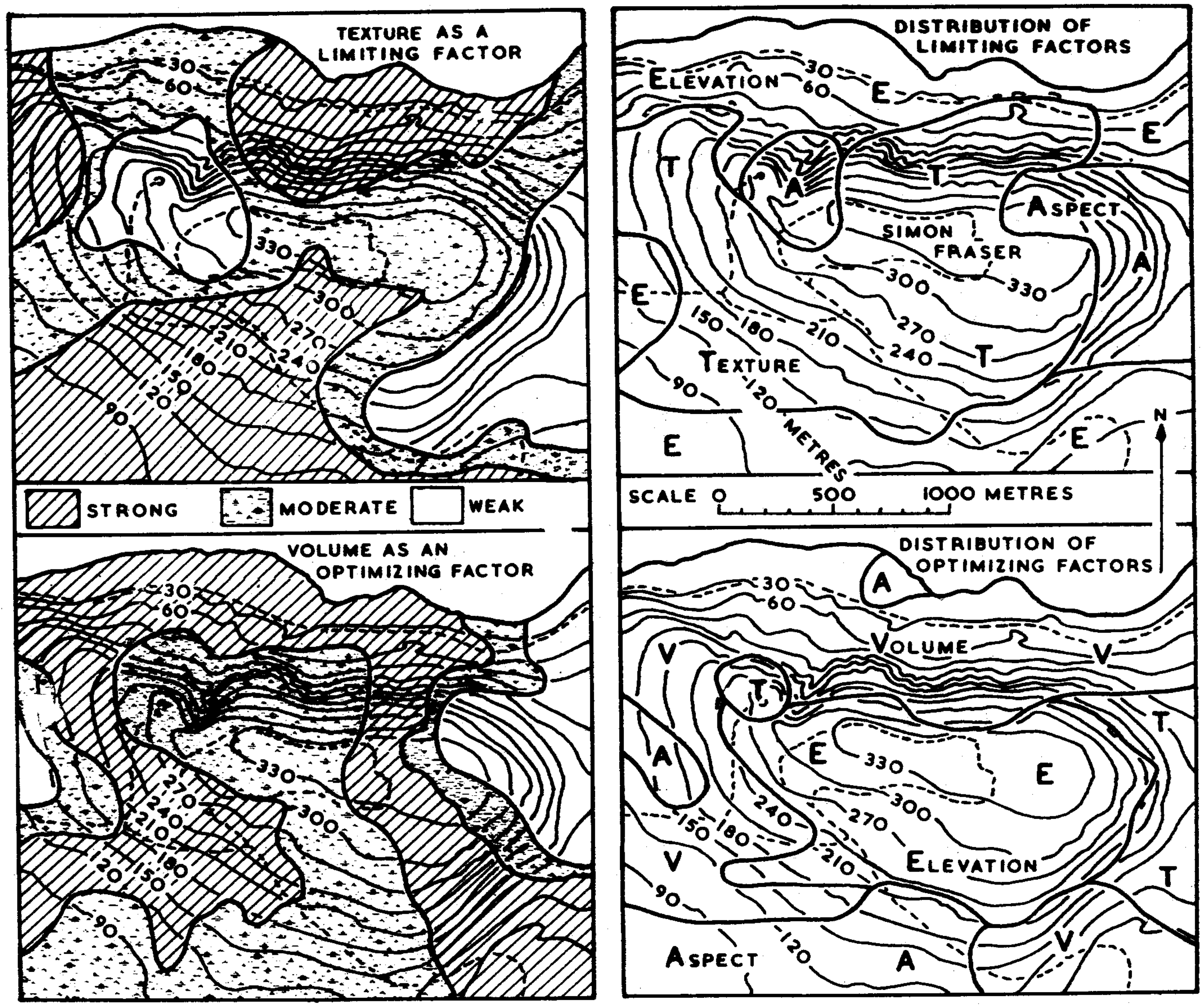


Fig. 32. Distribution of selected limiting and optimizing factors for drainage on Burnaby Mountain. (Volume = total volume of timber/unit area).

On the footslopes of the mountain, to the north and south (low) elevation is the chief limiting factor as water runs off the slopes to produce waterlogging in the soils which are either imperfectly drained Gleyed Eutric Brunisols or Fera and Rego Gleysols. The standing (forest) volume is the chief optimizing factor on the northern and southeastern footslopes, withdrawing great amounts of water from the soil because of heavy transpiration and so improving the state of soil drainage, to produce in some places the imperfectly rather than the poorly drained soils.

On the western flanks of the mountain, texture (clay content) as the limiting factor counterbalances standing (forest) volume as the optimizing factor, to produce moderately well drained and imperfectly drained soils. Aspect is the limiting factor on the eastern flanks of the mountain and, interestingly, within the deeply incised ravine below the Centennial Pavilion where, presumably, the slopes are in shadow for much of the day and the forest is cool. On the eastern flanks of the mountain the optimizing factor texture represents relatively sandy soils which allow rapid percolation of precipitation, to counterbalance the effects of the limiting factor aspect, yielding well drained Orthic Dystric Brunisols. The limiting factor of elevation on the southern footslopes is, to some extent, counterbalanced by the optimizing factor of a relatively warm, southerly and southwesterly aspect or, on southeasterly slopes, by high forest.

Fig. 32 also shows the contoured distribution of values for one factor, texture, as a limiting factor and the single factor of standing (forest) volume as an optimizing factor across Burnaby Mountain. As a limiting factor texture has its greatest effect within clayey tongues of substrate extending upslope from the southwest and northeast of the study-area, to the plateau top. Erratics are especially abundant within the area of these tongues, suggesting that during the last glaciation tongues of ice were pushed upslope over these areas and, on melting, deposited relatively clay-rich till with incorporated boulders (a boulder clay). The clayey substrate has produced a slow percolation of precipitation through the soil profile, encouraging the development of poor drainage. Locally, this has been partially offset by interaction with other factors. Texture has its least effect as a limiting factor on easterly and southeasterly flanks of the mountain where relatively sandy substrate occurs, and around the Centennial Pavilion. Presumably, shallow soils over sandstones and conglomerates, particularly on steep slopes of the ravine eroded along the major fault line crossing the mountain, have encouraged the development of good drainage.

As an optimizing factor the standing (forest) volume achieves its greatest effect on the northerly footslopes where the most mature forest on the mountain occurs, and in belts arcing across the plateau top and down onto the southwest and southeast slopes. Although this forest helps to produce better drained soils, comparison with the other maps indicates that elevation has a greater effect as an optimizing factor on the plateau top.

## Modeling the distribution of soil podzolization on Belcarra Mountain

### Introduction

Page (1968) observed greater leaching in podzolized soils after one generation of planted spruce than in the original grassland on adjoining, unplanted but similar sites. Pines may produce greater podzolization than the spruces or firs (Crampton, 1979). Pelisek (1963) reported less leaching below firs than below spruces. Thus it would appear that different trees produce different amounts of leaching or podzolization in the soils.

### Procedure

Within the framework of the 400-metre grid established across the mountain, at 91 sites distributed across the mountain a line of six profile pits, each pit 18 in. (46 cm.) from its neighbour, was dug towards the stem of a selected tree. Thus, there were 546 pits in total, at each of which the horizon thicknesses were measured, the textures and drainage were estimated, the pH values measured colorimetrically using dyes, and the soil colour recorded using the Munsell Soil Colour Charts. The site slope, aspect and elevation were also recorded, as was the tree species which included douglas fir, western hemlock, red cedar and broadleaf maple. The tree diameter (B.H.) was measured with a diameter tape. All variables were categorized into an arbitrary six classes.

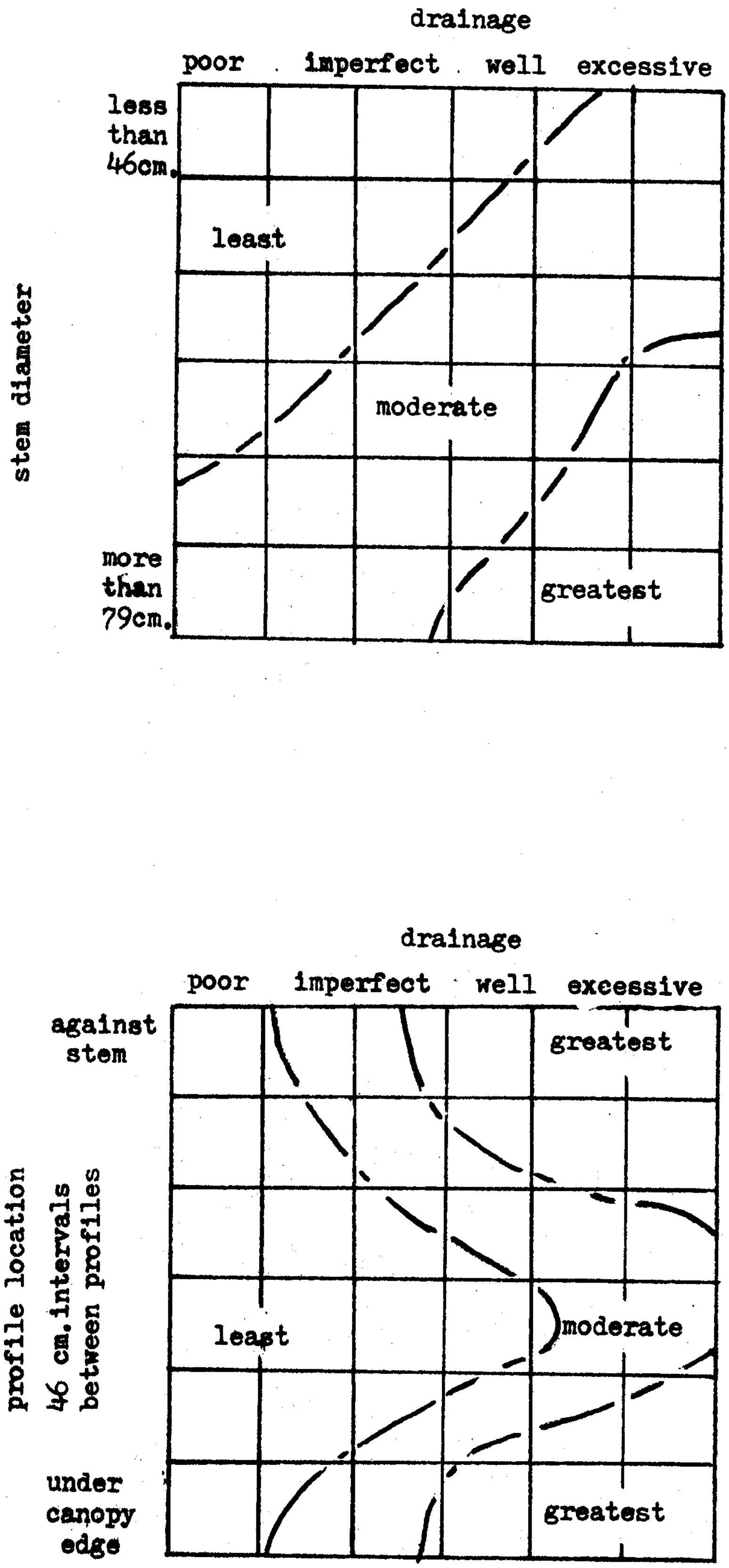
A measurement of the intensity of podzolization at each profile pit was required, based on those morphological features normally used in the field. Thus, the acidity of the organic "O" horizon, the thickness of the eluvial (leached) "A" horizon, the difference in pH between the A and "C" (parent material) horizons, and the difference in chroma between the A and "B" (illuvial zone of enrichment) horizons were determined, and given equal directional weight in a four-part, composite factor spanning minimum to maximum podzolization. Podzolization was judged greater with increasing acidity of the O horizon, with increasing thickness of the A horizon, with increasing pH difference between the A and C horizons (increasing leaching), and with increasing difference in chroma between the (grayish) A and (reddish-brown) B horizons (increasing translocation of iron).

A 20% random sample was extracted from the original population of 546 profiles and used to check the effectiveness of the analytical model. Thus, there were 437 sites for the analysis and 109 for the check.

The same analytical technique used for modeling the distribution of soil drainage on Burnaby Mountain was used for modeling the distribution of soil podzolization on Belcarra Mountain. In work on synergism it has been found that there is always a choice from several similarly significant interactions (Crampton, 1981), and the simplest significant interaction was obtained between the six independent variables of profile location (relative to the tree stem), tree species, tree diameter, profile drainage, slope and aspect, with profile location having the greatest influence on the intensity of podzolization. Using the independent sample, the anlysis was checked with the best fit method, yielding an $r^2$ of 0.68, and the same procedure was used to predict podzolization for a selected range of interacting variable combinations.

## Results

Because of difficulties illustrating a six-variable interaction, again selected two-variable systems have been extracted from the whole analysed interaction (Fig. 33). As part of a six-variable interaction, for broadleaf species the greatest podzolization occurs around the stem, whereas for conifers the most podzolized soils occur, first, immediately below the outermost canopy edge of the tree and, second, against the stem. The interaction diagram (Fig. 33) shows this bimodal distribution for conifers, and also suggests that profile drainage is acting primarily as a catalyst within the interaction rather than as a more direct influence. For all trees the least podzolization occurs midway between the stem and the canopy edge, particularly in poorly drained profiles but also within imperfectly drained soils. At this position below the canopy even excessively well drained profiles show only moderate podzolization.



Distribution of intensity of podzolization according to selected two-variable interactions extracted from the whole six-variable interacting system.

Fig. 33. Interaction diagrams for selected two-variable interacting systems extracted from the whole analysed interaction.

As part of the six-variable interaction, synergism is more apparent between profile drainage and tree stem diameter, the greatest podzolization being associated with large diameter trees growing in excessively well drained soils, and the least podzolization (the antagonistic effect) with small diameter trees growing in poorly drained soils (Fig. 33).

Within this complex interaction, podzolization is greatest below, first, douglas fir and, second, western hemlock and least below broadleaf trees, particularly broadleaf maple. Podzolization is also greatest on upper slopes facing north and northeast, and least on lower, more gently inclined slopes facing south. This is consistent with the analysis of the distribution of internal soil drainage on Burnaby Mountain where excessively well drained soils were found to favour these same upper slopes.

## Discussion

Mahendrappa (1974) found the stemflow from rainfall down certain conifers extremely acid. Gersper and Holowaychuk (1971) measured moderately acid soil horizons resulting from stemflow down hardwoods, including sugar maple, except at the surface the pH increasing away from the stem to a distance of 300 cm. (9.8 in.) (about the distance sampled away from each tree stem on Belcarra Mountain). Abrahamsen _et_. _al_. (1977) reported that rainfall penetrating a tree canopy became more acid mainly due to the washing of absorbed deposits and the leaching of excreted metabolites, the acidity of stemflow being about twice that prevailing halfway between the stem and the outer perimeter of the canopy. The quantity of stemflow varied with the form of the tree, being greatest for a broadleaf species such as birch, less for pine and least for the very different branching system of spruce.

Extrapolating from this research for tentative application to Belcarra Mountain, it would seem that below broadleaf species stemflow is greater than peripheral flow off the canopy, acidifying the soils around the stem, whereas for the more regularly branched conifers peripheral flow off the canopy is greater than stemflow, although the latter is not small, acidifying soils excessively below the canopy edge and, to a lesser extent, around the stem.

### A Dynamic rather than a Static Natural Environment

The natural environment of Burnaby and Belcarra Mountains is not static, but is constantly changing. In addition to long-term changes represented by the forest-soil interaction, whereby increasing forest maturity is associated with increasing withdrawal of moisture from the soil by the trees, such that there is a gradual extension of freely drained soils, there are also short-term changes.

## Rapid Changes of Internal Soil Drainage on Burnaby Mountain

### Introduction

Soil surveys of Burnaby Mountain during 1974 and 1978, and systematic profile investigations during the intervening years, have revealed distinct changes in the distribution of internal soil drainage. Changes of internal soil drainage, sufficiently great to require reclassification of the soils, have been observed in South Wales, Britain, arising about 30 years after afforestation of previously hill grasslands (Crampton, 1970). Improvement of internal soil drainage by planting trees has also been observed by Hinson et al.(1967). It is widely accepted that urbanization produces a redistribution of water flow within a landscape, but the following study of Burnaby Mountain records certain unusually rapid morphological changes in the soil profile arising from a major change of water flow after a large construction project (Crampton, 1979).

The prominent asymmetry of the north-south profile through Burnaby Mountain is most noticeable below an elevation of about 800 ft. (245 m.), the north-facing scarp face being precipitous in places (Fig. 36). Above 800 ft. (245 m.), to the summit at 1180 ft. (360 m.), the asymmetry is much less pronounced, and the plateau slopes at moderate to gentle angles to the north and south. A prominent feature in the Greater Vancouver area, Burnaby Mountain top captures an excessive amount of rain and snow, totalling about 80 in. (2030 mm.), compared with only about 45 in. (1140 mm.) on the lower slopes. Before construction of Simon Fraser University this precipitation flowed off the plateau northwards and southwards.

Following logging operations around 1940, secondary forest growth was re-established across the mountain, except on the plateau where regeneration was extremely slow (Fig. 34). Little clearing was required on the plateau to allow for the

Fig. 34. Vertical air photograph (BC 1675 : 33 and 34) of Burnaby Mountain before construction of Simon Fraser University commenced (1956).

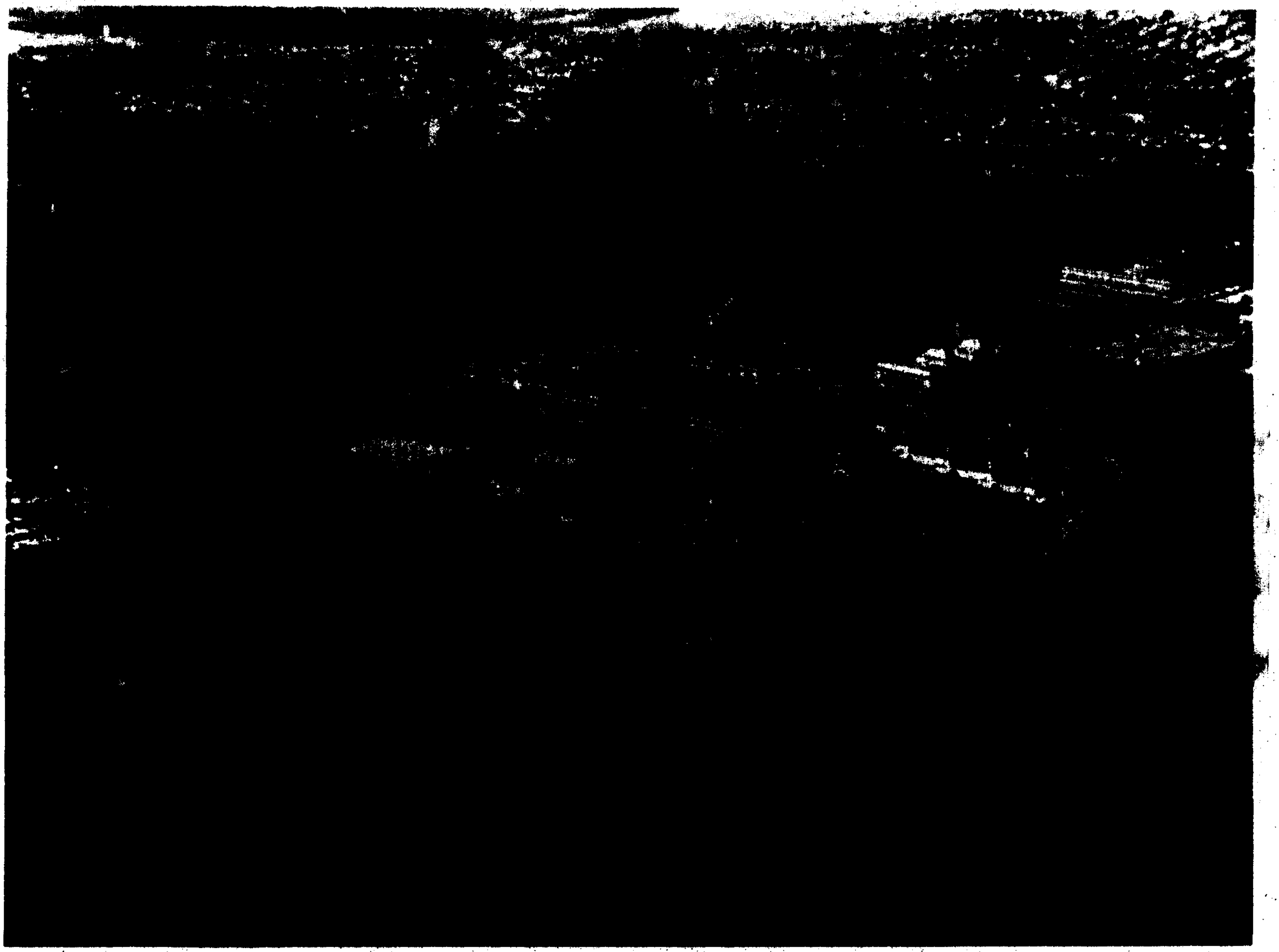


Fig. 35. Oblique air-photograph of the convex plateau of Burnaby Mountain (1979), showing the extension of a concrete apron across the top.

Fig. 36. Distribution of internal soil drainage across Burnaby Mountain in 1974.

Fig. 37. Distribution of internal soil drainage across Burnaby Mountain in 1978.

construction of the university from 1965 and onwards, except where construction spread off the gently convex plateau top (Fig. 35). Storm drains now channel precipitation off the plateau surface and into the underlying strata which dips at a low angle of about 6° southwards, thus depriving the north slope of much of its run-off.

## Method

The internal drainage was first mapped across the mountain during 1974 (Fig. 36), centred around a systematic survey of 250 sites distributed within the 400-metre grid established across the mountain. The systematically distributed sites were revisited each year and their profile morphology examined many times by students. An appraisal of changes of internal soil drainage prompted the remapping of the mountain soils during 1978 (Fig. 37). Thus two maps of internal soil drainage have been completed on the basis of orthodox surveys and systematic data collection.

## Results

The 1974 map (Fig. 36) shows well drained soils widespread across the plateau and upper slopes, associated with local occurrences of very well drained soils on the summit, and minor scarps formed on the dipslope by the outcrop of thin conglomerate bands. Moderately well drained and imperfectly drained soils occupy the lower dipslope, and the footslopes of the north-facing scarp where they occur with poorly and very poorly drained soils.

The 1978 map (Fig. 37) shows an area of very well drained soils only on the northeast slopes. Well drained soils occur locally on the lower north-facing slopes. The plateau is occupied by moderately well drained soils, and the south-facing dipslope by imperfectly drained soils. Poorly and very poorly drained soils occur only on the lower dipslope.

### Interpretation

Over a period of five years there has been a great change in distribution of different categories of internal soil drainage across the mountain. In 1974 poor and very poor drainage were associated with the footslopes of the north-facing escarpment, and the plateau with relatively well drained soils. By 1978 the footslopes of the south-facing dipslope were associated with poor and very poor drainage, and the plateau with moderate and imperfect drainage.

Before construction of Simon Fraser University, run-off from the heavy precipitation associated particularly with the plateau of Burnaby Mountain flowed to the north and south due to the convex nature of the plateau top (in contrast to the distinctly different symmetry associated with the middle and lower slopes). Construction of the university established a concrete platform across the plateau top and run-off was diverted into storm drains which channeled water directly into the underlying rock strata. Thin shale partings in this strata directed water flow in the direction of their southerly dip. The dipslope is more steeply inclined than the strata, and so the water flow eventually intercepted the land surface.

Thus, construction of the university has diverted water flow off the north-facing slopes and onto the south-facing slopes, producing a substantial change in distribution of internal soil drainage. Greater aeration of soils on footslopes of the north-facing escarpment over five years has changed those characteristics of the profile morphology associated with anaerobic conditions such as gray and mottled colours, to a more uniformly ochreous nature. More continuous saturation of previously well drained soils on the footslopes of the south-facing dipslope has caused an extension of profile colours associated with poor drainage.

## Variations of pH with Annual Cumulative Precipitation on Belcarra Mountain

### Introduction

Belcarra Mountain is situated opposite Burnaby Mountain, separated by the Burrard Inlet (Fig. 38). With an elevation of 950 ft. (290 m.), unlike the sedimentary structure of Burnaby Mountain, Belcarra Mountain is formed mostly of crystalline igneous rocks. During the last glacial ephisode massive ice moved down the Indian Arm, and some was unable to divert around Belcarra Mountain. A tongue of ice crossed the mountain, and field work indicates that it produced a north-south banding of soil parent material textures, discordant with the geological and topographical trends of the terrain. There is a central band of sands, with sandy loams on either side (Fig. 38). Very well drained, acid Podzols dominate the sands, and podzolized Brunisols the sandy loams. The

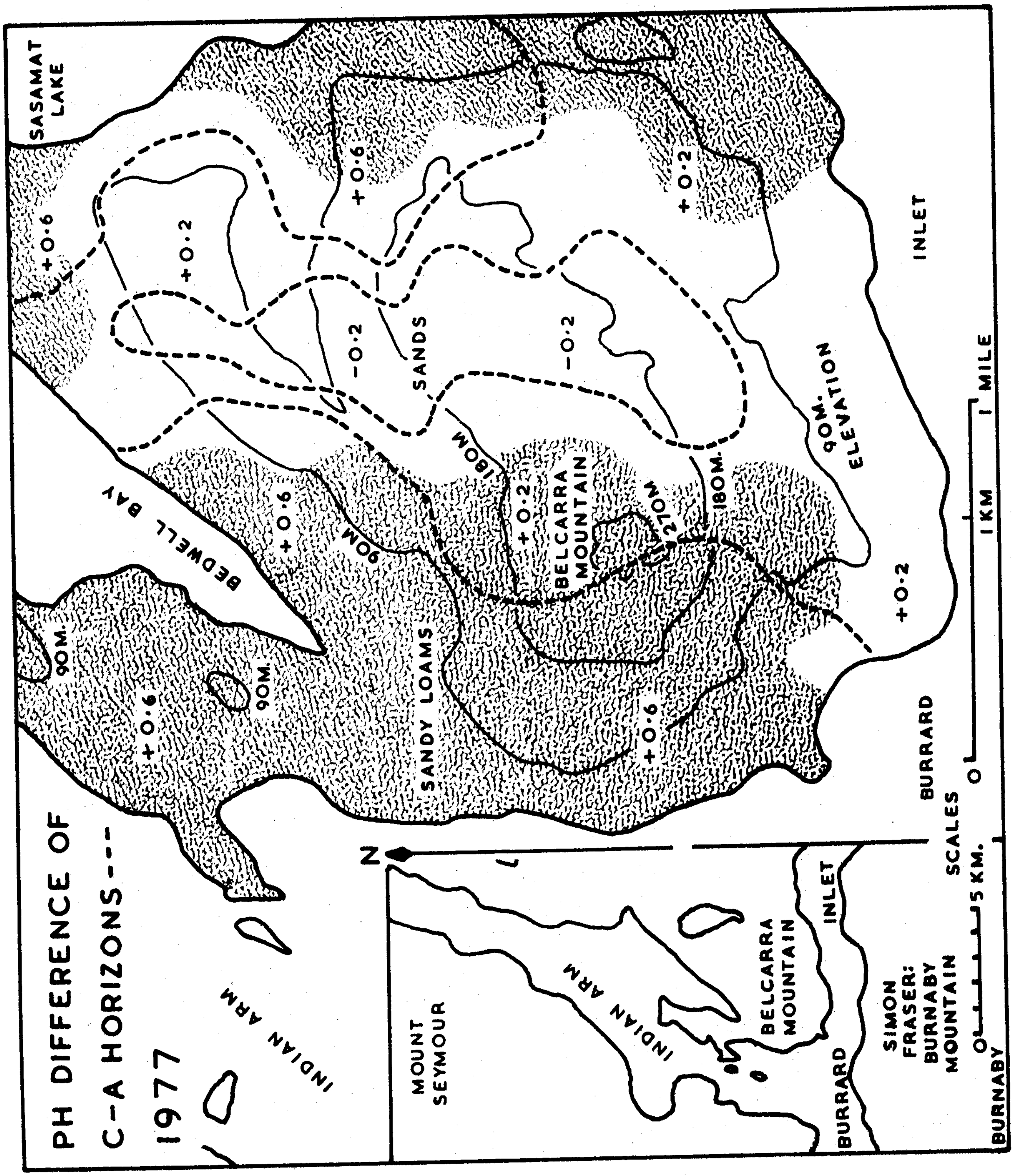


Fig. 38. Topography, and distribution of soil textures, and of the difference in pH values between the A and B horizons.

parent materials of these soils often extend into the gaping rock joints. The mean annual precipitation over Belcarra Mountain is assumed to be similar to that measured over Burnaby Mountain, with most occurring during the period from November to February.

### Method

During June and July of each of the years 1975 to 1978 colorimetric pH measurements were made using dyes on the A and B horizons of 230 profiles systematically distributed within the 400-metre grid established across the mountain (Crampton, 1980). Because colorimetric measurements of pH are approximate, only gross averages were used in this study. The averaged pH value for the sandy A horizon across the mountain was plotted against the cumulative precipitation for the winter season (for this study defined as November to February), the spring season (March to May), the summer season (June and July), and the total period from November of one year to July of the following year (Fig. 39).

### Results

The best linear relationship between average pH in A and preciptation involved the cumulative precipitation from November to July, that is through the winter, spring and summer seasons, increasing precipitation amounts correlating with increasing pH. The least linearity was achieved between pH in A and the cumulative precipitation during spring and summer. The winter precipitation appeared to be the primary influence on the summer pH of the sandy A horizon in these

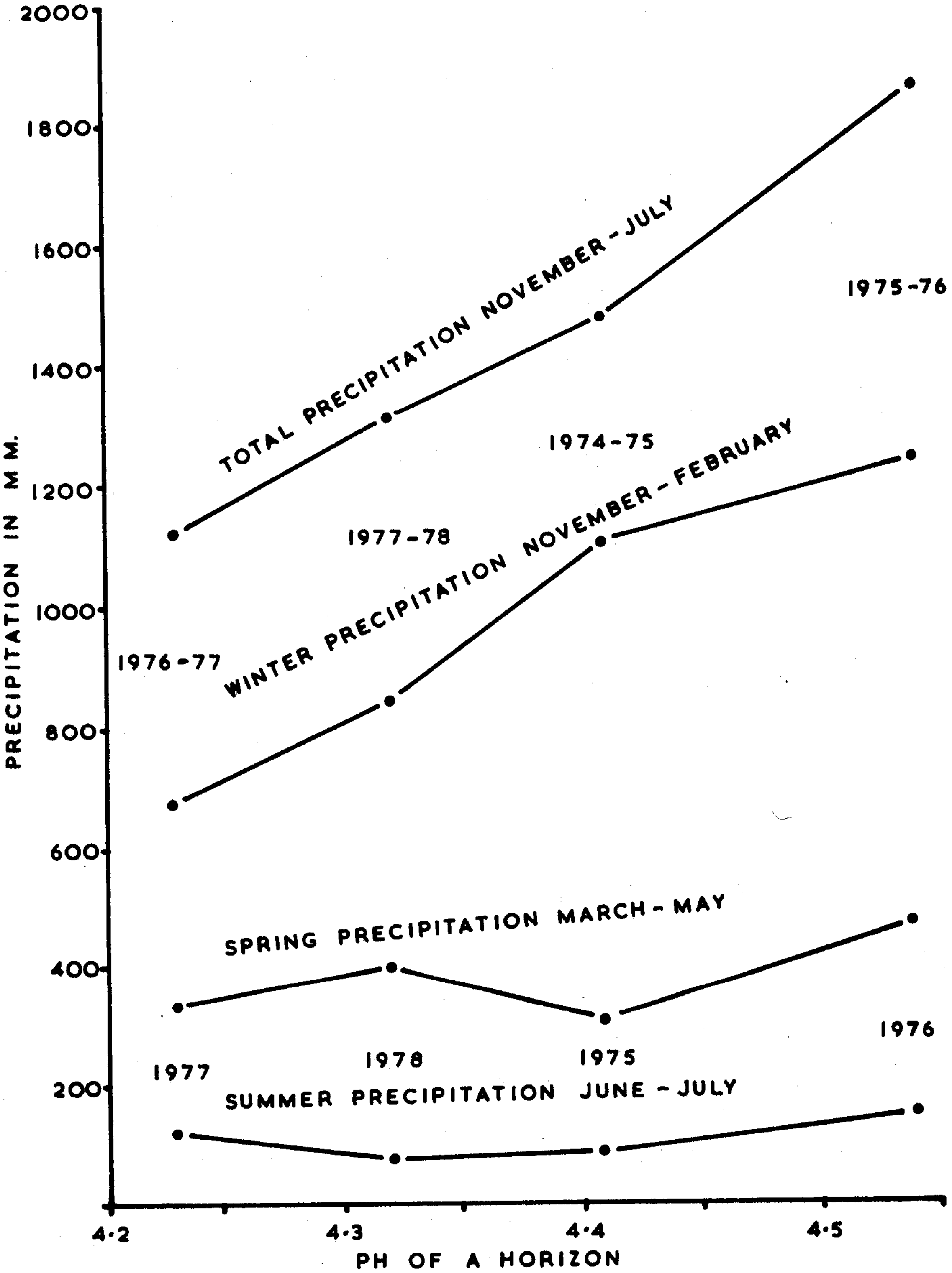


Fig. 39. The variation of pH in the A horizon and the total precipitation amounts for the different periods of the year.

podzolized soils, while the spring and summer precipitation appeared as a secondary influence, but only when added to the winter's precipitation (Fig. 39).

During a year when precipitation was great, in 1976, it was found that the pH value in the A and B horizons remained moderately constant across Belcarra Mountain, generally between 4.3 and 4.5 in A and 4.8 and 5.0 in B, with an average difference between the two horizons of 0.5. During a relatively dry year, in 1977, there were great variations in pH across the mountain. Where the subsoil was sandy loam (Fig. 38), both A and B horizons were more acid than during a wet year. It was found that the pH values of the A and B horizons were generally between 4.1 and 4.3, and 4.7 and 4.9, respectively, with an average difference between the two horizons of 0.6, the loamy sand of the A horizon having acidified more than the sandy loam of the B horizon compared with the wet year values. During the comparatively dry year of 1977, in the north-south belt of sands there was considerable acidification throughout the profile, with a reversal of the normal pH gradient. The pH value of the A horizon was generally between 3.8 and 4.0, and the B horizon between 3.6 and 3.8, with an average increase in acidity down the profile of 0.2 (Fig. 39).

## Interpretation

The seasonal decline of pH in well drained acid soils during summer has been tentatively attributed to the activities of fungi, bacteria and, possibly, tree root exudates (Brady, 1974). On Belcarra Mountain within the high rainfall coastal zone of British Columbia, however, this seasonal decline in pH is more pronounced following a relatively dry winter such as in 1977, and when the summer ranfall adds little additional moisture to the soils. A substantial precipitation during winter, as occurred during 1976, raises the water table and increases the soil moisture reserves, which impedes the decline of pH values during the summer.

Others (Van Lierop and Mackenzie, 1977: Huberty and Haas, 1940) have observed that preparatory drying of soils for laboratory analyses increases the acidity of the soils. Extended periods of dry weather have also been observed to increase field soil acidity (Haavisto, 1974: Holmen, 1964). The process of drying would appear to have operated in the acid forest soils on Belcarra Mountain, increasing soil acidity during summer being related primarily to a decrease in winter precipitation, such that the profile became excessively dry as the limited moisture reserves accumulated during winter were progressively depleted during summer.

On Belcarra Mountain the seasonal increase in acidity is also influenced by soil texture. Comparing the transition from the relatively wet 1976 winter to the relatively dry 1977 winter, where there are sandy loam subsoils the pH of the B horizon declined by, on average, only 0.1, whereas in the loamy sand D horizon the pH declined by an average 0.2. Comparing the same years, in the sands occupying the central north-south band across the mountain, acidification was very much greater following the relatively dry 1977 winter, the pH of the A horizon having declined by 0.5 to an average value of 3.9. In these podzolized sands there is no clay to help retain moisture reserves, and the process of acidification extended deeply into these very well drained profiles, producing a decline of pH in the B horizon of a remarkable 1.2, to an average value of 3.7. This process reversed the acidity gradient in the soil profile, causing the B horizon to have a summer pH value less than the A horizon.

Drainage in sands over well jointed rocks is very rapid and the soils dry out quickly, especially in the illuvial horizon where there is no immediately adjacent, thick organic mor as over the eluvial horizon. The apparent drying of soils from below, to produce greater acidification in the B than in the A horizon suggests that forest transpiration is chiefly responsible for depleting the moisture reserves.

## Bisequal Soil Profiles

At many places on the mountain slopes, especially Burnaby Mountain escaprment, there are bisequal soil profiles; that is, there are two complete profiles stacked one on top of the other, each with all the necessary horizonation to allow their classification. A bisequal profile from the north slope of Burnaby Mountain is described next, consisting of a Gleyed Eutric Brunisol at the surface showing colour mottling in C characteristic of imperfect drainage, over a somewhat disturbed but still identifiable organic horizon which caps a well to excessively well drained Eluviated Dystric Brunisol with a thin, eluvial horizon from which some leaching has occurred, over B and C horizons which merge into weathering sandstone.

In some other places three soil profiles have been seen stacked one on top of the other, each well preserved except that there has generally been an increasingly greater compression of the profile at greater depths.

Similar buried soil profiles have been seen elsewhere, apparently buried by erosion of material from upslope of the site, possibly following a forest fire at some time in the past (Crampton, 1969). A new soil profile has subsequently developed in the material that buried the previous land surface. If this explanation is correct, there have been several past fires across the mountains in the study-area, opening up the unprotected land surface to the weather, and erosion from off convex mountaintops to bury soil profiles on lower slopes.

The earliest survey of Burnaby Mountain was made during April of 1874 by the Royal Engineers under W. G. Pinder. He described the western half of the mountain and adjoining plateau as having been burnt at some earlier time, leaving much fallen timber. Scarred cedar stumps indicate that parts of the mountain have been burnt again since the turn of the century.

Bisequal Soil, consisting of a Gleyed Eutric Brunisol over a buried (b) Eluviated Dystric Brunisol, an imperfectly over a well drained soil, on a steep slope facing NNW at an elevation of 290 m., the escarpment of Burnaby Mountain.

| | |
|---|---|
| 0 - 8 cm. | Matted forest litter, over black humified organic matter containing abundant charcoal. pH 4.8; narrow boundary. |
| 8 -15 cm.<br>Ahej | Light gray (7.5YR 7/2), loose sandy loam with many roots. pH 4.9; narrow boundary. |
| 15 -30 cm.<br>Bmgj | Brown (7.5YR 5/4), friable loam with medium, subangular block structure, and many roots. pH 5.8; merging boundary. |

| | |
|---|---|
| 30 -56 cm.<br>Cg | Yellowish brown (10YR 5/4), with common, medium size, faint, brownish yellow (10YR 6/8) mottles, friable sandy loam with medium, subangular blocky structure, and roots. pH 6.2; disturbed boundary. |
| 56 -58/64 cm.<br>Ob | Black organic matter of varying thickness containing charcoal. pH 3.8; narrow boundary. |
| 64 -68 cm.<br>Aejb | Light gray (5YR 6/1), loose loamy sand with some roots. pH 4.4; narrow boundary. |
| 68 -87 cm.<br>Bfhjb | Yellowish red (5YR 5/6), friable sandy loam, with fine, sub-angular blocky structure and few roots. pH 5.2; merging boundary. |
| 87 -138 cm.<br>Cb | Yellowish brown (10YR 5/6), loose sandy loam with no roots. pH 5.5; merging into soft, weathering sandstone. |

Notice the charcoal in both the surface and buried organic horizons, implying that both surfaces have been burnt over at some time in the past. Charcoal fragments are often seen in the organic horizon of soils distributed across the mountains, and occur in the Podzol profile described previously.

## Summary and some Interactions

Podzolized, coarse-textured soils dominate Belcarra Mountain while medium-textured Brunisols dominate Burnaby Mountain. After clear-felling some rocky prominences on Belcarra Mountain may require much time for soil and vegetation to become re-established.

Large stands of timber, particularly conifers, extract great amounts of water from the soil to meet the demands of transpiration during a dry summer. It would appear that this extraction of water is sufficiently great to improve the state of profile drainage, thus extending the distribution of well drained soils. Most well drained soils, and accompanying podzolization occur in sandy materials on high, steeper slopes often facing north to northeast, whereas poorly drained soils are more frequently associated with broadleaf forests on lower, more gently inclined footslopes facing south and with finer textures.

The principle of limiting factors states that profile drainage can be no better than that allowed by the most limiting factor. If the principle of synergism is invoked, this "absolute" statement must be modified such that the state of internal drainage is considered as a compromise between the influences exerted by the antagonists, for example a clayey subsoil tending to hold water in the profile, and the synergists, for example a heavily transpiring forest which is removing great amounts of water from the profile.

It would seem that after rain, flow down the stems of irregularly branched broadleaf species is greater than off the canopy periphery, mildly acidifying the soils around the stems. Rainfall through the more regularly branched conifers produces the maximum flow off the canopy edge, greater than down the stem, which is greater than the throughfall from the canopy midway between the stem and the edge. This produces the most intense podzolization observed in the area below the canopy edge, less intense podzolization around the stem and the least podzolization midway between the stem and canopy edge. Douglas fir produces the most intense podzolization, followed closely by western hemlock.

Construction of Simon Fraser University on the convex plateau watershed of Burnaby Mountain has diverted the run-off from heavy precipitation associated with the plateau through storm drains into the underlying strata. Shale partings within the southerly dipping strata have channeled all of this water southwards, to intercept and saturate soils on the southern footslopes. Over a period of five years this diversion of run-off from surface drainage has caused an extension of well drained soils on the footslopes of the north-facing scarp, and poor drainage on the footslopes of the south-facing dipslope.

During summer on Belcarra Mountain intense acidification can occur in sandy soils if inadequate moisture reserves have accumulated from winter precipitation, and the soils dry out during the summer. This acidification is most intense in very well drained soils over jointed rocks, to the extent that the illuvial horizon can become more acid than the eluvial horizon. Soil acidification becomes progressively less intense in loamy sands and sandy loams as the clay content of the soil increases. The clay presumably helps to retain moisture for longer in the summer. A thick, organic mor may also help to retain moisture reserves during dry weather as forest transpiration withdraws water from the subsoil, although there is evidence from the measurement of soil profile temperature gradients that after about two weeks of dry sunny weather the wilting forest canopy fails to shield the organic layer from the sun's heat, and the surface soil starts to dry out.

Bisequal soil profiles are common, particularly on the escarpment of Burnaby Mountain. The lower soil profile was possibly buried at some time in the past by colluvium from upslope due to erosion of a land surface exposed after fire.

### Changes in Elderberry Distribution on Burnaby Mountain

Changes in drainage distribution on Burnaby Mountain do not occur in isolation; other associated changes also occur but undoubtedly as part of extremely complex interactions. Thus, using data collected within the 400-metre grid established across the area elderberry showed a prolific growth along the north-facing escarpment during 1974, the year of the first survey of internal soil drainage (Fig. 40). During 1978, by which time soils associated with the footslopes of the north-facing escarpment were drier, and soils associated with the dipslope were wetter than in 1974, there had been a considerable retreat of normally prolific elderberry to small areas on the footslopes of the north-facing escarpment. This redistribution of elderberry during five years is probably related to the simultaneous redistribution of internal soil drainage, but also to other factors since by 1978 there had been a slight retreat of elderberry up the dipslope onto the plateau top apparently discordantly with changes of soil drainage.

### Changes in Swordfern Distribution on Belcarra Mountain

On Belcarra Mountain during the relatively wet year of 1976 **swordfern** was prolific in small areas along the northwest-facing slope overlooking Indian Arm (Fig. 41). By the following year of 1977, during summer when the soils were both drier and more acid than in 1976, there had been a considerable extension of prolific swordfern growth to the northeast and southwest along the northwest-facing slope of the mountain, and to a lesser extent around the mountain onto the southwest-facing slope. This redistribution of swordfern could be related to either the changing moisture status of the soils, or to the changing soil acidity in response to the former change, probably both factors and many others. If so, these environmental changes would have improved the competitiveness of swordfern compared with plant species.

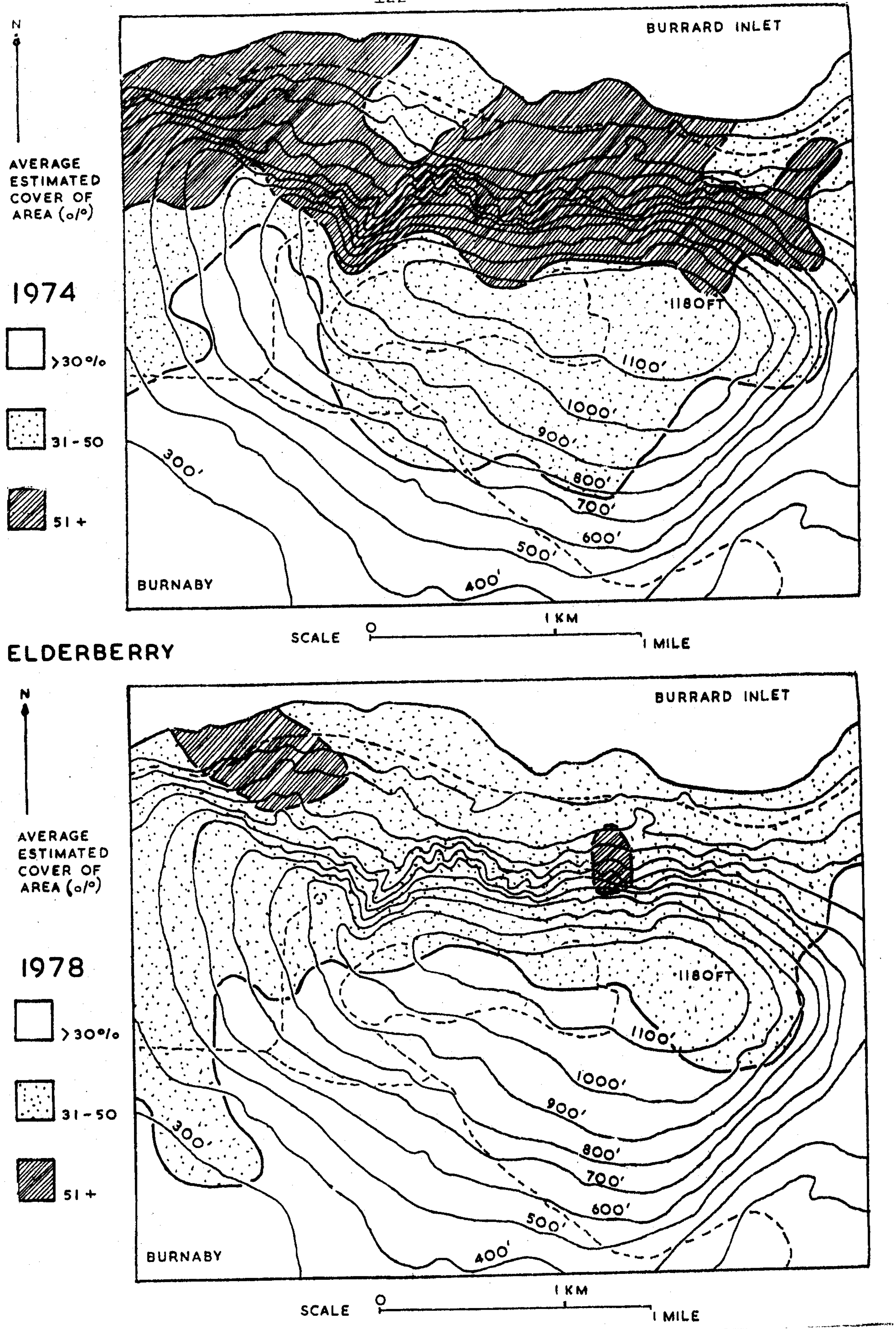


Fig. 40. Distribution of elderberry on Burnaby Mountain, based on the averaged estimated percentage cover within each square of the 400-metre grid.

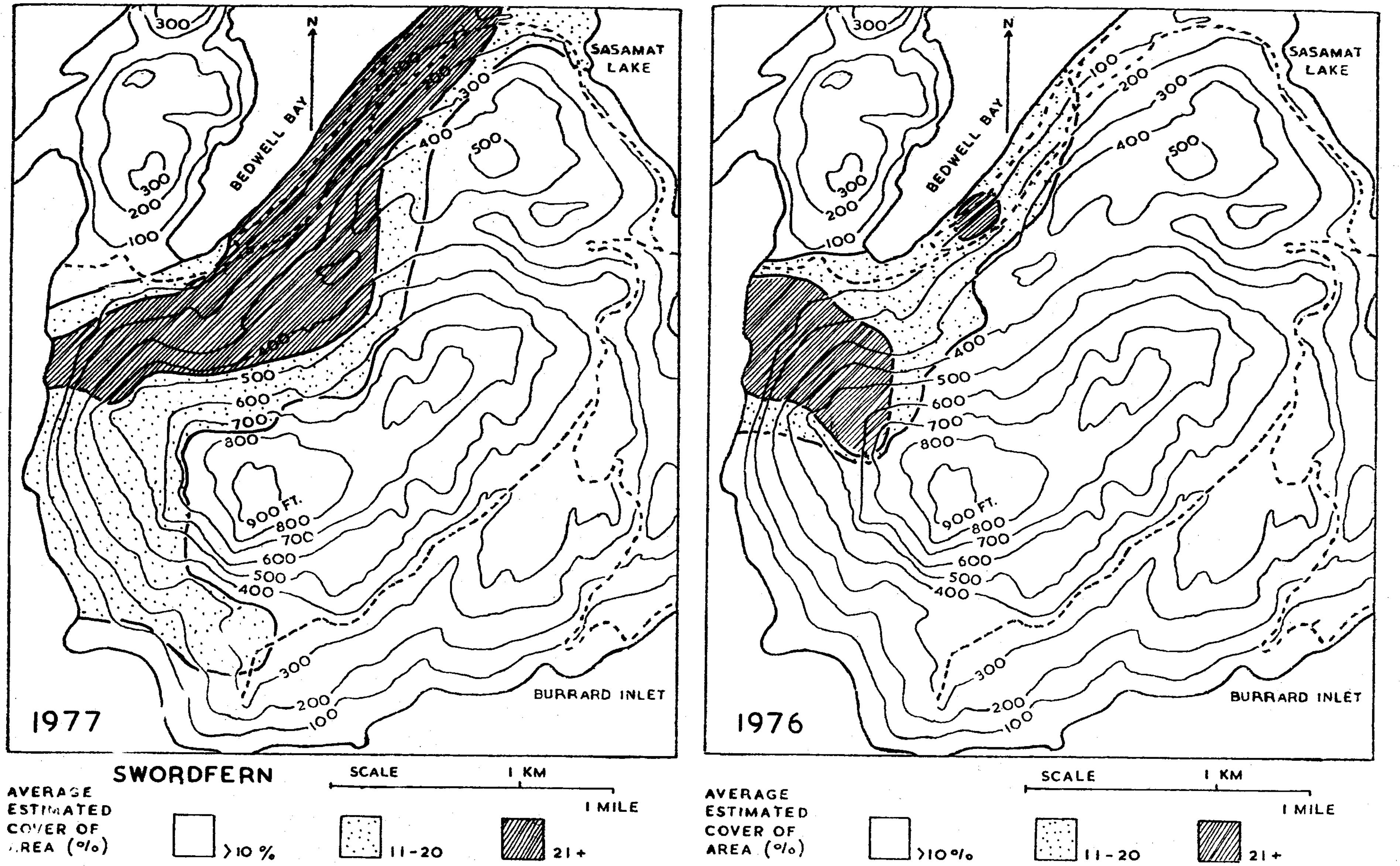


Fig. 41. Distribution of swordfern on Belcarra Mountain based on the averaged estimated percentage cover within each square of the 400-metre grid.

# VEGETATION

## The Succession of Flowering Plants

The earliest plant to flower is the hazelnut, appearing during early February. Indian plum (Fig. 42) flowers soon after bud-burst during early March when the last of winter's snow is thawing and uncovering the winterkill of, for example, grass. Like hazel, scouler willow flowers before leafing, during March. This is the first of several willows in the area to flower. As spring progresses the rate of new flowering increases and the forest floor turns green. During April flowering red current, salmonberry, the common dandelion, western bleeding heart, red elderberry, pacific dogwood, vine and broadleaf maple all appear. Large white trillium (Fig. 42), which also flowers during April, is a species in need of protection as the campus expands across the plateau top.

During May a large number of flowering plants appear; mitrewort, black twinberry or fly honeysuckle, western rowan, yellow skunk cabbage (in wet hollows), stinging nettles (stinging from hollow hairs with formic acid, and tending to grow on near-neutral disturbed sites), western buttercup (usually in poorly drained sites), winter cress and western saxifrage (on rocky sites of Belcarra Mountain). Appearing during May on Burnaby Mountain are the bluebell, yellow poppy, catchfly or campion and bladder campion, all introduced from Europe, the poppy and bluebell probably via gardens, reflecting the urban expansion of a largely immigrant population onto the footslopes of the mountain. (Also during May, fleshy, fertile stems of the common horsetail appear and wither before the sterile stems grow).

The peak of new flowering occurs during June, well clear of temperature inversions under clear skies which can produce frost, but still moist from winter and subsequent precipitation, as the daily temperatures climb towards their annual maximum. The flora includes false solomon's seal (or false spikenard, with its strong fragrance permeating the woodland), trailing blackberry, self-heal (heal-all), morning glory or hedge bindweed, common monkey flower, dame's violet or dame's rocket, bitter cherry, siberian miner's lettuce or western spring beauty, large-leaved avens, wild lily-of-the-valley or canada mayflower (generally in imperfectly or poorly drained areas), thimbleberry, western columbine (a graceful flower more common on Belcarra Mountain), broom (an introduced species), brooklime or american speedwell (on imperfectly to poorly drained sites), twin-flower, ox-eye daisy, devil's club, yarrow, goat's beard, fireweed or willow herb, salal (its name directly from Indian), and foxglove (another immigrant species from Europe which is particularly successful here, extending inland some distance and producing a riot of colour in unforested areas of Belcarra Mountain).

The frequency of newly appearing flowering species begins to decline during July. Long dry spells can sometimes occur during this month, scorching open areas in the forest. Hardhack, golden rod, common st. john's wort, hairy catsear, pearly everlasting, aster fleabane, wall lettuce, milk vetch, bull thistle and red huckleberry all flower during July. In August the newly flowering species include wild hop, purple loosestrife (near water), yellow

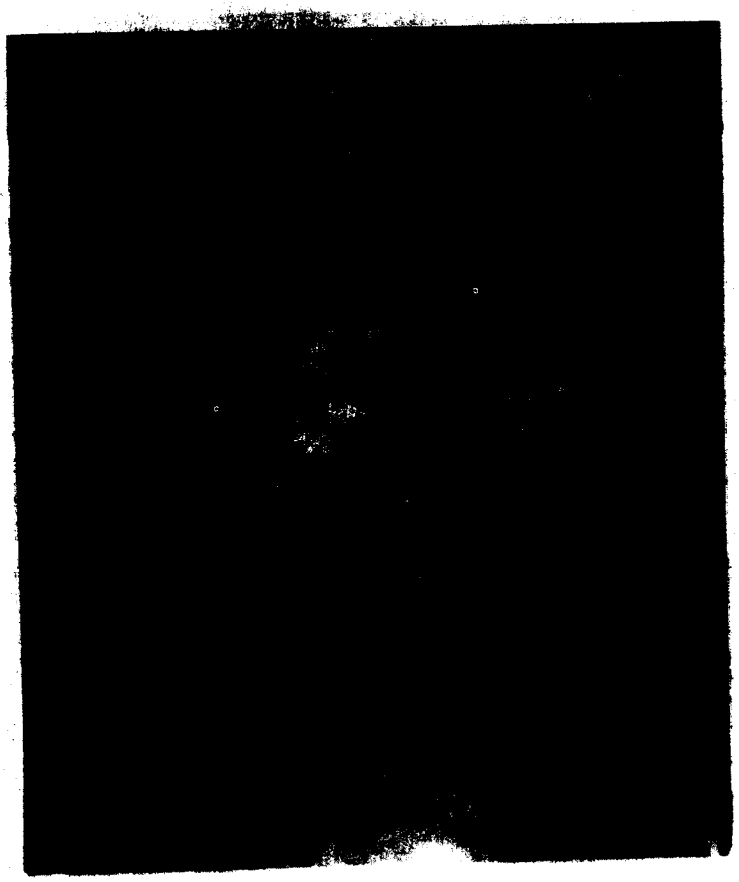


Fig. 42A. Indian plum showing budburst and flowering.

Fig. 42B. Trillium, a species needing protection.

flag (in poorly drained areas), oregon grape, the native jewelweed (yellowish brown) and the introduced jewelweed or pinkish touch-me-not from Europe, and the japanese knotweed introduced from the east. During September a second flowering of pacific dogwood may occur, after fruiting from the first flowering.

Ferns on the two mountains include bracken, western swordfern, deer fern, maidenhair fern, ladyfern and spiny woodfern. The latter can be distinguished from ladyfern by the basal pinnae since the lower pinnules are larger than the upper pinnules. Mosses on the mountains include hook moss, shiny moss, hair cap moss (often on more moist sites), schreber moss, plume moss, pacific mnium and bog moss (in poorly drained sites). The common rush and Juncus ensifolius grow in poorly drained areas, and cat-tails at the water's edge.

This is a simple list of species observed on the mountains and is far from comprehensive. However, the list does illustrate the site affinities of some species, and the introduction by immigrants of exotic species from the west and east. European earthworms and centipedes (with other species) were brought in with these plants, the former spreading throughout the valleylands and the latter invading and competing with indigenous species in the forested lands.

## List of plants referred to in the text

### Trees

| | |
|---|---|
| Douglas fir | *Pseudotsuga menziessi* (Mirb.) Franco. |
| Western hemlock | *Tsuga heterophylla* (Raf.) Sarg. |
| Western red cedar | *Thuja plicata* Donn. |
| Sitka spruce | *Picea sitchensis* (Bong.) Carr. |
| Broadleaf maple | *Acer macrophyllum* Pursh. |
| Vine maple | *Acer circinatum* Pursh. |
| Red alder | *Alnus rubra* Bong. |
| Balsam poplar | *Populus trichocarpa* Torr. & Gray. |
| Pacific dogwood | *Cornus nuttalli* Aud. |

Shrubs

| | |
|---|---|
| Hazelnut | *Corylus cornuta* Marsh. var. *californica* (D.C.) Sharp. |
| Indian plum | *Osmaronia cerasiformis* (T. & G.) Greene. |
| Scouler willow | *Salix scouleriana* Barratt. |
| Flowering red currant | *Ribes sanguineum* Pursh. |
| Red elderberry | *Sambucus racemosa* L. var. *arborescens* (T. & G.) Gray. |
| Western rowan | *Sorbus occidentalis* (S.Wats.) Greene. |
| Bitter cherry | *Prunus emarginate* Dougl. |
| Broom | *Cytisus scoparius* (L.) Link. |
| Red huckleberry | *Vaccinium parvifolium* Smith. |

Species accompanying shrubs

Salmonberry -------------------------- *Rubus spectabilis* Pursh.

Black twinberry ----------------------- *Lonicera involucrata* (Rich.) Banks.

Thimbleberry -------------------------- *Rubus parviflorus* Nutt.

Devil's club -------------------------- *Oplopanax horridum* (J.E.Smith) Miq.

Hardhack ------------------------------ *Spiraea douglasii* Hook.

Golden rod ---------------------------- *Solidago canadensis* L.

Wild hop ------------------------------ *Humulus americanus*

Purple loosestrife -------------------- *Lythrum salicaria* L.

Jewelweed (native) -------------------- *Impatiens capensis* Meerb.

Jewelweed (introduced) ---------------- *Impatiens glandulifera* L.

Ground flora

| | |
|---|---|
| Common dandelion | *Taraxacum officinale* Weber. |
| Western bleeding hearts | *Dicentra formosa* (Andr.) Walpers. |
| Large white trillium | *Trillium ovatum* Pursh. |
| Mitrewort | *Mitella pentandra* Hook. |
| Yellow poppy | *Papaver nudicaule* L. |
| Catchfly | probably hybrid of *Silene dioica* (red campion) and *Silene alba* Mill., E.H.L.Klause (white campion). |
| Bladder campion | *Silene cucubalus* Wibel. |
| Common horsetail | *Equisetum arvense* L. |
| Yellow skunk cabbage | *Lysichitum americanum* Hult. & St.J. |
| Stinging nettle | *Urtica dioica* L. var. *Lyallii* (Wats.) C.L.Hitchc. |
| Western buttercup | *Ranunculus occidentalis* Nutt. |
| Winter cress | *Barbarea orthoceras* Ledab. |
| Western saxifrage | *Saxifraga occidentalis* Wats. var. *Rufidula* (Small) C.L.Hitchc. |
| False solomon's seal | *Smilacina racemosa* (L.) Desf. |
| Bluebell (English) | *Endymion non-scriptus* |
| Trailing blackberry | *Rubus ursinus* Cham. & Schlecht. |
| Self heal | *Prunella vulgaris* L. |
| Morning glory | *Convolvulus sepium* L.var. *fraterniflorus* Mack. & Bush. |
| Common monkey flower | *Mimulus guttatus* D.C. |
| Dame's violet | *Hesperis matronalis* L. |
| Siberian miner's lettuce | *Montia sibirica* (L.) Howell. |
| Large-leaved avens | *Geum macrophyllum* Willd. |

| | |
|---|---|
| Wild lily-of-the-valley | *Maianthemum canadense* Desf. var. *interius* Fern. |
| Western columbine | *Aquilegia formosa* Fisch. |
| Brooklime | *Veronica americana* Schwein. |
| Twin-flower | *Linnaea borealis* (Gronov.) L. var. *longiflora* Torr. |
| Ox-eye daisy | *Chrysanthemum leucanthemum* L. |
| Yarrow | *Achillea millefolium* L. |
| Goat's beard | *Aruncus sylvester* Kostel. |
| Fireweed | *Epilobium angustifolium* L. |
| Salal | *Gaultheria shallon* Pursh. |
| Foxglove | *Digitalis purpurea* Linne. |
| Common st.john's wort | *Hypericum perforatum* L. |
| Hairy catsear | *Hypochaeris radicata* L. |
| Pearly everlasting | *Anaphalis margaritacea* (L.) B. & H. |
| Aster fleabane | *Erigeron peregrinus* (Pursh) Greene. |
| Wall lettuce | *Lactuca muralis* (L.) |
| Milk vetch | *Astragalus miser* Dougl. |
| Bull thistle | *Cirsium vulgare* (Savi) Airy-Shaw. |
| Yellow flag | *Iris pseudacorus* L. |
| Oregon grape | *Berberis nervosa* Pursh. |

## Ferns

| | |
|---|---|
| Bracken | *Pteridium aquilinum* (L.) Kuhn. |
| Western swordfern | *Polystichum munitum* (Kaulf.) Presl. |
| Ladyfern | *Athyrium filix-femina* (L.) Roth. |
| Spiny woodfern | *Dryopteris austriaca* (Jacq.) Waynar. |
| Deer fern | *Blechnum spicant* (L.) Roth. |
| Maidenhair fern | *Adiantum capillus-veneris* L. |

## Mosses

| | |
|---|---|
| Oregon beak-moss | *Eurhynchium oreganum* (Sull.) Jaeg. |
| Hook moss | *Dicranum scoparium* Hedw. |
| Shiny moss | *Hylocomium splendens* (Hedw.) (BSG.) |
| Hair cap moss | *Polytrichum commune* Hedw. |
| Schreber moss | *Pleurozium schreberi* (BSG.) Mitt. |
| Plume moss | *Hypnum* spp. |
| Pacific mnium | *Mnium* sp. |
| Bog moss | *Sphagnum capillaceum* (Weiss) Schrank. |
| | *Rhacomitrium canescens* (Hedw.) Brid. |

Rushes

Common rush ------------------------------ *Juncus effusus*

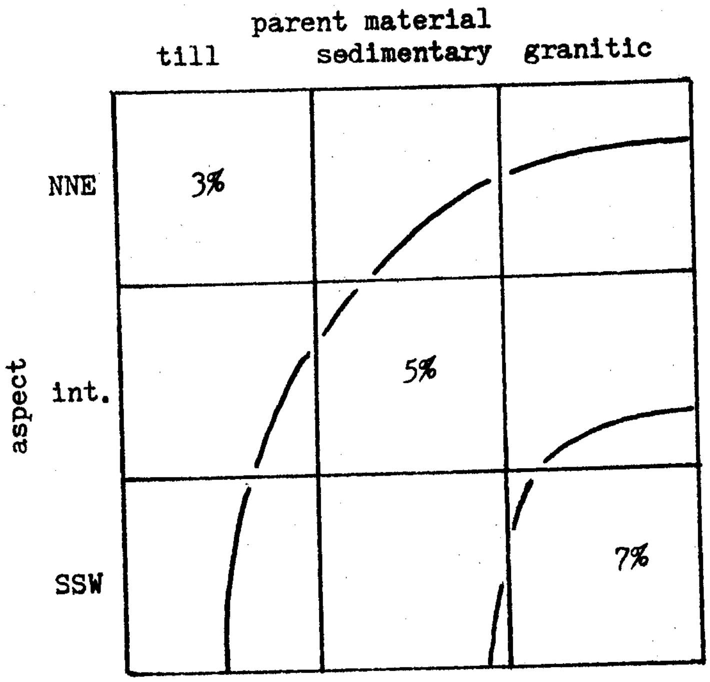
------------------------------ *Juncus ensifolius*

Cat-tails -------------------------------- *Typha latifolia*

## Analysis of the Distribution of Selected Plants

Using data collected from 521 points distributed systematically within the 400-metre grid established across the whole study-area, an averaged percentage cover estimate for selected plant species within each grid square acted as the dependent variable. A surrogate independent variable acted for a synergistic interaction between six factors; parent material, aspect, soil drainage, texture, pH B horizon, and forest cover (classified like the other factors into three categories - hardwoods, mixedwoods and softwoods). The creation of a model simulating natural conditions by this analytical technique has already been described.

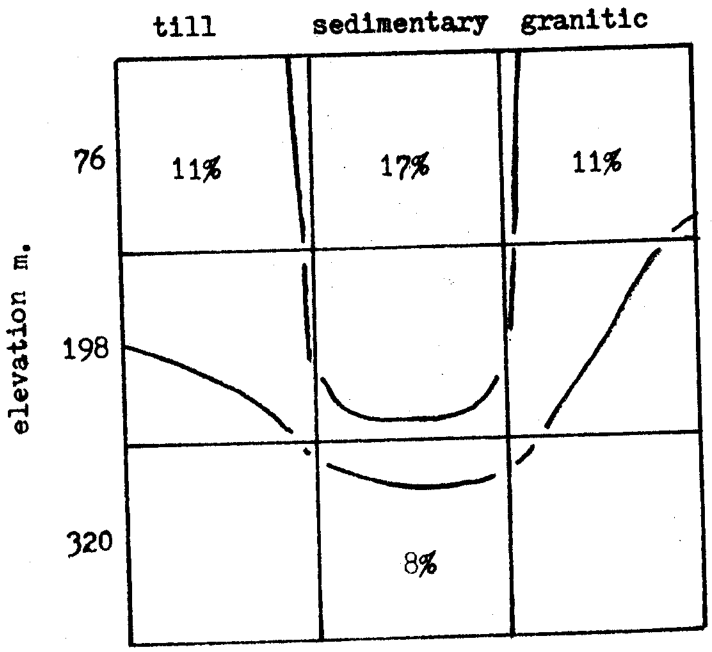
Selected two-variable interaction systems have been extracted from the whole analysed interaction to illustrate some relationships. The most important two-variable interaction system for huckleberry involves aspect and parent material, huckleberry being most extensive on southsouthwest-facing slopes over granitic rocks of Belcarra Mountain (Fig. 43). Parent material also has an important influence upon the distribution of swordfern where, as part of a six-variable interaction, the fern is most prolific over the sedimentary rocks of Burnaby Mountain at low to intermediate elevations. The forest cover type strongly influences the distribution of salmonberry which is most prolific under hardwoods on southsouthwest-facing slopes. Forest cover type also strongly influences oregon beak-moss, which forms the thickest cushions under softwoods over sandy soils and under hardwoods over clay loam soils, thereby displaying a bimodal distribution as part of a



**huckleberry**

Maximum cover on SSW-facing slopes over granitic rocks.

$r^2$ (check) = 0.65

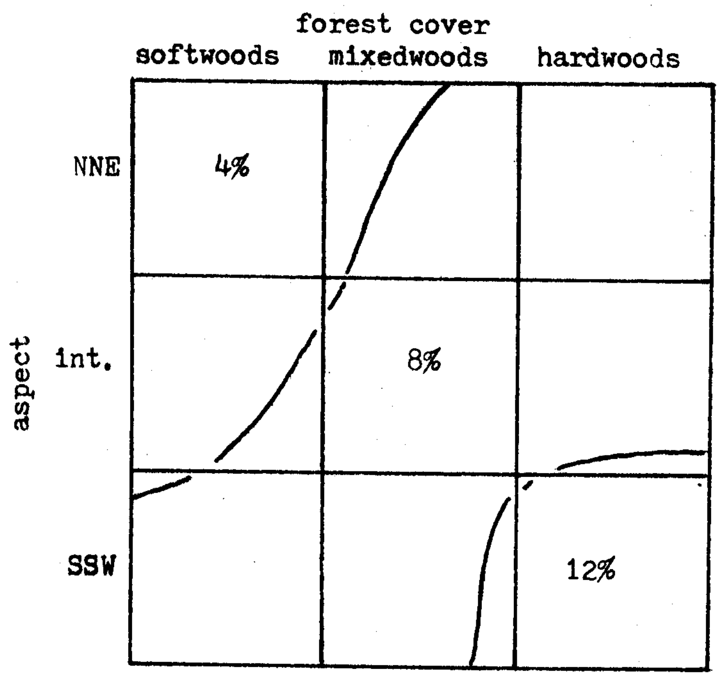


**swordfern**

Maximum cover associated with low to intermediate elevations over sedimentary rocks.

$r^2$ (check) = 0.69

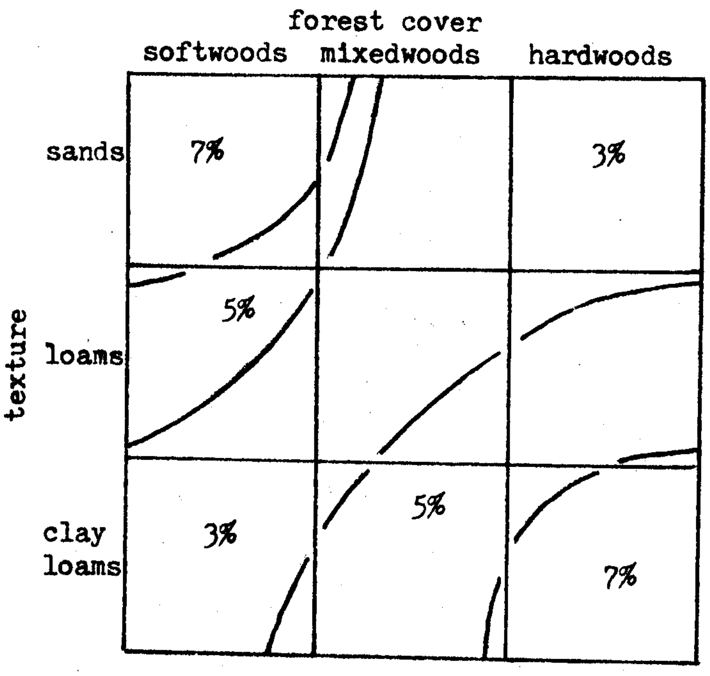
Fig. 43. Interaction diagrams for selected two-variable interacting systems extracted from the whole analysed interaction.



salmonberry

Maximum cover under hardwoods on SSW-facing slopes. Minimum cover mostly under softwoods on NNE-facing slopes.

$r^2$ (check) = 0.70

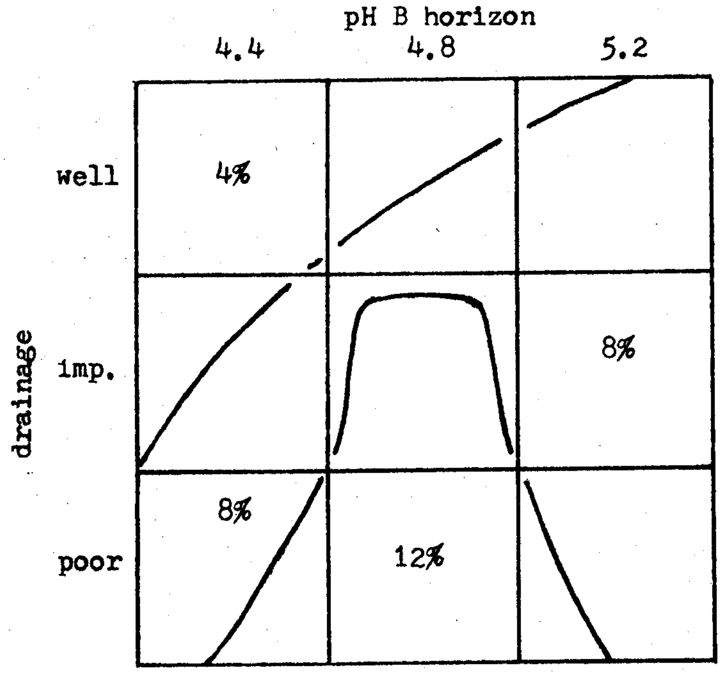


oregon beak-moss

Maximum cover under softwoods on sandy soils and under hardwoods on clay loam soils. Minimum cover associated with a balanced transition from hardwoods on sandy soils to softwoods on clay loam soils.

$r^2$ (check) = 0.72

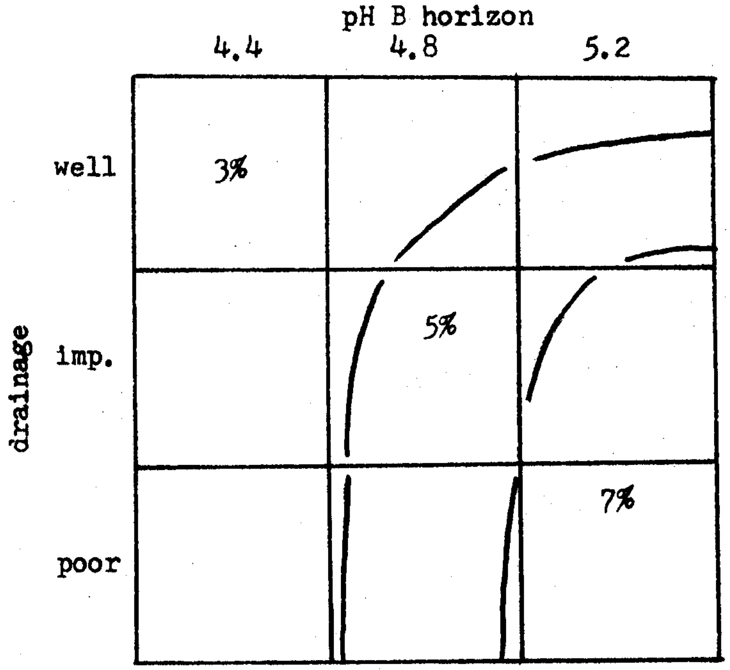
Fig. 44. Interaction diagrams for selected two-variable interacting systems extracted from the whole analysed interaction.



**Salmonberry**

Maximum cover associated with intermediate pH values in the B horizon in imperfectly and poorly drained soils. Minimum cover mostly associated with relatively acid B horizon in well drained soils.

$r^2$ (check) = 0.69



**Thimbleberry**

Maximum cover associated with relatively high pH values in the B horizon in imperfectly and poorly drained soils.

$r^2$ (check) = 0.67

Fig. 45. Interaction diagrams for selected two-variable interacting systems extracted from the whole analysed interaction.

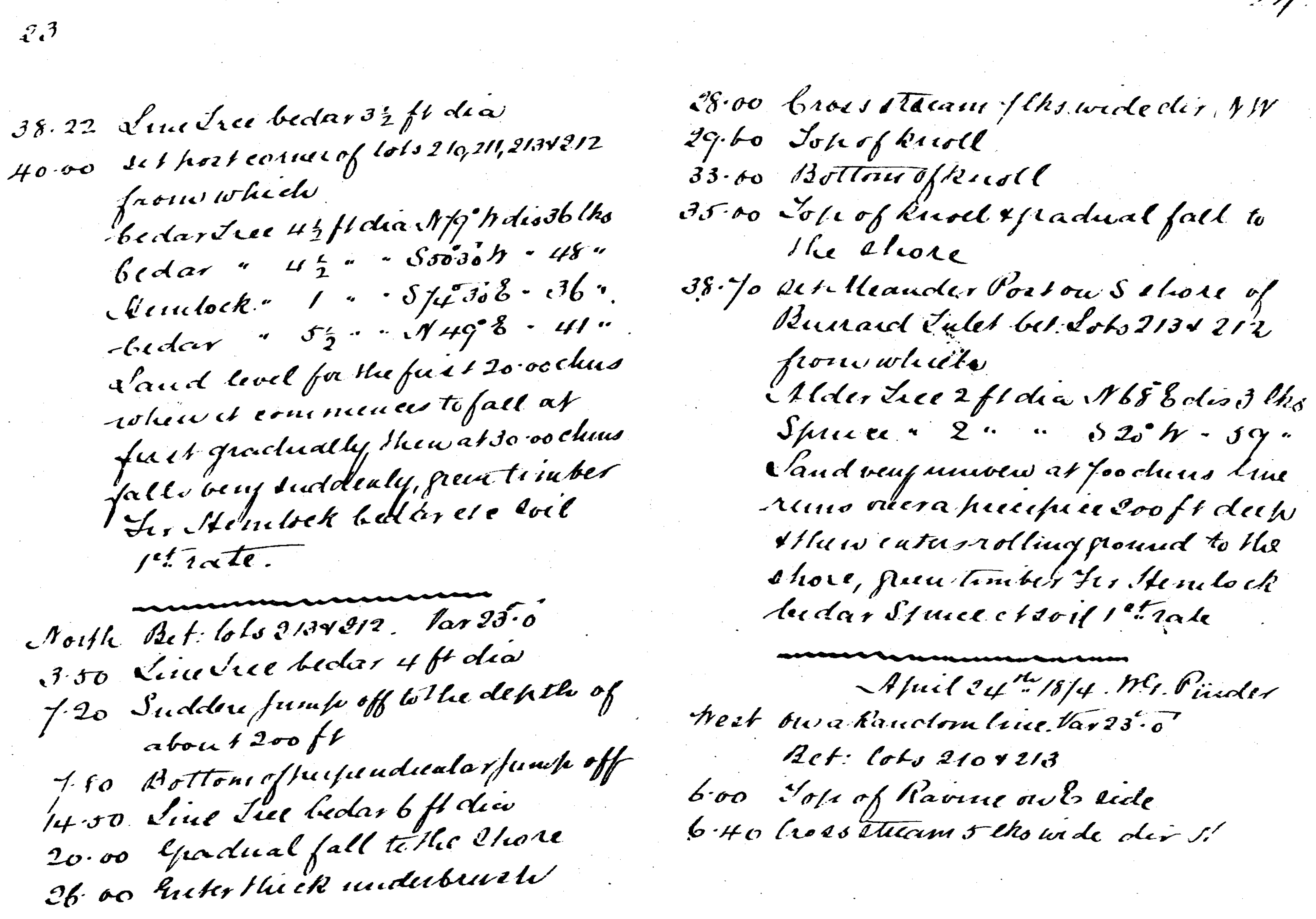
six-variable interacting system (Fig. 44). Soil influences are important within synergistic interactions for salmonberry which is extensive over poorly and imperfectly drained soils where there are intermediate pH values associated with the B horizon, and for related thimbleberry which is widespread over, once again, poorly and imperfectly drained soils, but where the B horizon is less acid (Fig. 45).

The species mentioned are a fraction of the total flora, but they serve to illustrate some interactions within the landscape.

## The Forests

Before logging commenced on the mountains, moose and deer were hunted in forest stands containing some trees with butts so large that, particularly in the case of cedars, they were felled about 3.5 m above ground. While cruising timber on Burnaby Mountain during 1874 W.G. Pinder recorded some sitka spruce and grand fir (called "balsam") (Figs. 46 and 47), as well as the ubiquitous douglas fir, western hemlock and red cedar to be seen today.

The lower slopes of Burnaby Mountain were being selectively cut-over before the turn of the century, and full scale logging of cedar started during 1904 when a skid road was constructed along what is now Curtis Street, and beyond to a camp on the crest of the mountain along the still discernible trail, down which logs were hauled using a donkey engine on the footslopes. A railway hauled the logs from here to the nearly Burrard Inlet. Only hemlock remained as good stands after this operation (since it had been regarded as an inferior



23

38.22 Line Tree Cedar 3½ ft dia
40·00 set post corner of lots 210, 211, 213 & 212
from which
Cedar Tree 4½ ft dia N 79° W dis 36 lks
Cedar " 4½ " " S 50°30' W " 48 "
Hemlock " 1 " " S 74°30' E " 36 "
Cedar " 5½ " " N 49° E " 41 "
Land level for the first 20·00 chns
where it commences to fall at
first gradually then at 30·00 chns
falls very suddenly, green timber
Fir Hemlock Cedar etc Soil
1st rate.

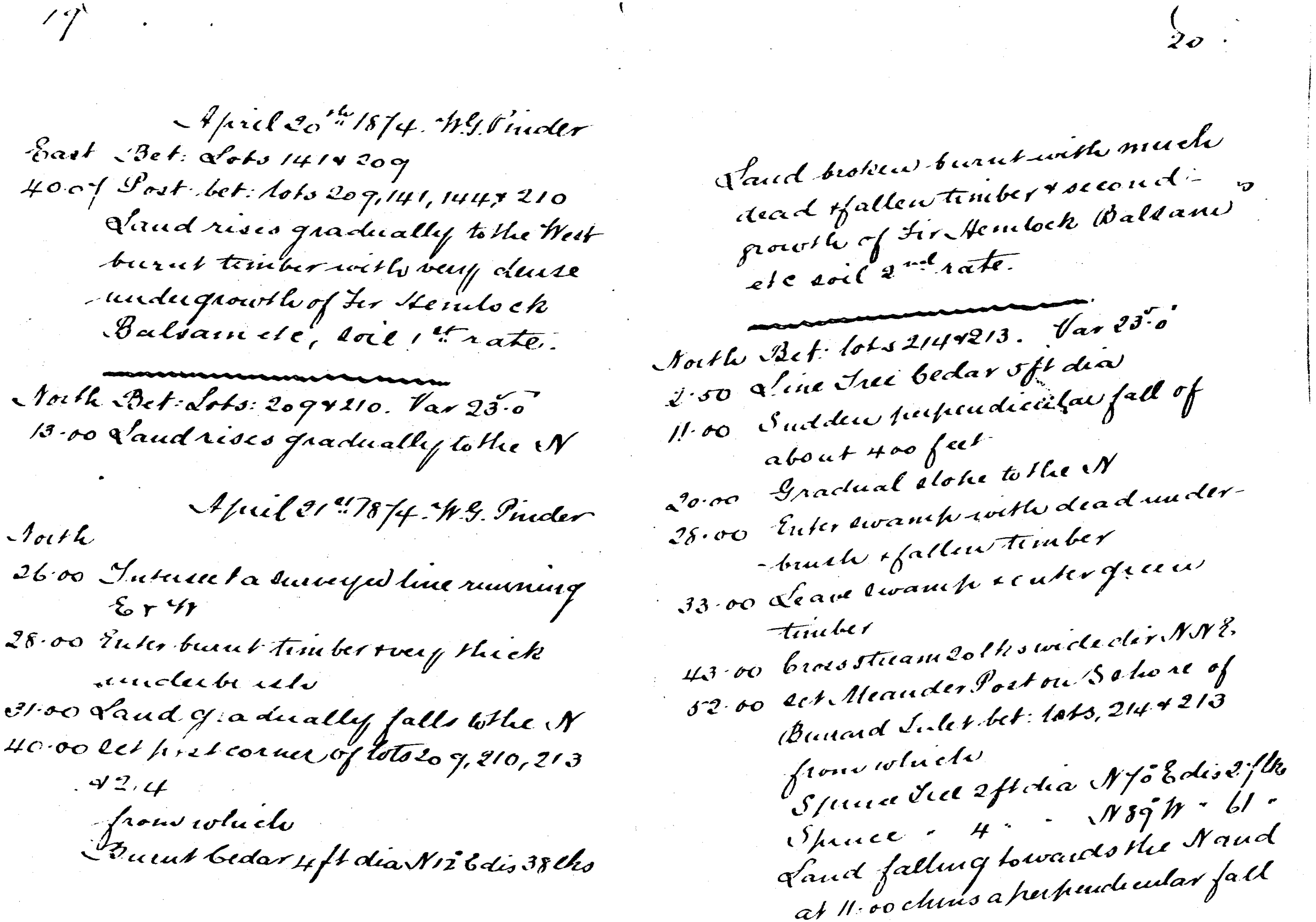
North Bet: lots 213 & 212. Var 23°0'
3·50 Line Tree Cedar 4 ft dia
7·20 Sudden jump off to the depth of
about 200 ft
7·80 Bottom of perpendicular jump off
14·50 Line Tree Cedar 6 ft dia
20·00 Gradual fall to the Shore
26·00 Enter thick underbrush

24

28·00 Cross Stream 7 lks wide dir NW
29·60 Top of knoll
33·60 Bottom of knoll
35·00 Top of knoll & gradual fall to
the shore
38·70 set Meander Post on S shore of
Burrard Inlet bet: Lots 213 & 212
from which
Alder Tree 2 ft dia N 68° E dis 3 lks
Spruce " 2 " " S 20° W " 59 "
Land very uneven at 7·00 chns line
runs over a precipice 200 ft deep
& then enters rolling ground to the
shore, green timber Fir Hemlock
Cedar Spruce etc soil 1st rate

April 24th 1874. W.G. Pinder
West on a Random line. Var 23°0'
Bet: Lots 210 & 213
6·00 Top of Ravine on E side
6·40 Cross Stream 5 lks wide dir S.

Fig. 46. Pages from timber cruise survey by W.G.Pinder in 1874.



19

April 20th 1874. W.G. Pinder
East Bet: Lots 141 & 209
40.00 Post bet: lots 209, 141, 144 & 210
Land rises gradually to the West
burnt timber with very dense
undergrowth of Fir Hemlock
Balsam etc, soil 1st rate.

North Bet: Lots: 209 & 210. Var 23°0'
13.00 Land rises gradually to the N

April 21st 1874. W.G. Pinder
North
26.00 Intersect a surveyed line running
E & W
28.00 Enter burnt timber very thick
underbrush
31.00 Land gradually falls to the N
40.00 Set post corner of lots 209, 210, 213
& 214
from which
Burnt Cedar 4 ft dia N 12° E dis 38 lks

20

Land broken burnt with much
dead & fallen timber & second
growth of Fir Hemlock Balsam
etc soil 2nd rate.

North Bet: lots 214 & 213. Var 23°0'
2.50 Line Tree Cedar 5 ft dia
11.00 Sudden perpendicular fall of
about 400 feet
20.00 Gradual slope to the N
28.00 Enter swamp with dead under-
brush & fallen timber
33.00 Leave swamp & enter green
timber
43.00 Cross stream 20 lks wide dir. N N E.
52.00 Set Meander Post on S shore of
Burrard Inlet bet: lots, 214 & 213
from which
Spruce Tree 2 ft dia N 70° E dis 27 lks
Spruce " 4 " " N 89° W " 61 "
Land falling towards the N and
at 11.00 chns a perpendicular fall

Fig. 47. Pages from timber cruise survey by W.G.Pinder in 1874.

timber species). By the time logging recommenced during the 1940's a method of kiln drying was developed that prevented excessive warping, and the remaining hemlock was marketed as "Alaska Pine". After 1915 two shingle mills were in operation using the high cedar stumps left after the earliest cutting. Railway ties were also cut from the mountain, from second growth timber. During this period fires repeatedly occurred on the mountain. Belcarra Mountain was first logged between 1905 and 1920, and again around 1940 (McGeachie, 1975).

The greater part of the land on either side of Burrard Inlet now consists of forest stands about 50 years old, with younger pockets on Belcarra Mountain (Fig. 48). The north-facing escarpment of Burnaby Mountain has stands over 70 years old, some around 90 years old below the cliffs by the Centennial Pavilion. There are local areas of forest over 100 years old in the north of Belcarra Mountain, principally overlooking Bedwell Bay. Many of the old cedar stumps are charred suggesting a casual attitude towards burning the forest after logging.

Despite this logging history, and the construction of Simon Fraser University atop Burnaby Mountain, much of the two mountains is now covered with verdant forest, albeit mostly young, which is rapidly masking the scars left from past activities. The most disturbed sites are colonized by red alder. Because of its nitrogen-fixing capacity through its roots (Tarrant et al., 1969), red alder should not be regarded merely as a weed to be hacked at will, but as a species that quickly covers unsightly land and which improves the fertility of the impoverished soils.

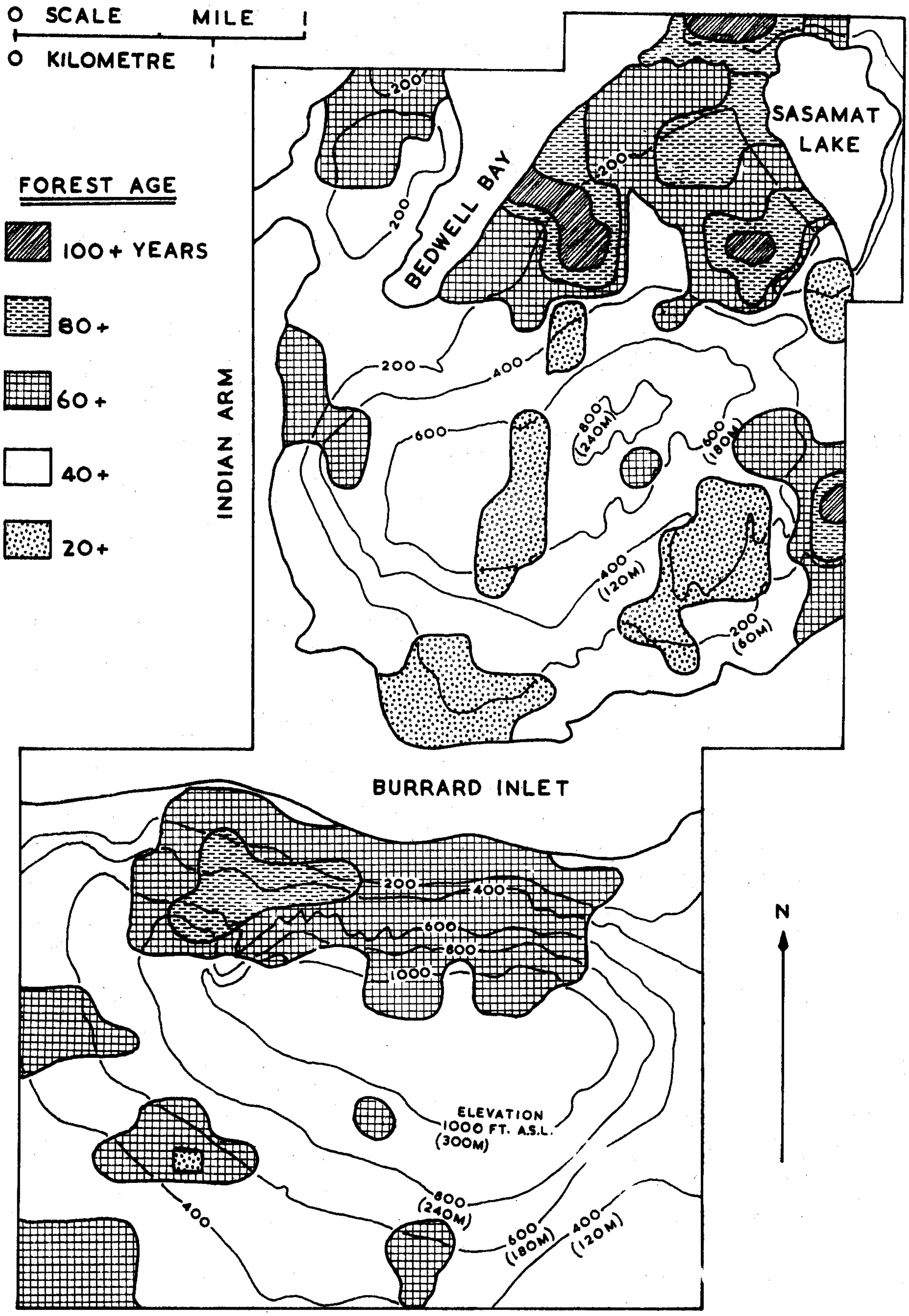


Fig. 49. Distribution of forest stand age across Burnaby and Belcarra Mountains.

# TERRAIN EVALUATION

Extensive land classification interpreted from the observed vegetation and physiographic relationships has been undertaken in several countries; generally earlier in Australia and New Guinea by the Commonwealth Scientific and Industrial Research Organization (CSIRO, 1970 and 1973), later in Canada by Hills (1961), Vold (1977) and Block (1978). A biophysical survey identifies and classifies ecologically different parts of a large land area. The landscape unit generally shown on the map has been called the Land System, which is conceived as defining a recurring pattern of landforms, soils and vegetation recognizable in air photographs (Mitchell, 1973), and characterized by ground inspection at localities selected on the basis of an air photograph interpretation. In this study the area for analysis was smaller than that generally considered for most terrain evaluations and, after an air photograph interpretation, it was found useful to associate a Land System with a particular geological unit, mostly within a narrow range of aspect since this, along with the suite of soils formed from the specific rock type, appeared to strongly influence the vegetation.

The unit of subdivision of the Land System has often been called the Land Facet which, according to Mabbutt (1968), is a more homogeneous unit based on more detailed ground inspection. In this study a Land Facet is associated mostly with one mapped soil type.

Land Systems can be combined on the basis of common attributes into Land Regions which have climatic connotations. In this study the effects of a wind blast produced as air is lifted by a mountain slope to reinforce winds blowing across a highly exposed ridge top causes top-dying of douglas fir, and the tree grows poorly at these elevations, as can be seen along the crest of the escarpment of Burnaby Mountain and along the ridge crest of Belcarra Mountain. The climatic regime implied by the vegetation in this way is used to divide the study-area into two Land Regions. Land Regions, with Land Systems and Land Facets provide a possible three-level stratification of the landscape for a biophysical land classification. An essential element in this style of classification is a gross simplification of the natural complexitity so that the classification becomes of practical use to those not involved in its construction.

Fig. 50 shows the topography of the study-area. Burnaby Mountain rises to an elevation of 360 m., and its plateau is occupied by Simon Fraser University. Burrard Inlet separates Burnaby Mountain from Belcarra Mountain which reaches an elevation of 290 m. The Coombe Peninsula extends from Belcarra Mountain into Indian Arm on one side of Belcarra Mountain, and Sasamat Lake is situated on the other side. Waterfront dwellings abound along the coastline (Fig. 51). The study-area adjoins urban regions along its southwest and south sides (Burnaby)(Fig. 35), and along its eastern side (Port Moody and Ioco) (Fig. 3). Housing and industrial construction impinge upon the area; for example, along the northern footslopes of Burnaby Mountain either side of the busy Barnet Highway and the Canadian Pacific Railway, and along the eastern side of Belcarra Mountain. The still spreading campus of Simon Fraser University across the top of Burnaby Mountain represents urbanization right within the study-area (Fig. 35), making the study a terrain evaluation of a wilderness and semi-urban region. An evaluation of an urban area requires greater attention to the underlying geology and Hydrology (Roed, 1977).

The changing distribution of soil drainage on Burnaby Mountain due to the diversion of precipitation off the plateau watershed, through storm drains into the underlying strata, which guides this water to dipslope soils causing them to become wetter, has already been described. Older buildings on the mountain utilize well water and septic sewage disposal systems. The changing water table levels will affect well levels, and for a septic tile drain field to operate properly requires an adequate volume of well drained soil in which there can be complete decomposition of the effluents from the tank or pit.

Burnaby Mountain is a cuesta formed primarily of sedimentary sandstones, capped by conglomerates which dip gently southwards. These rocks are associated with the potential for hydrocarbons such as gas and coal. A slide, now apparently stable, has occurred on the northwest footslopes (Fig. 24). The escarpment of Burnaby Mountain faces Belcarra Mountain on the other

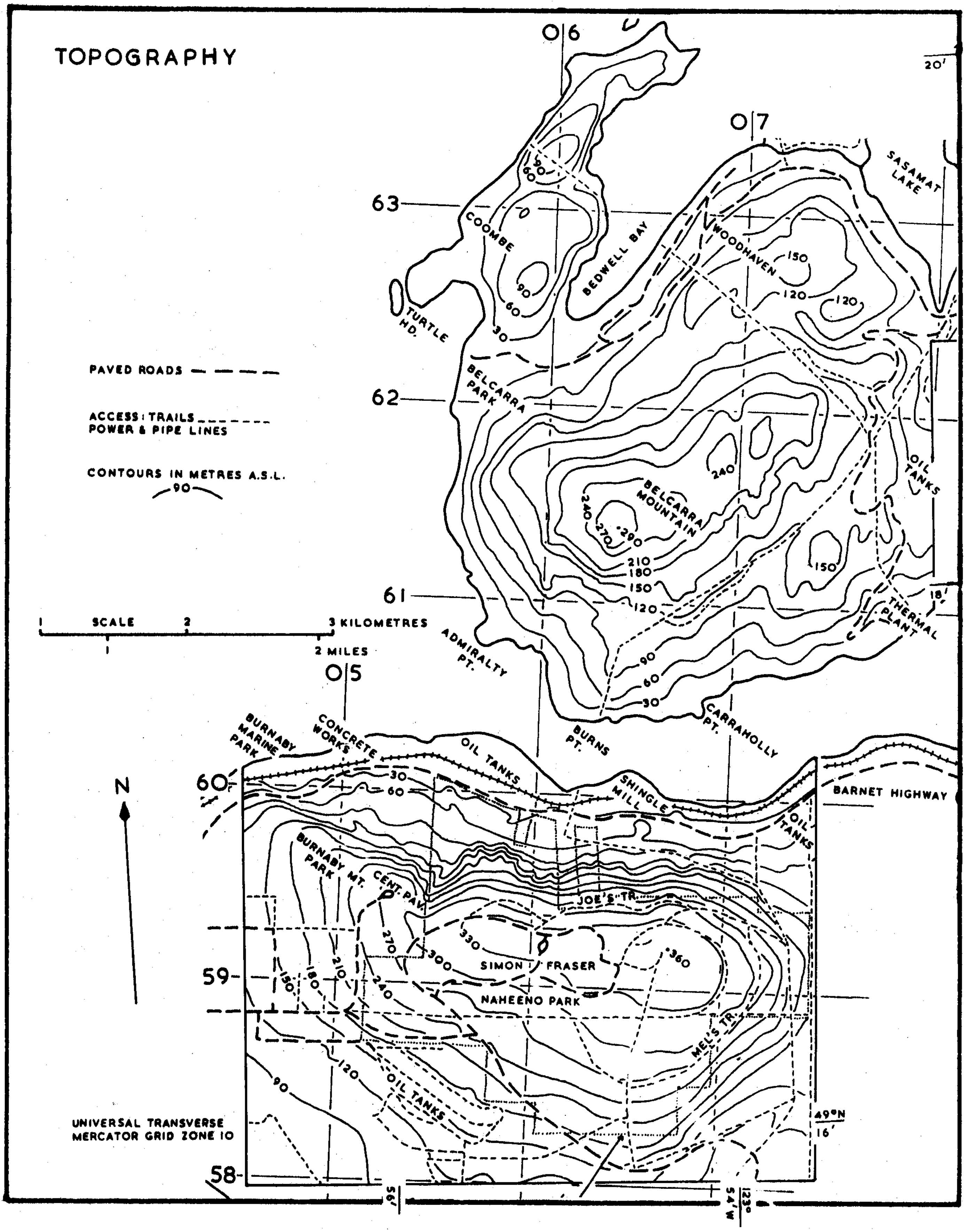


Fig. 50. Topography of the study-area.

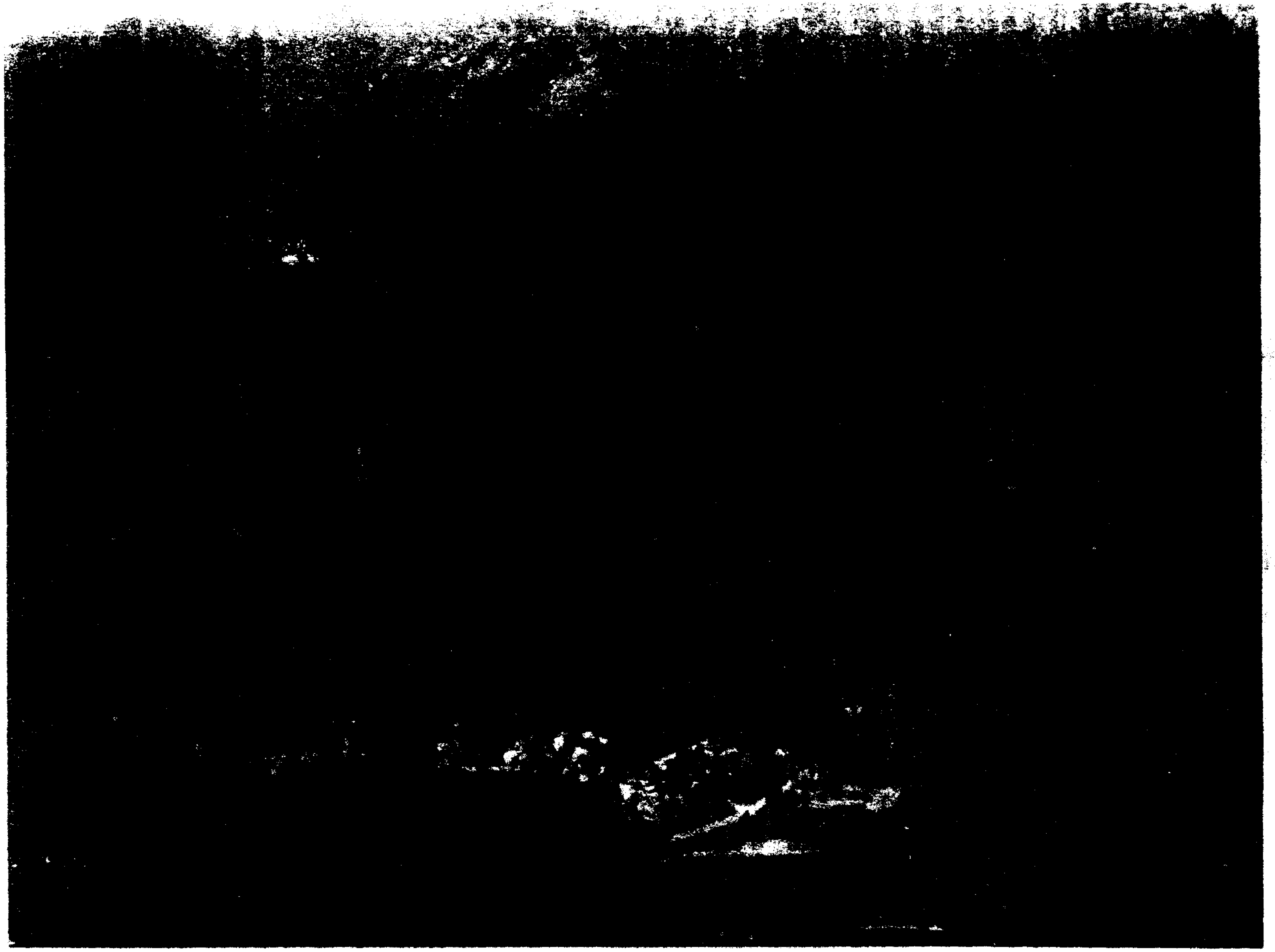


Fig. 51. Coombe Peninsula and Bedwell Bay, with many waterside dwellings.

side of Burrard Inlet, Belcarra Mountain being an irregularly domed batholith of igneous diorite contrasting with the Burnaby Mountain sediments. Roof and wall pennants of metamorphosed sediments on the flanks of the batholith crop out on the Coombe Peninsula (Fig. 52), containing lime-silicate rocks which are often associated with ore bodies, and so there is the potential for mining development, exemplified by the now-closed Twin Island Mine. The lower flanks of the mountains are mantled with surficial deposits of till, lacustrine, glacio-fluvial and marine origin. The coarse-textured glacio-fluvial outwash deposits are used as a local source of gravel.

Very well drained Orthic Humo-Ferric Podzols occur locally on Burnaby and Belcarra Mountains, generally high on north and northeast slopes (Fig. 53). Well to very well drained Eluviated Dystric Brunisols occur on Burnaby Mountain, but are more widespread over the igneous rocks of Belcarra Mountain. Well drained Orthic Dystric Brunisols are widespread, generally at higher elevations across the study-area. Moderately well drained Orthic Eutric Brunisols are most widespread on lower mountain flanks where they merge into valley-lands. Imperfectly drained Gleyed Eutric Brunisols occur at lower elevations, associated with poorly drained Rego and Fera Gleysols around Sasamat Lake and on the lower footslopes of Burnaby Mountain to the north and south of the main ridge.

The division of the landscape of the study-area into Land Systems must be based on the more permanent features such as geology and associated relief. Thus, the so-called Naheeno

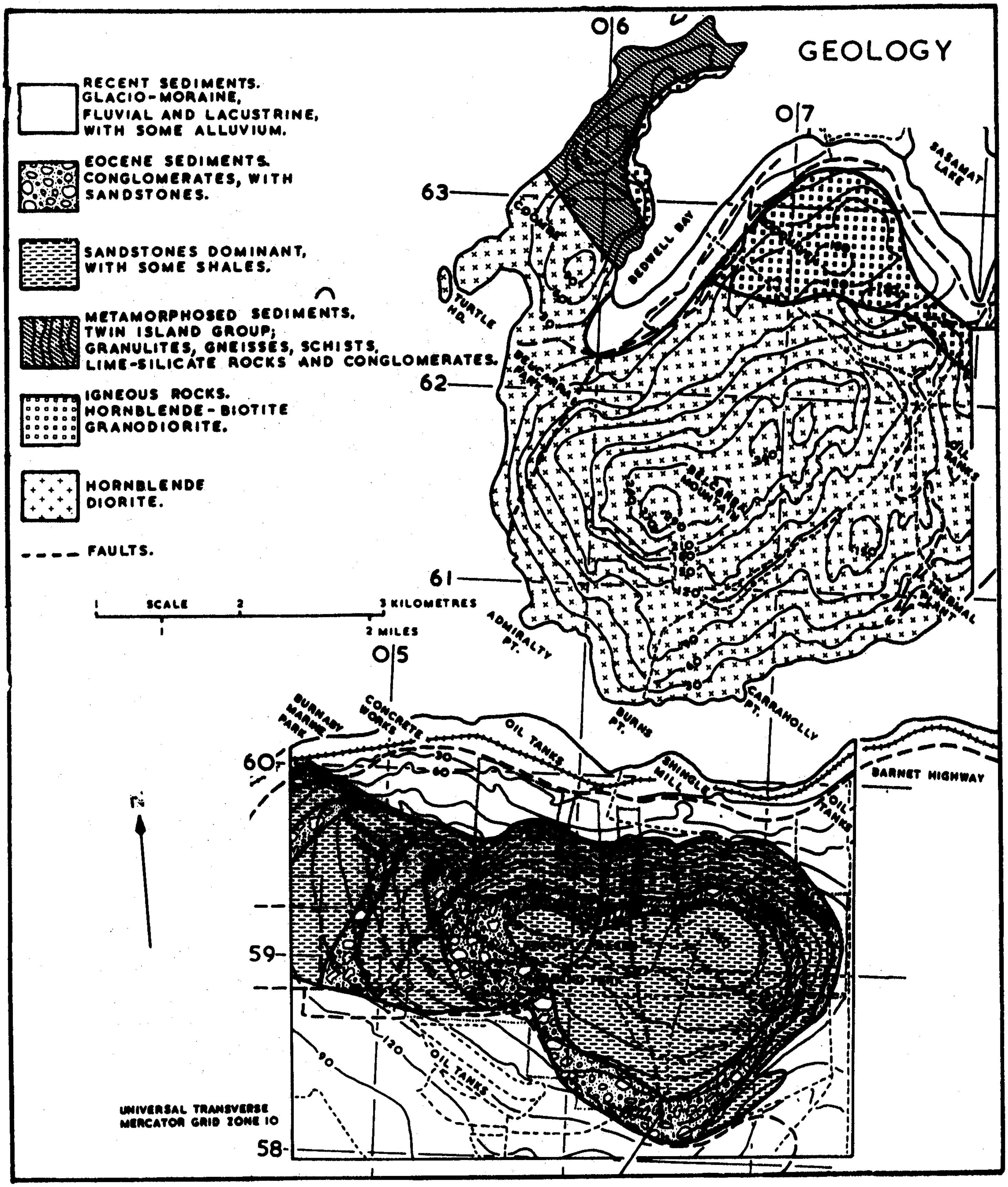


Fig. 52. Geology of the study-area.

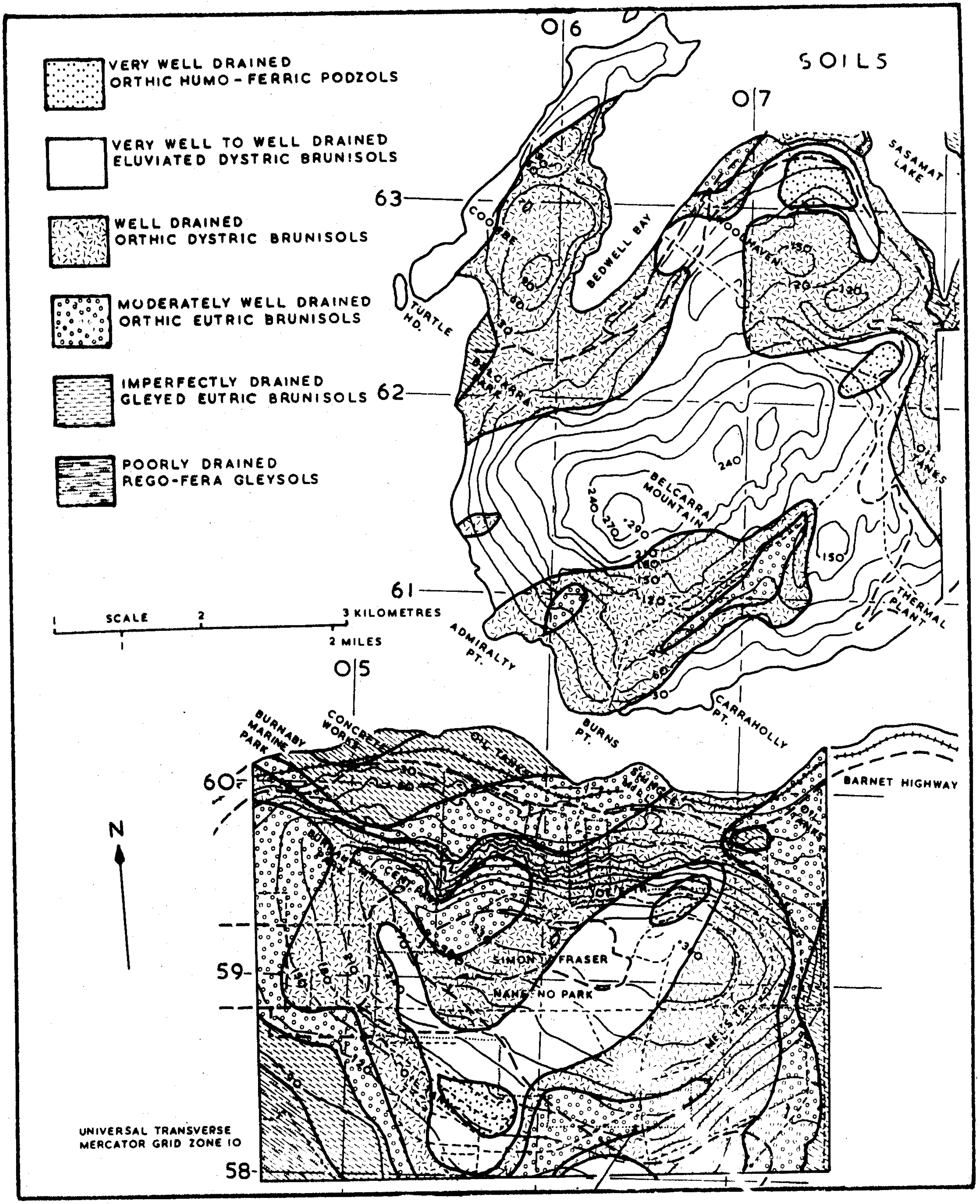


Fig. 53. Soils of the study-area (1976).

Land System 7 defines mountain upland associated with sedimentary rocks on Burnaby Mountain (Fig. 54), whereas the Woodhaven Land System 10 defines mountain upland associated with igneous rocks on Belcarra Mountain. Great differences of slope angle are important in determining land use, and so the Scarp Land System 6 defining the escarpment of Burnaby Mountain has been separated from the more gently inclined Naheeno Land System 7. Different aspects are associated with different microclimates, which can profoundly affect the distribution of vegetation types as well as land use, and so the northeast- to northwest-facing igneous slopes of the Farrer Land System 5 have been separated from the much warmer southwest-opening slopes of the Admiralty Land System 11. Lime-silicate rocks have the potential for mining operations, whereas sedimentary rocks have the potential for hydrocarbons, and so the Coombe Land System 9 on metamorphosed sediments has been separated from the Naheeno Land System 7 on unmetamorphosed sediments. The hydrology of surficial deposits can be very different from that of hard rock, and so the Sasamat Land System 4 associated with marine deposits on the southwest slopes of Burnaby Mountain has been separated from the upland sedimentary rocks of the Naheeno Land System 7.

Major differences of elevation have been accounted for primarily by dividing the study-area into two Land Regions, Land Region 1 defining less exposed areas and Land Region 2 defining those highly exposed mountain plateaus and ridges to which douglas fir appears very sensitive. Most tree tops of douglas fir on the exposed ridges of Burnaby and Belcarra Mountains are dead, reflecting the hostile environment.

Although particular features of the vegetation have been used to help define Land Regions, it is intended that they, and Land Systems, should represent the unchanging part of the landscape. Land Facets chiefly define differences in soils from place to place. Soils can change their character, especially following certain kinds of intervention by man into the landscape as on Burnaby Mountain. The Land Systems have been subdivided into Land Facets, from very well drained (1) to very poorly drained (6), to facilitate consideration of land-use issues, but the Land Facets should be regarded as the least permanent part of the terrain.

A terrain evaluation always has its objective defined at the start, in this study as the basis for multiple land-use considerations. The land is mostly forested, and has been logged from one end of the study-area to the other, a process that started at the turn of the century and was concluded during the 1940's. A secondary forest succession has now been established across most of the study-area (except on protected, steep slopes such as the Scarp Land System 6 defining the north-facing escarpment of Burnaby Mountain), and it could be logged again, if that is a desirable land-use. Possible logging would have to be weighed against the communal benefits (however these are judged) of preserving the land for recreation by the very large urban population in the area, a type of land-use that is rapidly spreading, especially around water bodies

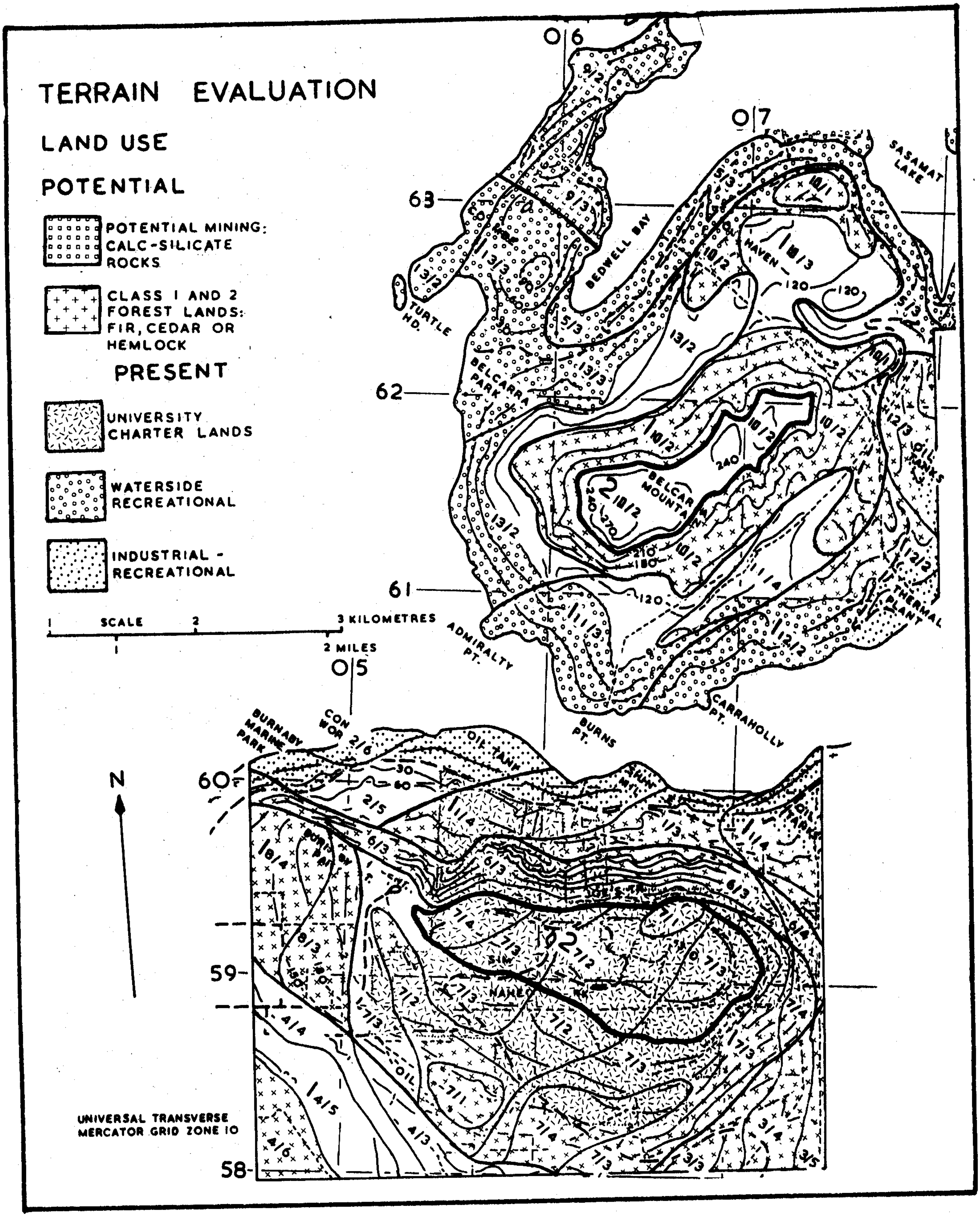


Fig. 54. Terrain evaluation of the study-area.

| LAND REGION | LAND SYSTEM<br>% of Land Region | LAND FACET<br>% of Land System | |
|---|---|---|---|
| 1 Low exposure (88%) | Surficial deposits of till, glacio-fluvial, glacio-lacustrine, slides and alluvium. | | |
| | 1/ BURRARD<br>5% Glacial, from sedimentary rocks; north aspect. | 1/3 Orthic Dystric Brunisol sandy loams | 26% |
| | | 1/4 Orthic Eutric Brunisol loams | 74% |
| | 2/ SLIDE<br>4% Rock slide, from sedimentary rocks; north aspect. | 2/5 Gleyed Eutric Burnisol clay loams | 91% |
| | | 2/6 Fera and Rego Gleysol silty clay loams | 9% |
| | 3/ BURQUITLAM<br>2% Glacial, from sedimentary rocks; southeast aspect. | 3/3 Orthic Dystric Brunisol sandy loams | 45% |
| | | 3/4 Orthic Eutric Brunisol loams | 33% |
| | | 3/5 Gleyed Eutric Brunisol clay loams | 22% |
| | 4/ SASAMAT<br>9% Glacial, from sedimentary rocks; southwest apsect. | 4/3 Orthic Dystric Brunisol sandy loams | 8% |
| | | 4/4 Orthic Eutric Brunisol loams | 42% |
| | | 4/5 Gleyed Eutric Brunisol clay loams | 42% |
| | | 4/6 Fera and Rego Gleysol silty clay loams | 8% |
| | 5/ FARRER<br>11% Glacial, from igneous rocks; valleylands. | 5/2 Eluviated Dystric Brunisol loamy sands | 24% |
| | | 5/3 Orthic Dystric Brunisol sandy loams | 44% |
| | | 5/4 Orthic Eutric Brunisol loams | 29% |
| | | 5/5 Gleyed Eutric Brunisol clay loams | 3% |
| | Sedimentary rocks of sandstones, with conglomerates and some shales. | | |
| | 6/ SCARP<br>5% Escarpment; north aspect. | 6/3 Orthic Dystric Brunisol sandy loams | 92% |
| | | 6/4 Orthic Eutric Brunisol loams | 8% |

| LAND REGION<br>% of area | LAND SYSTEM<br>% of Land Region | LAND FACET<br>% of Land System | | LAND REGION<br>% of area |
|---|---|---|---|---|
| | 7/ NAHEENO<br>10% of 1: 47% of 2<br>Dipslope; mostly south aspect. | 7/1 Orthic Humo-Ferric Podzol sands | 5% | 2 High exposure (12%) |
| | | 7/2 Eluviated Dystric Brunisol loamy sands | 28% | |
| | | 7/3 Orthic Dystric Brunisol sandy loams | 51% | |
| | | 7/4 Orthic Eutric Brunisol loams | 16% | |
| 1 Low exposure (88%) | 8/ CENTENNIAL<br>3% west aspect. | 8/3 Orthic Dystric Brunisol sandy loams | 48% | |
| | | 8/4 Orthic Eutric Brunisol loams | 52% | |
| | Metamorphic rocks of gneisses, schists and lime-silicate bodies | | | |
| | 9/ COOMBE<br>4% Northward-directed low ridges | 9/2 Eluviated Dystric | 44% | |
| | | 9/3 Orthic Dystric Brunisol sandy loams | 56% | |
| | Igneous rocks of quartz, biotite and/or hornblende diorites. | | | |
| | 10/ WOODHAVEN<br>12% of 1: 22% of 2<br>Rugged upland terrain. | 10/1 Orthic Humo-Ferric Podzol sands | 4% | |
| | | 10/2 Eluviated Dystric Brunisol loamy sands | 79% | |
| | | 10/3 Orthic Dystric Brunisol sandy loams | 17% | |
| | 11/ ADMIRALTY<br>11% Southwest aspect. | 11/3 Orthic Dystric Brunisol sandy loams | 59% | |
| | | 11/4 Orthic Eutric Brunisol loams | 41% | |
| | 12/ CARRAHOLLY<br>6% Southeast aspect. | 12/2 Eluviated Dystric Brunisol loamy sands | 71% | |
| | | 12/3 Orthic Dystric Brunisol sandy loams | 29% | |
| | 13/ TURTLE<br>9% Mostly west aspect. | 13/2 Eluviated Dystric Brunisol loamy sands | 50% | |
| | | 13/3 Orthic Dystric Brunisol sandy loams | 50% | |

(Fig. 51). To some extent the two activities can occupy different parts of the landscape, and shading has been utilized to reflect current recreational interests and those areas supporting the most productive forests (Fig. 54). A general separation of the two activities has caused many to believe that logging can be allowed in upland areas (thus supporting a labour force, as just east of the study-area), provided that it is not allowed to extend over mountain crests onto slopes that can be seen from water bodies and spoil the view of any recreationers on the water or along the water's edge.

Unfortunately, the study-area consists mostly of alternating mountains and lower areas containing lakes and inlets, from which every mountain top and ridge crest in the study-area can be seen. Possibly the study-area is too small, and is located too close to an urban area for the activities of logging and recreation to be compatible. Possibly the study-area is best considered as a recreational lung for the urban population. If this is so, a visual analysis of the study-area becomes very important. In the past the evaluation of environmental intangibles has been considered an immeasurable part of the landscape (Coomber and Biswas, 1973), but recent attempts have been made to remedy this matter. Surveys have been made concerning perceptions of the landscape by different people, and common attitudes have been defined. This is a new and rapidly evolving field of study. Recreational activity will be profoundly affected by microclimates, both from a visual and comfort point of view, and this is another field of study that needs careful consideration. Recreational activity interacts badly with mining. If the Coombe Land System 9 on lime-silicate metamorphic rocks contained a useful ore load, the crushing and concentrating process would create a horrendous scar within Indian Arm, completely incompatible with the recreational housing along the water's edge.

## Vegetation as part of terrain evaluation

### Distribution of Forest Cover

Hardwoods and hardwood-dominant mixedwoods cover most of Burnaby Mountain. Mixedwoods occur in a belt along the southern coastline of Belcarra Mountain, opposite Burnaby Mountain. Mixedwoods also occur in a broad belt from Belcarra Park to Bedwell Bay, incorporating the southern part of the Coombe Peninsula. The remaining area of Belcarra Mountain, down to Sasamat Lake, is dominated by softwoods and softwood-dominant mixedwoods.

### Distribution of Forest Stand Age

A forest stand age of around 70 years, locally increasing to 100 years, occurs on and below the north-facing escarpment of Burnaby Mountain, down to the shores of Burrard Inlet; and from west, through northwest, to north of Sasamat Lake, to the coastline of Bedwell Bay and Farrer Cove. Much of the remaining forest is aged around 50 years on Burnaby Mountain, and 45 years on Belcarra Mountain.

### The Preferential Distribution of Selected Flora and Fauna

(The distribution of certain carnivorous insects, presumably, follows more prolific prey species).

Northeast Slopes

Oregon beak-moss, elderberry and swordfern.

North Slopes

Oregon beak-moss; elderberry, especially on the sediments of Burnaby Mountain; swordfern; insects less common on cool slopes.

Northwest Slopes

Oregon beak-moss and swordfern, especially on the igneous rocks of Belcarra Mountain; ladyfern, especially on the sediments of Burnaby Mountain; elderberry.

West Slopes

Ladyfern; salmonberry, especially on the sediments of Burnaby Mountain and in imperfectly and poorly drained soils; red ants.

Southwest Slopes

Huckleberry, especially on the sediments of Burnaby Mountain; ladyfern; salmonberry; spiders, with the greatest spread occurring on Burnaby Mountain, and the fewest occurring in the central, north-south belt of sands across Belcarra Mountain (Fig. 38); centipedes, especially on the sediments of Burnaby Mountain; red ants, all of the insects occurring preferentially on the warmer slopes and the well and imperfectly drained soils.

South Slopes

Huckleberry; thimbleberry, especially on the sediments of Burnaby Mountain; spiders, centipedes and red ants.

Southeast Slopes

Huckleberry; bracken, especially on the sediments of Burnaby Mountain; centipedes.

East Slopes

No preferred distribution.

## Forest Productivity

### Procedure

An analysis of forest productivity involved the measurement of the following six variables.

Stand density; based on counts per tenth acre circular plots distributed systematically within the 400 m. grid established across the study-area.

Forest cover type; douglas fir, hemlock or cedar dominated stands with some or few other coniferous or deciduous species.

Parent material; thin sandy or sandy loam regolith over igneous rocks of Belcarra Mountain, thin sandy loam regolith over metamorphosed sediments, thin loam reolith over sedimentary rocks of Burnaby Mountain, thick loamy glacial material - morainal, lacustrine or glacio-fluvial - over igneous rocks around the footslopes of Belcarra Mountain, and thick clay loam glacial material over sedimentary rocks around the footslopes of Burnaby Mountain.

Drainage; very well drained - Podzols, well drained - Eluviated Dystric Brunisols generally on Belcarra Mountain and Orthic Dystric Brunisols more commonly on Burnaby Mountain, moderately well drained - Orthic Eutric Brunisols, imperfectly drainage -

Gleyed Eutric Brunisols, poorly drained - often Fera Gleysols, very poorly drained - often organic Rego Gleysols generally on the footslopes of Burnaby Mountain.

Elevation; six classes from sea level to greater than 276m.

Aspect.

Productivity was assessed routinely and approximately in terms of the mean annual increment (M.A.I.) as cu. ft./ acre, transformed into cu. m. / hectare, calculated from basal area measurements using a prism, and from average tree volumes based on measurements of tree diameter and height made during 1974 and 1975 with a diameter tape and hypsometer using Provincial Standard Cubic-Foot Volume Tables (Browne, 1962). The tree ages were determined by coring.

The analyses utilized all six independent variables in one synergistic interaction for each of the species douglas fir, western hemlock and western red cedar. As with the other analyses of this type, a 20% random sample was extracted from the original population and used to check the effectiveness of the analysis.

## Results

For douglas fir the fortuitous events determining stand density (e.g. chance seeding, seedling survival and stand competition during early growth) constitut the most important factor influencing today's productivity, whereas aspect is the least important factor involved. In contrast, for hemlock aspect is the most important factor influencing productivity and stand density the second least important factor, with parent material being the least important. The productivity of cedar is most strongly influenced by drainage, and least influenced by the presence of other species within the cedar-dominated stand.

In all cases the relatively open, least dense stands are the least productive, whereas the most dense stands are the most productive, and the presence of other conifers in a stand dominated by one species inhibits productivity in varying degrees, but all the species of interest are most productive if some deciduous trees are present.

Poorly drained soils are most productive of cedar, imperfectly drained soils of hemlock, and well drained soils of douglas fir, and the reverse is true for least productivity. Glacial loam and clay loam deposits are the most productive of cedar, loams and sandy loams over sedimentary or metamorphic rocks are most productive of hemlock, and a sandy regolith over igneous rocks is most productive of douglas fir. Low elevation is most productive of cedar, high elevation of hemlock and moderate elevation of douglas fir. Top-dying of douglas fir is sadly evident around the high plateau of Burnaby and Belcarra Mountains. Southsoutheast-facing slopes, those with warm soils under forest and receiving the greatest precipitation from the prevailing summer winds, are the most productive of cedar and douglas fir, whereas the cooler northeast-facing slopes are the most productive of hemlock which appears to compete better with other species on these slopes.

Summarising, all species of interest are more productive in dense stands with some deciduous trees present. Adequate

Fig. S5. Generalized interaction table for western hemlock.

| MAI | | Parent Material | Drainage | Elevation | Aspect | Forest Cover | Stand Density |
|---|---|---|---|---|---|---|---|
| c m/h:c | f/a | | | | | | |
| | | | Podzols | 0 | SW | with | about |
| 0.52 | 45 | igneous | | to | | some | 170 |
| | | | Gleysols | 110 m | S | cedar | trees/hect. |
| 1.03 | 90 | | | | | | |
| | | surficial from sedimentary | Eluviated Brunisols | 111 | NW-W | with | about |
| 1.54 | 135 | | | to | | some | 320 |
| | | surficial from igneous | Gleyed Brunisols | 220 | SE | douglas fir | trees/hect. |
| 2.06 | 180 | | | | | | |
| | | metamorphic | Dystric Brunisols | | N-NE | with | about |
| | | | | | | some | 990 |
| 2.57 | 225 | | | 221+ | | | |
| | | | | | | deciduous | trees/hect. |
| | | sedimentary | Eutric Brunisols | | E | | |
| 3.09 | 270 | | | | | | |

Intercept = -14 (c f/a) N (analysis) = 1200 Mean = 123 Standard Deviation = 97 $r^2 = 0.74$
N (check) = 300 (total N = 1500) $r^2 = 0.63$

Within a complex synergistic interaction great productivity is associated with sedimentary rocks supporting well and moderately well drained Dystric and Eutric Brunisols, at high elevations with E, through NE, to N aspect, and dense stands with some deciduous trees. Moderate productivity is associated with surficial deposits over igneous and sedimentary rocks supporting imperfectly and well drained Gleyed Brunisols and Eluviated Brunisols, at moderate elevations with SE or NW to W aspect, and moderately dense stands with some douglas fir. Poor productivity is associated with igneous rocks supporting poorly and very well drained Gleysols and Podzols, at low elevations

(MAI = mean annual increment in cubic metres/hectare and cubic feet/acre).

Fig. S6. Generalized interaction table for douglas fir.

| MAI c m/h:c | f/a | Parent Material | Drainage | Elevation | Aspect | Forest Cover | Stand Density |
|---|---|---|---|---|---|---|---|
| 0.57 | 50 | surficial from sedimentary | Gleysols | 0 | NW-W | with | about |
| | | | | to | | some | 170 |
| 1.14 | 100 | surficial from igneous | Gleyed Brunisols | 110 m | SW | hemlock | trees/hect. |
| 1.72 | 150 | sedimentary | Eutric Brunisols | | N-NE | with | about |
| | | | | 221+ | | some | 320 |
| 2.29 | 200 | metamorphic | Dystric Brunisols | | E | cedar | trees/hect. |
| 2.86 | 250 | | Eluviated Brunisols | 111 | S | with | about |
| | | igneous | | to | | some | 990 |
| 3.43 | 300 | | Podzols | 220 | SE | deciduous | trees/hect. |

Intercept = +4 (c f/a) N (analysis) = 1095 Mean = 150 Standard Deviation = 104 $r^2 = 0.78$
N (check) = 273 (total N = 1368) $r^2 = 0.73$

Within a complex synergistic interaction great productivity is associated with igneous rocks supporting well drained Podzols and Eluviated Brunisols, at moderate elevations with SE and S aspect, and dense stands with some deciduous trees. Moderate productivity is associated with metamorphic and sedimentary rocks supporting well to moderately well drained Dystric and Eutric Brunisols, at high elevations with E, through NE, to N aspect, and moderately dense stands with some cedar. Poor productivity is associated with surficial deposits over igneous and sedimentary rocks supporting imperfectly drained and poorly drained Gleyed Brunisols and Gleysols, at low elevations with SW, through W, to NW aspect, and open stands with some hemlock.

(MAI = mean annual increment in cubic metres/hectare and cubic feet/acre).

Fig. S7. Generalized interaction table for western red cedar.

| MAI c m/h | c f/a | Parent Material | Drainage | Elevation | Aspect | Forest Cover | Stand Density |
|---|---|---|---|---|---|---|---|
| 0.50 | 44 | | Podzols | | NW-W | with | about |
| | | igneous | | 221+m | | some | 170 |
| 1.01 | 88 | | Eluviated Brunisols | | SW | douglas fir | trees/hect. |
| 1.51 | 132 | metamorphic | Dystric Brunisols | 220<br>to | N-NE | with<br>some | about<br>320 |
| 2.01 | 176 | sedimentary | Eutric Brunisols | 111 | E | hemlock | trees/hect. |
| 2.52 | 220 | surficial over igneous | Gleyed Brunisols | 110<br>to | SE | with<br>some | about<br>990 |
| 3.02 | 264 | surficial over sedimentary | Gleysols | 0 | S | deciduous | trees/hect. |

Intercept = -24 (c f/a) N (analysis) = 530 Mean = 99 Standard Deviation = 70 $r^2 = 0.84$
N (check) = 132 (total N = 662) $r^2 = 0.72$

Within a complex synergistic interaction great productivity is associated with surficial deposits over sedimentary and igneous rocks supporting poorly drained and imperfectly drained Gleysols and Gleyed Brunisols, at low elevations with S and SE aspects, and dense stands with some deciduous trees. Moderate productivity is associated with sedimentary and metamorphic rocks supporting moderately well and well drained Eutric and Dystric Brunisols, at moderate elevations with E, through NE, to N aspect, and moderately dense stands with some hemlock. Poor productivity is associated with igneous rocks supporting well drained Eluviated Brunisols and Podzols, at high elevations with SW, through W, to NW aspect, and open stands with some douglas fir.

(MAI = mean annual increment in cubic metres/hectare and cubic feet/acre).

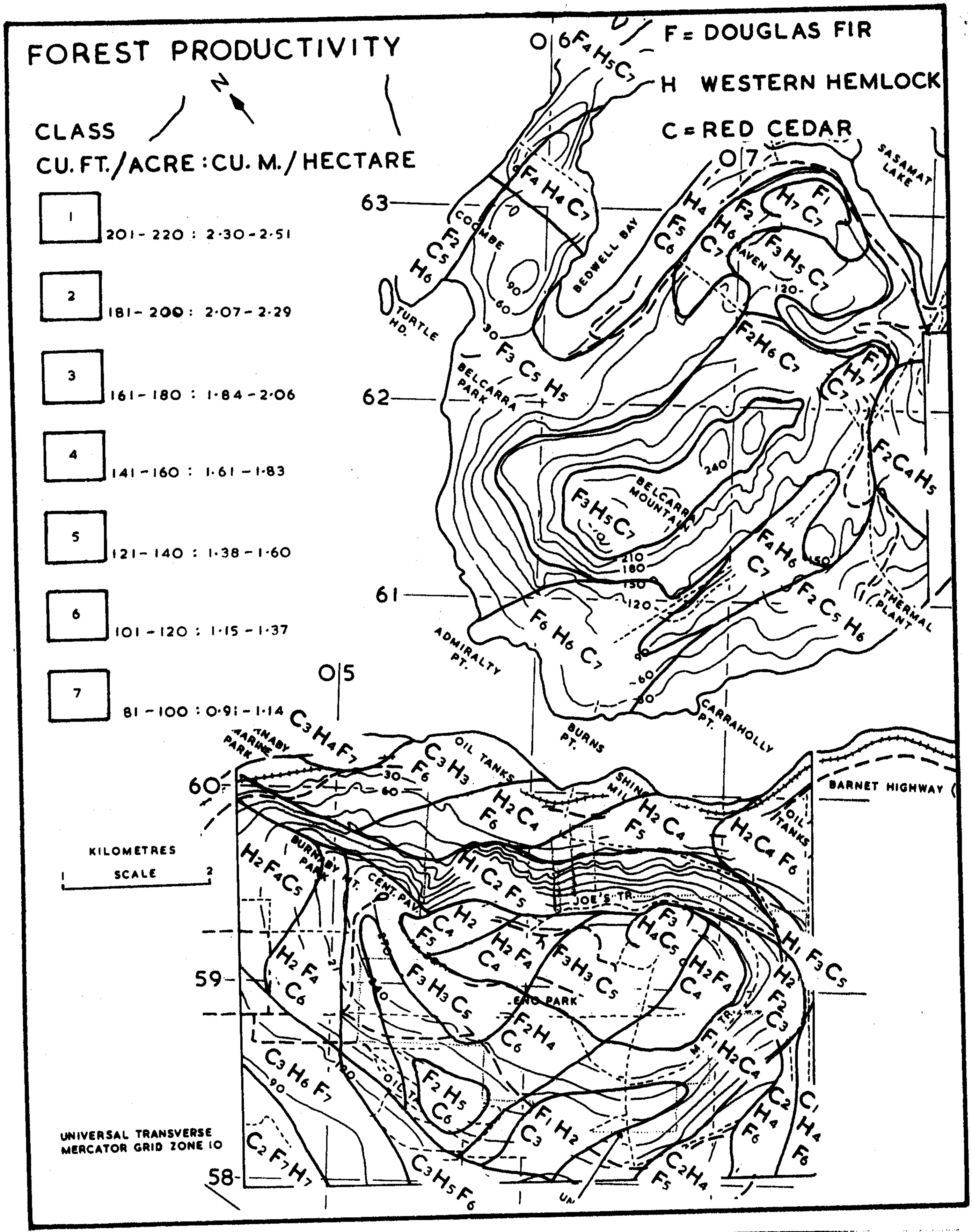


Fig. 58. Forest productivity of the study-area, based on the land classification.

water supplies in low-lying, relatively fine-textured, poorly drained soils over valley glacial deposits on southeast-facing slopes of Burnaby and Belcarra Mountains appears to be the environment most conducive to the growth of cedar. Imperfectly drained, medium-textured soils on upland sedimentary sites on Burnaby and Belcarra Mountains facing northeast where there is better conservation of moisture appear to be most conducive to the growth of hemlock. Douglas fir appears to achieve its best growth on the igneous upland of Belcarra Mountain where the soils are sandy and well drained, although where droughty conditions are ameliorated on southeast slopes receiving most summer rainfall (Figs. 55-57).

Using the results of the analysis of forest productivity by site description, the M.A.I./unit area was predicted for each Land Facet, within each Land System, within the land classification of Fig. 54, and categorized by productivity classes for each of the three species, douglas fir, western hemlock and red cedar (Fig. 58).

## Visual Analysis

There is a dichotomy in this study between, first, terrain evaluation derived from the earth sciences, which serves as a basis for, second, landscape analysis which attempts to introduce a certain discipline into the subjective appraisal of the intangible, aesthetic qualities of a landscape. The two analyses involve very different approaches and the need for two different language philosophies. The first utilizes words to define a complex physical environment involving geology, soils and vegetation, reduced to its simplest terms so that the land classification can be used by those not involved in its construction. The second uses words, sometimes more precisely for landscape classification purposes, but sometimes to create visual images of parts of this landscape. However, it is submitted that the landscape analysis is enhanced by having its roots within the earth sciences represented by terrain evaluation, particularly as regards wilderness qualities, just as consideration of mining and forestry potential, again based on the terrain evaluation, further enhances an analysis of the landscape in terms of its tourist qualities.

When assessing landscape attractivity for outdoor recreation, Lewis et al. (1979) of the Lands Directorate, Environment Canada, developed a five-fold classification based on the variety of topography, vegetation and water, with the assumption that landscapes having great variety were the most attractive. Class 1 lands have a great amplitude of relief, extensive water bodies and a mixedwood-parkland type of vegetation, whereas class 5 lands are flat, with little water and are associated with an unchanging vegetative expanse. The system for visual resource management developed by the Bureau of Land Management, U.S. Department of the Interior (in preparation for publication) also has five classes. Class 1 provides for natural ecological changes across the landscape and does not exclude very limited management activity (although any man-made contrast in the area must not attract attention), whereas in class 5 lands there has been an erosion of scenic quality because of unacceptable cultural encroachment and where rehabilitation is needed (although careful change may add acceptable visual variety to the area).

The above two scales can be combined into classes 1 to 5, representing the gradation from land showing the maximum natural variety in the landscape where human intervention for recreational purposes creates no visual conflict, to land greatly modified by human intervention where visually pleasing variety sometimes has to be deliberately created. This classification attempts to rank landscape quality and assess the required management for conservation, wilderness recreation and commercial tourism. Different people have different recreational needs, but Gunn (1976) has argued that there is a strong synergism operating between the different forms of recreation which have greater total impact and interdependencies that the summation of their individual impacts.

Using this combination scale, presumably Sasamat Lake in the Farrer Land System 5 would be class 1 land for recreation since, although the lake has been dammed to supply water to a nearby refinery, there is a natural serenity pervading the environs. The few waterside dwellings do not clash with the natural landscape, but merge with the mountain forest and waterside scenery. Human intervention has not damaged the beauty of the landscape or, alternatively, there has been time for the modified shoreline to evolve a natural looking transition to forested slopes, although there is the need to define limits to recreational development so that no irreversible deterioration occurs, consistent with maximizing recreational opportunities. There is a need to preserve this declining area of ridge and lake wilderness, for recreation by an increasing proportion of the public.

The extensive sea shoreline in the study-area is a highly sensitive zone since it is clearly visible from recreational boats, just like the shoreline of Bowen Island (Block, 1978). The tumble of rocky slopes and spurs along the southern and western shores of Belcarra Mountain in the Turtle Land System 13 locally shelter small coves, particularly off Indian Arm. The mountain ridges of the hinterland reach upward into view from the Arm, forming an impressive backdrop for boaters. Generalizing, the landscape offered by areas of water with accessible shoreline and areas of high relief nearly always attract visitors (Lewis et al., 1979). Within the Coombe and Turtle Land Systems 9 and 13 around the Coombe Peninsula there are many waterside dwellings, and further building is spreading along the shoreline away from this congested part, some of the buildings ostentatious, some merging comfortably into there natural background landscapes. The spread of recreational housing would place this zone within class 2, and it is imperative that further development is controlled since unmanaged building could degrade this otherwise spectacular shoreline scenery into class 3. It would, of course, be outrageous to allow any mining of the lime-silicate rocks on the Coombe Peninsula in the Coombe Land System 9.

The dominantly coniferous cover of Belcarra Mountain has been somewhat scarred by power lines, which must be kept clear of forest regrowth for line maintenance, and careful management is needed to ensure no further erosion of scenic quality (which erosion would be seen from Indian Arm and Burrard Inlet). The shallow, organic soil is easily eroded from any igneous prominences after uncaring logging, and by clearing operations along power lines where rocky piles locally protrude through the vegetation, and reforestation of such areas can exceed 100 years. This would be class 3 land. The extensive "fresh" soils (well to moderately well drained) developed on the crystalline rocks of Belcarra Mountain support a well-lit, attractive forest with a rich herbaceous ground flora, especially on the warmer south - and southwest-facing slopes, accessed by numerous trails into this wilderness area (Fig. 59). Rocky mounds and dead tree tops are most frequently seen along the ridge top in the Woodhaven Land System 10 in Land Region 2.

The footlands alongside Burrard Inlet and below the escarpment of Burnaby Mountain within the Burrard and Slide Land Systems 1 and 2 would be class 4 land since there has been a distinct erosion of scenic quality, and rehabilitation is needed, possibly with careful changes such as the construction of Burnaby Marine Park (Fig. 59) to add acceptable visual variety to the area. This facility jostles with urban industrial activities, but any visual deterioration of this waterfront is not irretrievable. The Canadian Pacific Railway and busy Barnet Highway cross these footlands, linking the dockside bustle of Port Moody with Vancouver, but there is still much woodland mantling the slopes and ameliorating any industrial harshness. Also, the highway cannot be seen from the the Inlet and the railway cannot be seen from the footslopes of the escarpment.

Most of Burnaby Mountain would be class 5 recreational land, badly scarred by access roads, overhead lines and underground pipelines, in great need of rehabilitation. The exception is the Scarp Land System 6 which is class 1 land, but in urgent need of protection to preserve it as a quiet oasis set within a noisy urban scene, with a gun range and a busy highway at its base, and a university campus behind its crest. The campus is a completely artificial landscape, to be judged primarily by its architecture, but plans are now being developed to increase the visual variety in the landscaping by carefully introduced exotic species after detailed assessment of microenvironments across the campus. The campus is a highly exposed site in Land Region 2 and exposure coupled with other factors has killed some trees. Sensitive species will have to be planted against sheltered, sunny walls for protection from the chilling effect of vortex-eddies and through-flow gusts.

The sedimentary dipslope of the Naheeno Land System 7 supports aggressive forest growth, of hemlock at higher elevations, of douglas fir at intermediate elevations and of cedar in imperfectly and poorly drained soils distributed across the southeast, through south, to southwest footslopes (Fig. 58). If properly supervised, this healthy regrowth could help forest recovery after past disturbance, especially now that a research park, a school field centre and another access road are being proposed for the dipslope within the

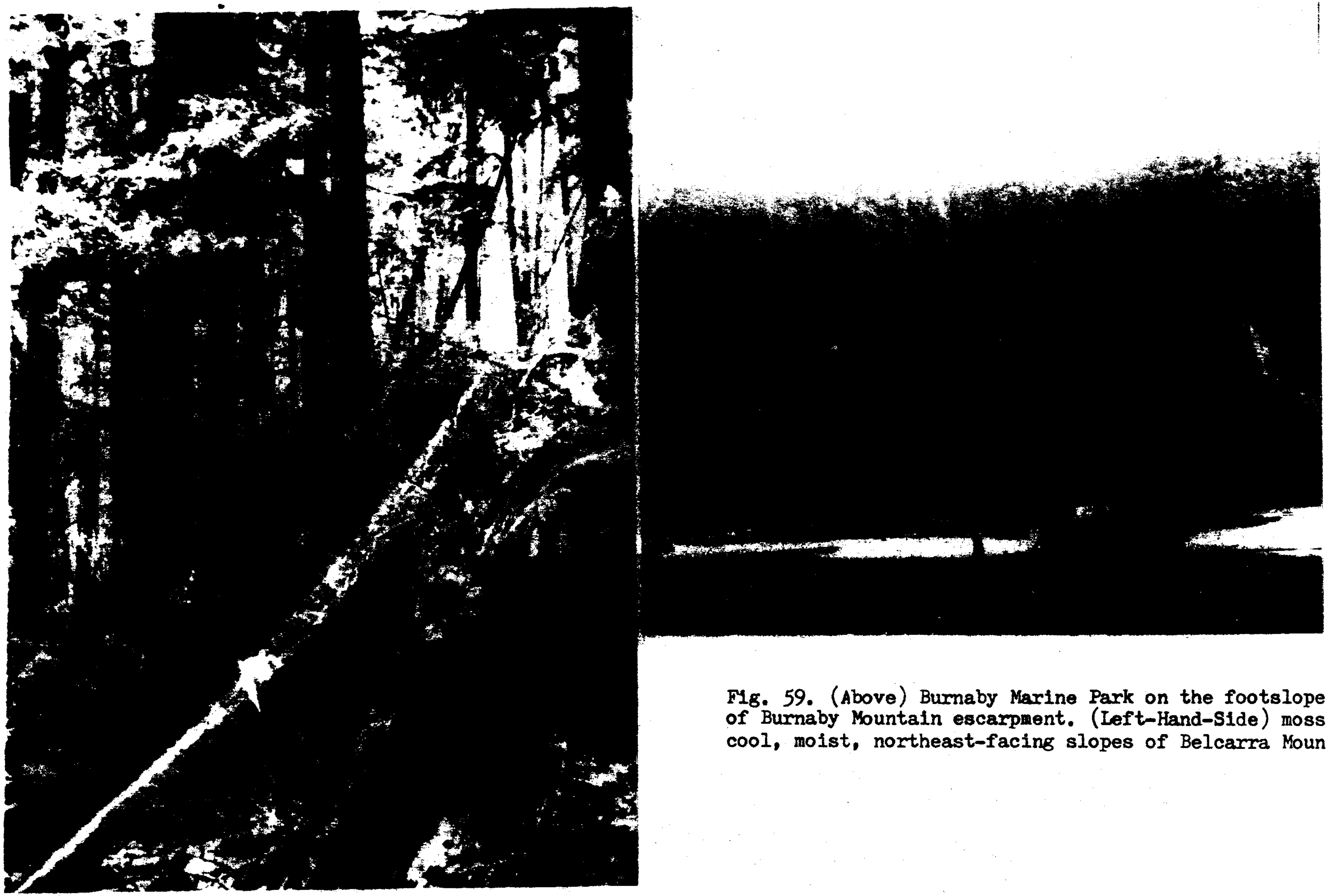


Fig. 59. (Above) Burnaby Marine Park on the footslopes of Burnaby Mountain escarpment. (Left-Hand-Side) mossy, cool, moist, northeast-facing slopes of Belcarra Mountain.

University Endowment Lands. All too often urban developers have a most casual attitude towards the natural landscape, and control of construction activity will be needed to avoid completely spoiling the remaining forest. Its present appearance should not be considered a measure of its potential. The creation of forested buffer zones between building blocks should be used as a reason for upgrading forests degraded by past construction activities, which then could be used for field studies by students.

Substantial public access into a forest tends to destroy the shrub layer, creating a forest floor which Patey and Evans (1979) found was aesthetically preferred by many. However, removal of the shrub layer also removes the tree seedlings constituting the next generation of the forest. Also, in some of the more popular parks, for example in the Buntzen Lake Park just outside the study area, concentrations of people have so eroded the surface soils as to expose the upper root boles of trees, which eventually die. Forest management of Burnaby Mountain would, therefore, be needed, involving the removal of diseased or deformed trees, and the planting of selected tree species to enrich the present forest, which would need some degree of protection from people. Great numbers of people can destroy the very scenery that attracts them. In the buffer zones between campus units walking traffic should be encouraged by careful layout to use prescribed trails, with study and research groups mostly utilizing the forest environs.

The susceptibility of a landscape to visual damage from management intervention for recreational or logging purposes, its visual vulnerability (Tetlow and Sheppard, 1979) or its visual absorption capacity (Yoemans, 1979) is affected chiefly by the degree of visual penetration (the distance into a landscape one can see from a vantage point), and the complexity of the landscape (the angle of slope together with amplitude of relief, the vegetative diversity and the soil and rock stability and colour contrast). Areas near landscape focal points, ridgetops, forest-meadow or waterside edge landscapes, have a limited capacity to absorb management interventions. Thus, the coastline landscape of the Coombe Land System 9 would have a limited visual absorption capacity for the characteristic management of the area, recreational housing. Care would have to be exercised if negative management effects are to be avoided. Steep slopes with uniform forest stands and contrasting soil colours also have a low visual absorption capacity. Thus, the Woodhave Land System 10 containing the upper slopes around Belcarra Mountain has a limited capacity to accept cuts on steep slopes through the forest for power transmission lines without visual scarring because of the contrast in colour of the exposed podzolized soils and diorite rock with the dominantly coniferous forest cover.

When aesthetic values are superimposed upon the land's physical character, guidelines are needed to aid perception of the components of a recreational environment. The landscape analysis for the study-area was based on methods of the landscape architect as described by Burton Litton (1972). Examples of the application of this approach are Yoeman's (1976) intensive study of the Spallumcheen area in British Columbia, and Gordon and Shaine's (1978) extensive study of Alaskan natural landscapes.

Burton Litton (1972) has suggested that the primary elements of a landscape could be defined as the form, that is a convex landscape feature such as the main ridge of Belcarra Mountain, and the space, that is a concave feature such as Sasamat Lake enclosed by mountainous ridges. Prominence can be given to both elements by proximity and contrast, for example the isolation of the escarpment of Burnaby Mountain and the edge contrast of Sasamat Lake surrounded by forest. The magnitude of the higher rock walls of the ravine eroded into the escarpment of Burnaby Mountain below the Centennial Pavilion within the Scarp Land System, merging down into forested slopes, adds the perspectives of proportion and texture to an appreciation of the landscape, while the complex configuration of Sasamat Lake and the local vegetative succession from water to forest can help sustain interest in the landscapes.

Secondary elements of the landscape concern the position of the observer. From an observer normal position on the Academic Quadrangle of Simon Fraser University campus a complex panoramic view unfolds across the irregular, hummocky contours formed by successive, hard, igneous and metamorphic ridges aligned across the background, with the Woodhaven Land System 10 on Belcarra Mountain in the foreground. From an observer superior position on the campus summit of the Naheeno Land System 7 an equally spectacular view opens up on moist but clear days when looking down Indian Arm washing the rocky, irregular northwestern coastline of the study-area, towards wide, hanging valleys of a glaciated landscape in the haze and subdued colours of the distant background. From an observer inferior position on a boat in Indian Arm the ridges can be shrouded by torn clouds, visibly swirling in a vortex-eddie on the lee side during the aftermath of stormy weather.

For an observer, say on the road to Belcarra Park, travelling along the southwest shore of Sasamat Lake, there tends to be an hierarchical sequence of visual impacts in the landscape; first, a dominant landform such as the silhouette of Buntzen Ridge in the background beyond the west margin of the study-area; second, the eye sweeps down the intervening slopes to the nearest water body, the configuration of bays and peninsulas along the opposite shoreline of Sasamat Lake, third, the vegetation in the form of the forested slopes linking the ridge with the lake. Within this middleground softly coloured landscape types can be differentiated. Across the lake in the foreground the observer is a participant within the intimate interaction of water and overhanging trees around about, where visual detail, touch, colour and smell can be appreciated with maximum intensity.

From Burrard Inlet the rising sun makes the escarpment of Burnaby Mountain in the Scarp Land System 6 appear sombre and massive, but impressive, the steep slopes falling in perpetually cool shade because of their northerly aspect, contrasting with the greater appreciation of depth and colour in the landscape yielded by the side-lighting of late afternoon. This north face offers a welcome relief during hot summer days. Only projecting spurs of Burnaby Mountain escarpment feel the meagre warmth from side-lighting, reddened by late sunset rays. Direct sunlight during the day illuminates only higher parts of the ridged and troughed slide area which flowed beyond the main shadow of the high escarpment (Fig. 3). Other ephemeral influences of time on the landscape occur after a night's temperature inversion under clear skies as transient mists float in the cold air over Sasamat Lake in the Farrer Land System 5, and when frequent morning fogs drift down Burrard Inlet, hiding another world below, from the protruding forests of Belcarra and Burnaby Mountains. Surges of morning fog up the ravines eroded into faults dissecting the escarpment of Burnaby Mountain may carry industrial smells to the crest, noticeable by comparison with returning eddies of mountain air.

## Description of Land Systems

Land Region 1: low exposure (88% of study-area).

Burrard Land System 1 (5% of Region).

Location: on the footslopes between the escarpment of Burnaby Mountain and Burrard Inlet.

Parent Material: surficial glacio-fluvial and glacio-morainal deposits derived chiefly from sedimentary rocks.

Elevation: between 0 and 90 m.

Aspect: N. Only the late afternoon sun directly illuminates these slopes.

Vegetation and Microfauna: hardwood-dominant stands around 70 years old; ground flora dominated by oregon beak-moss, swordfern and elderberry; microfauna scarce.*

Land Facets: 1/3 = well drained Orthic Dystric Brunisols with sandy loams (26% of System).

1/4 = moderately well drained Orthic Eutric Brunisols with loams (74% of System).

Forest Productivity: class 2 hemlock stands are the most productive on both Land Facets, and class 5 and 6 douglas fir stands are the least productive.

Recreation: land bordering Burrard Inlet has, in part, been taken up with oil storage facilities and other industrial activities, with the C.P. Railway and Barnet Highway crossing lower land from east to west. The C.P. Railway originally ended at Port Moody, but later was extended below the escarpment of Burnaby Mountain to Vancouver. Barnet Highway is the old Dewdney Trunk Road which extends along the Fraser Valley. Despite these constructions,

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* Although only an extremely few species of plants and insects are considered, they illustrate some important inter-relationships within the landscape.

except for the waterside oil storage tanks, the view from Burrard Inlet is not particularly spoilt, and with care could be improved. In the central area, land above the Barnet Highway lies within the Simon Fraser University Charter Lands, giving the university an influence on future recreational development in this area. Burnaby Municipality is interested in opening up this and adjoining land for recreational parkland with trails.

Slide Land System 2 (4% of Region).

Location: on the footslopes between the western escarpment of Burnaby Mountain and Burrard Inlet.

Parent Material: rock slide from the higher escarpment of sedimentary rocks at some time in the post-glaciation period, locally with pressure ridges alternating with troughs, now considered stable because of the tall, straight tree trunks.

Elevation: between 0 and 90 m.

Aspect: N.

Vegetation and Microfauna: hardwood-dominant stands around 70 years old; ground flora dominated by oregon beak-moss, swordfern and elderberry; microfauna scarce on these cool footslopes shaded by the escarpment of Burnaby Mountain.

Land Facets: 2/5 = imperfectly drained Gleyed Eutric Brunisols with clay loams (91% of System).

2/6 = poorly drained Fera and Rego Gleysols with silty clay loams (9% of System). The poorer drained soils occupy the lower land.

Forest Productivity: class 3 cedar stands are the most productive on poorly drained Land Facet 2/6, with hemlock on imperfectly drained Land Facet 2/5, and class 6 and 7 stands of douglas fir are the least productive.

Recreation: similar to that for the Burrard Land System. Additionally, the Burnaby Marine Park has been created on the waterfront as part of the recreational development plan of Burnaby Municipality (Fig. 59). Being situated on the western footslopes of the escarpment, this land receives more of the late day's sun than the escarpment and so it is warmer. An unusual coolness occurs only during the morning when the escarpment shields the land from the rising sun.

Burquitlam Land System 3 (2% of Region).

Location: the southeast footslopes of Burnaby Mountain.

Parent Material: glacio-fluvial, glacio-lacustrine and glacio-morainal surficial deposits derived chiefly from sedimentary rocks.

Elevation: 90 to 150 m.

Aspect: SE. Air temperatures warm early, but also peak in the day.

Vegetation and Microfauna: hardwood to softwood-dominant mixedwoods of about 50 years of age; ground flora dominated by huckleberry and bracken; microfauna dominated by centipedes.

Land Facets: 3/3 =well drained Orthic Dystric Brunisols with sandy loams (45% of System).

3/4 = moderately well drained Orthic Eutric Brunisols with loams (33% of System).

3/5 = imperfectly drained Gleyed Eutric Brunisols with clay loams (22% of System).

Better drained soils higher on the slope; less well drained soils at the base of the slope.

Forest Productivity: class 1 cedar stands on the imperfectly drained Land Facet 3/5, and class 2 cedar stands on the moderately to well drained Land Facets 3/4 and 3/3 are the most productive, whereas class 5 and 6 douglas fir stands are the least productive.

Recreation: these footslopes are dissected by power lines and cut up by motor bike trails. They could provide good walking trails through the forest, and offer convenient access to exposures of glacio-fluvial and glacio-lacustrine deposits for university classes. However, because of closeness to built-up areas, a determined effort will be needed to preserve the land under forest for current recreational uses. Motor bike trails constitute one legitimate recreational use of land, especially near a built-up area, and

and where there are no exceptional other uses for the land, but effective control of this activity is needed to ensure that it does not slowly degrade the land where bikes leave the appointed trails. Groups of young people with bikes are generally supervised by an adult; it is the lone bike users who can be seen using these trails to gain access to all parts of the mountain, jostling with classes and joggers as they make their way to the campus.

Sasamat Land System 4 (9% of Region).

Location: the southwest footslopes of Burnaby Mountain and land adjoining the southern and western sides of Sasamat Lake.

Parent Material: glacio-fluvial and glacio-morainal surficial deposits derived chiefly from sedimentary rocks on Burnaby Mountain and igneous rocks around Sasamat Lake.

Elevation: 60 to 180 m.

Aspect: SW. These lower slopes achieve the highest air and soil temperatures by late afternoon compared with all other slopes.

Vegetation and Microfauna: hardwood stands on Burnaby Mountain, softwood or softwood-dominant mixedwood stands adjoining Sasamat Lake, from 50 to 40 years of age, respectively; ground flora dominated by huckleberry (especially on Burnaby Mountain), ladyfern, salmonberry (especially on Burnaby Mountain and in imperfectly and poorly drained Land Facets 4/5 and 4/6 below); microfauna dominated by spiders (especially on Burnaby Mountain), centipedes (again, mostly on Burnaby Mountain), and red ants, preferentially on the better drained Land Facet 4/3 below.

Land Facets: 4/3 = well drained Orthic Dystric Brunisols with sandy loams (8% of System).

4/4 = moderately well drained Orthic Eutric Brunisols with loams (42% of System).

4/5 = imperfectly drained Gleyed Eutric Brunisols with clay loams (42% of System).

4/6 = poorly drained Fera and Rego Gleysols with silty clay loams (8% of System).

The poorer drained soils generally occupy the lower land and the better drained soils the higher slopes.

Forest Productivity: class 2 (on poorly drained Land Facet 4/6) and class 3 cedar stands on better drained land are the most productive, whereas class 6 and 7 hemlock and, especially, douglas fir stands are the least productive.

Recreation: oil storage facilities and other urban activities are already encroaching upon the southwest slopes of Burnaby Mountain, and possibly this is land that should be released up to a predetermined elevation for housing to relieve the building pressure in Burnaby. The warm footslopes adjoining Sasamat Lake need protection to preserve the charm of this lake.

Farrer Land System 5 (11% of Region).

Location: alongside the southeast side of Bedwell Bay, around the western and northern margins of Sasamat Lake.

Parent Material: chiefly glacio-morainal surficial deposits derived from igneous rocks.

Elevation: 0 - 210 m.

Aspect: chiefly W.

Vegetation and Microfauna: softwood and softwood-dominant mixedwood stands about 40 years old; ground flora dominated by ladyfern, and salmonberry (especially in imperfectly drained Land Facet 5/5 below); microfauna dominated by red ants.

Land Facets: 5/2 = well to very well drained Eluviated Dystric Brunisols with loamy sands (24% of System).

5/3 = well drained Orthic Dystric Brunisols with sandy loams (44% of System).

5/4 = moderately well drained Orthic Eutric Brunisols with loams (29% of System).

5/5 = imperfectly drained Gleyed Eutric Brunisols with clay loams (3% of System).

Forest Productivity: class 4 hemlock stands on all Land Facets, except for class 5 stands on the worst drained (5/5) and the best drained (5/2), are the most productive forests in the System, and class 5 and 6 douglas fir or cedar are marginally the least productive.

Recreation: waterside cottages are scattered alongside Bedwell Bay, and the west side of Sasamat Lake, generally discretely beneath an open tree canopy. Roads have been constructed and service these areas. Control of building should be strict to ensure that the cottages enhance the landscape rather than detract from it. An open canopy of trees around a dwelling, and between it and the waterside, plus a careful use of construction materials, allows the dwelling to appear a natural part of the landscape. A proposed campsite development adjoining the shoreline of Sasamat Lake would need similar careful planning.

Scarp Land System 6 (5% of Region).

Location: the steep north - or northeast-facing escarpment of Burnaby Mountain.

Parent Material: sedimentary conglomerates and sandstones, with thin chales and coals.

Elevation: 90 to 300 m.

Aspect: N. and NE. Cool and moist slopes mostly shaded from the direct rays of the sun. Snow remains longer on the ground than on other slopes.

Vegetation and Microfauna: hardwoods and hardwood-dominant mixedwoods aged about 70 years, increasing to 80 years and greater in the broad ravine below the Centennial Pavilion protected from earlier fires; ground flora dominated by oregon beak-moss, elderberry and swordfern; microfauna scarce on these cool slopes. Budburst and flowering occur later on these shaded slopes compared with other slopes.

Land Facets: 6/3 = well drained Orthic Dystric Brunisols with sandy loams (92% of System).

6/4 = moderately well drained Orthic Eutric Brunisols with loams (8% of System).

The most precipitous slopes in the ravine below the Centennial Pavilion carry Lithic Regososls since there is little opportunity for soil profile development.

Forest Productivity: class 1 stands of hemlock are the most productive and class 5 stands of cedar are the least productive.

Recreation: the coolness of these shaded slopes is refreshing during hot summer weather. Joe's Trail allows access to the upper slopes east of the Centennial Pavilion. The Simon Fraser University Charter Lands extend over the crest of the escarpment in the central part, down to the Barnet Highway, and the only reasonably accessible route from the crest of the steepest section of the escarpment, down a spur to the footslopes adjoining the Barnet Highway, occurs within these Charter Lands. Unfortunately, this route leads directly onto the gun range on the footslopes and several accidents have only been avoided by the efficient alarm system of the range. The lease of the range is near termination, and Burnaby Municipality would prefer the range to relocate, thus opening up this area for recreational trails. If this were done, a trail constructed with steps on the steepest sections would link the system of trails proposed for construction on the footslopes by the Municipality, with the system of trails already constructed around the upper slopes of Burnaby Mountain, making the mountain a primary recreational resource set within the dense urban area of Burnaby, equivalent to the Endowment Lands of the University of British Columbia in Vancouver. The escarpment forest, ecology, geology and geomorphology would become accessible to university classes, and running trails would be greatly extended.

Centennial Land System 8 (3% of Region).

Location: the gentle slopes below the Centennial Pavilion on Burnaby Mountain.

Parent Material: sedimentary sandstones and conglomerates.

Elevation: 150 to 270 m.

Aspect: W.

Vegetation and Microfauna: hardwoods and harwood-dominant mixedwoods about 50 years of age; ground flora dominated by ladyfern, swordfern and, on the more southwesterly-facing slope, salmonberry; microfauna dominate by red ants.

Land Facets: 8/3 = well drained Orthic Dystric Brunisols with sandy loams (48% of System).

8/4 = moderately well drained Orthic Eutric Brunisols with loams (52% of System).

Better drained soils on higher slopes. Imperfectly drained soils occur along the major fault zones which cross the Centennial Park, water collecting within the fault line troughs from surrounding land.

Forest Productivity: class 2 hemlock stands are the most productive and class 5 and 6 cedar stands are the least productive.

Recreation: Burnaby Centennial Park occupies much of the Land System, with blocks of trees distributed across an open parkland landscape. The Park is much used during summer for walking, and for viewing across the precipitous slopes of the ravine which has been eroded into the escarpment fault system. It also has a popular dining facility in winter, and summer panoramic views can be gained across the Burrard Inlet to Belcarra Mountain and up Indian Arm.

Coombe Land System 9 (4% of Region).

Location: the Coombe Peninsula.

Parent Material: metamorphosed sediments, some still recognizable as conglomerates, with granulites, gneisses, schists and lime-silicate rocks of the Twin Island Group.

Elevation: 0 - 110 m.

Aspect: ridges projecting NE.

Vegetation and Microfauna: softwoods (and softwood-dominant mixedwoods) around 70 years of age; ground flora dominated by oregon beak-moss, elderberry and swordfern; microfauna not prolific.

Land Facets: 9/2 = well to very well drained Eluviated Dystric Brunisols with loamy sands (44% of System).
9/3 = well drained Orthic Dystric Brunisols with sandy loams (56% of System).

Forest Productivity: class 4 douglas fir stands are the most productive with hemlock as productive on Land Facet 9/3, and class 7 cedar stands are the least productive.

Recreation: shoreline dwellings are the principal land-use, some carefully constructed as part of the landscape, and a few intended as ostentatious display (Fig. 51). Lime-silicate rocks constitute a potential source of ores but the area of such rocks is like the nearby Twin Island Mine, probably too small for commercial development. The Coombe Peninsula has obvious potential for recreation. Currently, there is a land-use dispute involving the G.V.R.D. which wishes to zone the peninsula as a park in order to conserve the area in its present form, so that careful thought can be given to its ultimate use. The other party to the dispute, The Belcarra Residents' Association Incorporated, wishes to keep the peninsula open for further waterside dwelling construction. The peninsular represents the only unspoilt remnant of scenic coastline in study-area.

Admiralty Land System 11 (11% of Region).

Location: the southwest-facing valley-lands on Belcarra Mountain opening out onto Burrard Inlet.

Parent Material: hornblende diorite.

Elevation: 0 - 270 m.

Aspect: SW.

Vegetation and Microfauna: softwoods, to hardwood-dominant mixedwoods at lower elevations, around 30 years of age; ground flora dominated by huckleberry, ladyfern and salmonberry; microfauna dominated by spiders, centipedes and red ants.

Land Facets: 11/3 = well drained Orthic Dystric Brunisols with sandy loams (59% of System).

11/4 = moderately well drained Orthic Eutric Brunisols with loams (41% of System).

Forest Productivity: class 4 and 5 douglas fir stands are the most productive, and class 6 and 7 stands of hemlock and cedar, respectively, are the least productive.

Recreation: no special features, except where the land overlooks Burrard Inlet towards the escarpment of Burnaby Mountain.

Carraholly Land System 12 (6% of Region).

Location: the southeast footslopes of Belcarra Mountain.

Parent Material: hornblende diorite.

Elevation: 0 - 120 m.

Aspect: SE.

Vegetation and Microfauna: softwood-dominante mixedwoods, from 40 to 100 years of age; ground flora dominated by huckleberry and thimbleberry; microfauna dominated by centipedes.

Land Facets: 12/2 = well to very well drained Eluviated Dystric Brunisols with loamy sands (71% of System).
12/3 = well drained Orthic Dystric Brunisols with sandy loams (29% of System).

Forest Productivity: class 2 douglas fir stands are the most productive, and classes 5 and 6 hemlock or cedar are the least productive.

Recreation: waterside recreational potential exists along the Inlet, although few houses have been built as yet, possibly because of nearby industrial plants and port facilities.

Turtle Land System 13 (9% of Region).

Location: sidelands and footlands around the east side of Belcarra Mountain.

Parent Material: hornblende diorite.

Elevation: 0 - 150 m.

Aspect: E. and NE.

Vegetation and Microfauna: mostly softwood-dominant mixedwoods about 50 years of age; ground flora dominated by oregon beak-moss, elderberry and swordfern; microfauna scarce.

Land Facets: 13/2 = well to very well drained Eluviated Dystric Brunisols with loamy sands (50% of System).
13/3 = well drained Orthic Dystric Brunisols with sandy loams (50% of System).

Forest Productivity: class 3 douglas fir stands are the most productive, with class 5 cedar and hemlock stands the least productive.

Recreation: waterside recreational houses are scattered along the shoreline, particularly around the extension of the Land System onto Coombe Peninsula. From higher points there are views across Indian Arm to the White Rock coastline.

Land Region 2: high exposure, with top-dying of douglas fir (12% of study-area). Land Systems described also occur in Land Region 1.

Naheeno Land System 7 (47% of Land Region 2; 10% of Land Region 1).

Location: the dipslope of Burnaby Mountain.

Parent Material: mostly conglomerates on the plateau top in Land Region 2, with sandstones on the southerly dipslope in Land Region 1.

Elevation: 150 to 300 m. in Land Region 1, to 360 m. in Land Region 2.

Aspect: around S.

Vegetation and Microfauna: hardwoods and hardwood-dominant mixedwoods of about 50 years of age; ground flora dominated by huckleberry and thimbleberry; microfauna dominated by spiders, centipedes and red ants.

Land Facets: 7/1 = very well drained Orthic Humo-Ferric Podzols with sands (5% of System).

7/2 = very well to well drained Eluviated Dystric Brunisols with loamy sands (28% of System).

7/3 = well drained Orthic Dystric Brunisols with sandy loams (51% of System).

7/4 = moderately well drained Orthic Eutric Brunisols with loams (16% of System).

Forest Productivity: class 1 to 3 stands of hemlock or douglas fir, with class 1 douglas fir stands occurring on the southeast-facing slopes, the most productive, with class 3 and 6 stands being the least productive.

Land Use: the System includes the University Charter Lands where they occur on the dipslope of Burnaby Mountain. Although the University is subject to political pressures just like any other Provincial institution, it does have an influence on the use of these lands. A Research Park is proposed (on the initiative of the Provincial Government) for the area east of the junction of Curtis with Gaglardi, mostly within Land Facet 7/2 in Land Region 1. It is proposed to locate the Research Park between Neheeno Park and a new access road from the junction of Curtis and Gaglardi Way to the President's Trail, linking with the present University ring road near the President's House (Fig. 60). This would leave the forested land of Neheeno Park as a shield between the University and the Research Park.

Recreation: the forested land southwest and south of the Research Park, within the University Charter Lands, could also constitute a buffer zone, separating the University lands from the spread of Burnaby around the footslopes of Burnaby Mountain. The dipslope lands have been scarred by access roads and power lines and, in the absence of any plan, they are progressively downgrading. Suitable protection within planned development of the dipslope lands could re-establish a healthy verdant cover.

The steep southeast and east slopes of Burnaby Mountain are situated partly in Burnaby Municipality and partly within the University lands. There are some fine stands of douglas fir and hemlock on these slopes which, hopefully, can be

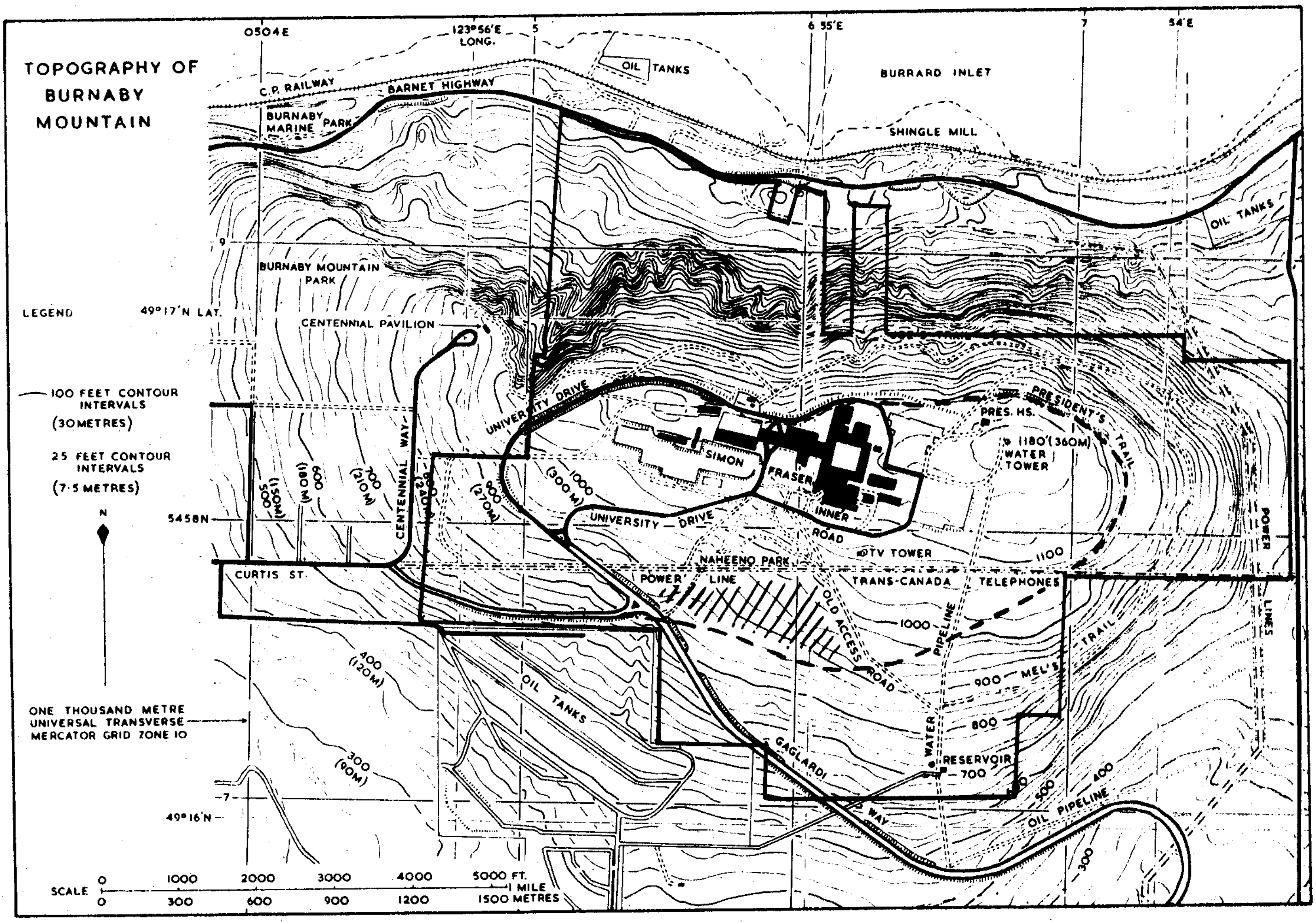

Fig. 60. Burnaby Mountain and the shaded location of the proposed Research Park, and the route of a proposed new access road around the mountain and linking with the President's Trail. The University Endowment Lands are also shown.

preserved as parkland for Burnaby residents and for university classes and research. The power line along the eastern footslopes is used by trail bikes, and although a valid recreational use of the land, the bikes scar the land particularly where it is imperfectly drained, which scarring can be seen in places around Burnaby Mountain.

Simon Fraser University campus attracts many visitors because of its architectural style, and this constitutes an important part of the recreational use of the study-area. From the Academic Quadrangle fine views can be obtained looking up the Indian Arm, across to Belcarra Mountain and Buntzen Ridge. Industrial plants in the valleys are hidden, although their pollution undoubtedly encourages the drifting of evil-smelling smog up the numerous ravines that have been eroded into the escarpment, and onto the mountain plateau, mostly during early day.

Because of its high exposure, on windy, rainy days the campus can be extremely unpleasant, a blast funneling through the Mall and beneath the Rotunda. There are plans to have exotic species planted across the campus, which will require a careful survey of climatic micro-environments.

Woodhaven Land System 10 (22% of Land Region 2; 12% of Land Region 1).

Location: the double-peaked crest of Belcarra Mountain.
Parent Material: hornblende diorite.
Elevation: 225 to 270 m.
Aspect: a NE and SW ridge.

Vegetation and Microclimate; softwoods of about 30 years of age; ground flora dominated by oregon beak-moss and swordfern on northwest-facing slopes, and huckleberry and bracken on southeast-facing slopes; microfauna dominated by centipedes on the relatively warmer southeast-facing slopes. Top-dying of douglas fir is particularly noticeable in the col between the two higher prominences of Belcarra Mountain.

Land Facets: 10/1 = very well drained Orthic Humo-Ferric Podzols with sands (4% of System).

10/2 = very well to well drained Eluviated Dystric Brunisols with loamy sands (79% of System).

10/3 = well drained Orthic Dystric Brunisols with sandy loams (17% of System).

Forest Productivity: class 1 douglas fir on the very well drained Land Facet 10/1, and classes 2 and 3 on other Land Facets are the most productive stands, with class 7 cedar the least productive.

Recreation: expansive views from the ridge extend northwards to Bedwell Bay and southeast across Port Moody wherever there are clearings in the forest. The black bear may pose a hazard to some recreationers, although there is some excellent wild-land hiking in this area.

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