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1988 SURVEY OF THE GLACIERS ON MT RUAPEHU, TONGARIRO NATIONAL PARK -A BASELINE FOR DETECTING EFFECTS OF CLIMATE CHANGE

by

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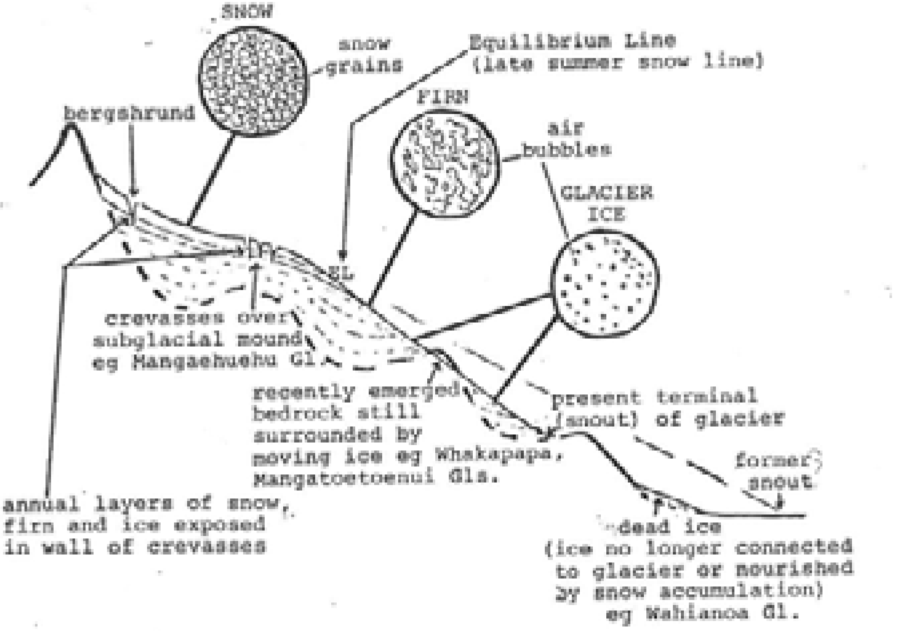
CONTENTS

Figure 1. Longitudinal section through a glacier on Mt Ruapehu showing basic examples of snow, firn and glacier ice and other features of the glaciers.



SUMMARY

1. Mt Ruapehu has 9 glaciers, up to 130 m thick, 1.8 km long and covering 4 square kilometres (0.5% of the Park area).
2. Most of the glaciers have thinned by 5-30 m and retreated by an average of 240 m since 1961.
3. The Whangehu is now the only glacier which receives ice from the Summit Plateau ice field.
4. A small glacier on the north side of the Crater Lake has thickened by up to 30 m since 1961 and still has a positive budget.
5. Ice in the Mangatoetoenui Glacier is moving at 24±5 m/y and at the head of the Whangaehu Glacier at about 7 m/y.
6. Glacial striations on andesite lava recently exposed by receding ice remain with fine details for about 30 years but are weathered away within 100 years.
7. A predicted climate warming due to increased levels of carbon dioxide and other pollutants in the atmosphere may accelerate the recession of some of the glaciers but should not make them all disappear.
8. A photo site network has been established to detect any changes in the glaciers.

INTRODUCTION

The glaciers on Mt Ruapehu in Tongariro National Park are the northern-most glaciers in New Zealand. They are situated near the extreme climatic and topographic limits for the formation of permanent ice in this country. As such, they are extremely sensitive to changes in climate. Heights on Ruapehu massif range from Mitre Peak at 2591 m to Tahurangi at 2797 m compared to Mt Taranaki (Egmont) at 2518 m and Mt Ngauruhoe at 2287 m. Ruapehu is the only North Island mountain with glaciers although Taranaki and Ngauruhoe both have permanent snow or ice patches in their craters.

Any future changes to these glaciers could provide an early demonstration of climatic change induced by the so-called "greenhouse effect" in New Zealand. Increased levels of carbon dioxide and other gases in the atmosphere will warm Earth's atmosphere by 1.5 to 4.5 degrees Celsius by the year 2050 AD (Bolin and others, 1986) which could accelerate the melting of snow and ice on Ruapehu. However precipitation and cloudiness may increase and wind patterns change, all of which could alter the distribution, composition and accumulation of seasonal snow on the mountain.

Study of how and when the glaciers respond to these changes could have significant implications and benefits for management. If glacier changes can be related to specific climatic trends it will be poasible to make informed predictions about the future state of glaciers, seasonal snow and viability on the mountain. The large skifields would be affected by changes in snow distribution or snow conditions including glaze or rime accumulation. Snow safety, such as avalanche control may require different management techniques. There may also be implications soon for water run-off and flood control, and eventually for alpine vegetation. Disappearance of

Ruapehu's glaciers would affect many of the scenic, recreational and cultural values for which the mountain and the National Park are so well known and regarded. Such a study to increase knowledge of glacial processes and their response to climate change is inherently supported by policies in the Tongariro National Park Management Plan.

Since the last systematic, ground-baaed survey of Heine (1963) it is common knowledge that at least some of Ruapehu's glaciers have retreated dramatically. Such retreat is due to a succession of years in which these glaciers have had negative balances (that is they have lost more ice and snow due to melting, evaporation etc than they have gained snowfall). This has been attributed to less precipitation in late winter and spring than "normal" and warmer air temperatures (Krenek 1959; Heine, 1962) although dry or long summers and decreased cloudiness 1970) contributed.

The extent of Ruapehu'a glaciers has not been properly measured for 26 years. Therefore, the actual magnitude of recession, including downwasting, or the reasons for it, are not well known. The most recent maps of the area (e.g. DOSLI, 1987: infomap 273-4, Tongariro National Park, scales 1:80,000 and 1:12,500) are based on earlier and aerial photos but they do not portray the present glacier margins accurately. A reliable survey is required to locate the extent of glacier ice accurately and provide a reference against which the effects of climatic change, particularly future change, can be assessed.

Close examination of the glaciers at the time of minimum snow cover is required to determine accurately the boundaries of glacier ice. Repeated photographic coverage from fixed points is needed during March and April, together with selected sampling of the ice material. Aerial photos may give a false impression of glacial extent because from a distance it is often not possible to tell the difference between old snow (less than one year old - see Figure 1, but in places fused into ice or otherwise partially modified by melting), firn (snow over one year old and partially transformed into ice, but having a density of less than about 800 kg per cubic metre) and true glacial ice (ice in a glacier, transformed from firn by a variety of processes including consolidation, and in which air has been isolated into separate bubbles). Volcanic debris, lehar deposits and moraine cover large parts of some of Ruapehu's glaciera and further complicate the interpretation of aerial photos.

GLACIERS ON MT RUAPEHU

Several glaciers exist on the Ruapehu massif. The most recent account is that of Williams (1984) who identified the Whakapapa, Mangatoetoenui, Whangaehu, Wahianoa, Mangaehuehu, Mangaturuturu and Crater Basin Glaciers as well as the Summit Plateau ice field (Figure 2). All except the ice field have characteristics of cirque glaciers, although the 1.8 km long Whangaehu and the 1 km long Mangaehuehu Glaciers have active valley tongues. The ice of the Summit Plateau is at least 130 m thick and (to some extent) contributes to the Whangaehu Glacier (and up to recently the Mangatoetoenui Glacier - see below).

The present Whakapapa Glacier was referred to by Heine (1962) after the mid 1950s as the Whakapapaiti Glacier. This was to distinguish it from the Whakapapanui Glacier which had appeared as a separate lobe about 1 km long at that time. This Whakapapanui Glacier disappeared as a valley glacier during a major retreat phase starting about 1955 and ending in the 1970s (Williams, 1984).

The Crater Basin Glacier can be regarded as two glaciers, which are dynamically and physically quite distinctive. Williams (1984) described how the northern part under Paretetaitonga Peak has thickened and advanced since 1953 when the level of Crater Lake dropped 8 m producing a flood wave down the Whangaehu River and causing the Tangiwai Disaster. Over the same period the southern part of the glacier has thinned by up to 90 m. The dynamic northern part, while only 550 m long, deserves its own name and is referred to here, provisionally, as the "Un-named" Glacier.

There are several large patches of firn and old snow on the mountain away from the glaciers listed above and some contain what is probably glacier ice. The largest of these is situated east-north-east of Te Heuheu Peak at about 2500 m under the Waihohonu Ridge. Another is located at the head of the Whakapapanui valley at 2450 m under Restful Rocks (Figure 2). Both appear, from signs of crevassing or bubble texture in the ice as well as the presence of old snow, to contain active glacier ice and may be further examined and monitored in future. Another firn patch with no old snow is located lower down in the Whakapapanui valley at 2360 m at the site of the Whakapapanui Glacier in the 1960-62 period (Heine, 1962). This patch may have been absent a few years ago (Arnold Heine, personal communication). Close examination showed that meltwater has considerably modified it towards ice ("snow ice" or "regelation ice") but it does not seem to contain any glacier ice. A similar unvisited patch of "ice" at 2250 m under Mitre Peak appears to have been separated from the Wahianoa Glacier due to downwasting (see Figure 1). There was no snow associated with it and therefore it is not discussed further here.

OBJECTIVES OF THIS STUDY

With this background then, the objectives of this study are to:

1. find Heine's (1963) photo points and establish new ones where necessary due to erosion or glacial recession;

2. rephotograph the glaciers from these points to map the present day extent of glacier ice on Mt Ruapehu;
3. determine the changes in the glaciers since the 1960's and monitor their future changes in order to determine the effects of climate change caused by the greenhouse effect;
4. reconnoitre the areas of snow accumulation on the glaciers and near them as an additional means of predicting the response of the glaciers and seasonal snow extent to the greenhouse effect.

DATES OF FIELDWORK AND PERSONNEL INVOLVED

Two trips to the mountain were made in the 1988 autumn. On 27 March Karen Williams, Lisle Irwin (Senior Ranger, Ohakune) and I visited the Mangaehuehu, Crater Basin (see below), and Mangaturuturu Glaciers and overlooked the Wahianoa Glacier. The following day Karen and I examined the site of the "former" Whakapapanui Glacier and surveyed the Whakapapa Glacier. On 23 April Rob McCallum (Ranger, Ohakune) and I examined the Whangaehu and Mangatoetoenui Glaciers making additional observations of the Wahianoa Glacier. Rob and Simon Noble (Park Interpreter, Whakapapa) have made additional trips (eg 26 April) and improved the photographic coverage, including from the air.

PHOTO SITES

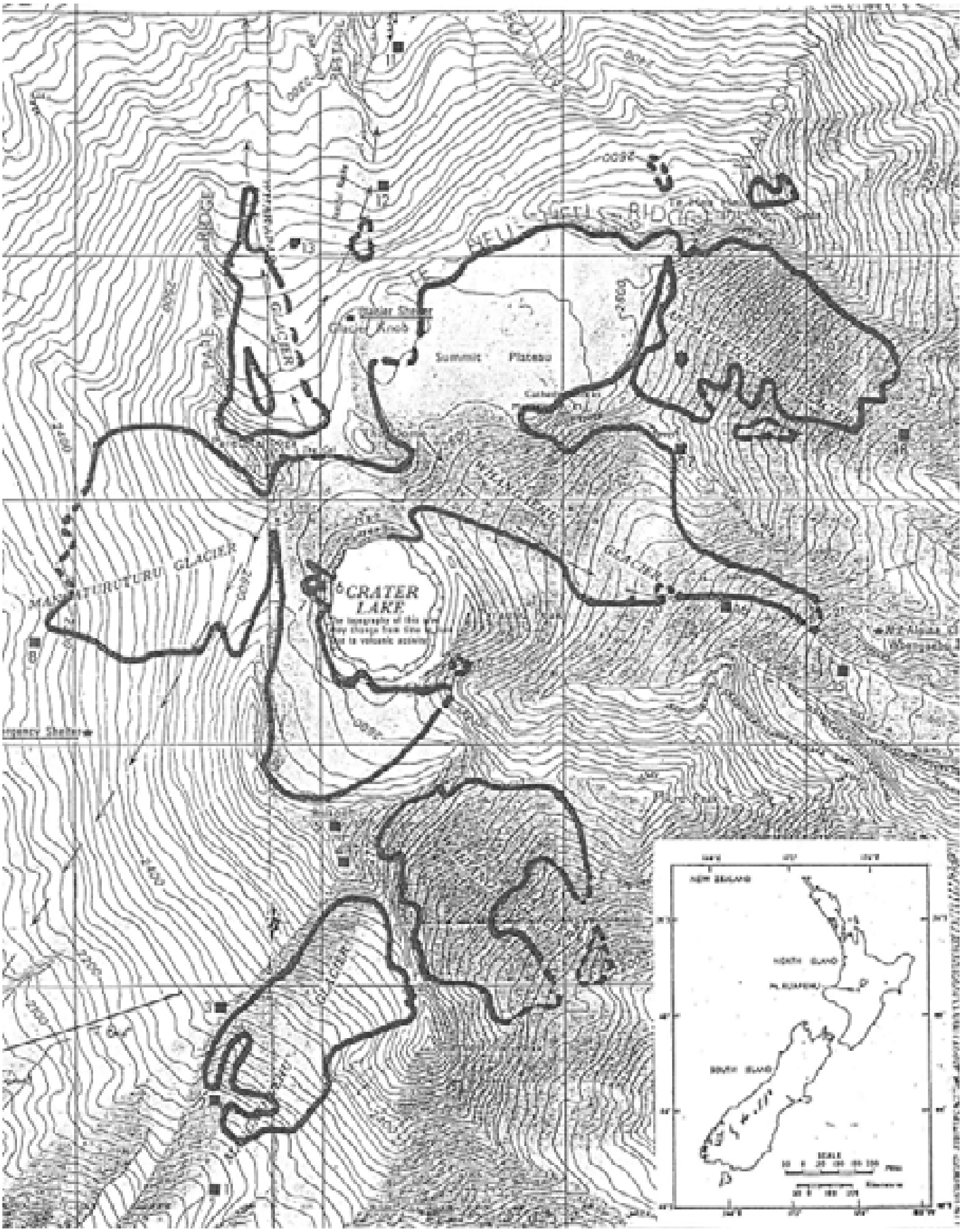
The emphasis this year was on finding as many as possible of Heine's (1963) photo points, repeating the photography there and examining the present glacier margins. Many of the photo points established by Heine for his annual glacier surveys during the early 1960s took some time to locate as significant changes had occurred. Glacial recession and erosion meant that we needed to establish additional photo sites (eg see Figure 3). Those of Heine's points that we located plus new sites are described in Table 1 and their locations shown in Figure 2. Photography was limited to hand held 35 mm cameras using standard 50 mm lens. Elevations were obtained from the latest Park map with 20 m contour intervals).

Four black and white films were exposed. These photos have been used for comparison with photos lent by Heine, and to produce the data and information given below.

PRESENT EXTENT OF GLACIERS

The extent of glaciers on Ruapehu in March and April 1988 been mapped at a scale of 1:12,500 and is shown in Figure 2. The glacier margins were determined from ground-based (oblique) photographs (Figure 3) and from close examination of the ice. The texture and size of bubbles in hand samples of "ice" gave an indication of whether true glacial ice, meltwater ice or firn were present as these have quite different bubble characteristics and density (see Figure 1). The solid lines drawn to depict the glacier are likely to be mostly within 20-50 m of the actual margin. The

Figure 2. Map showing present boundaries of glaciers and glacier ice on Ruapehu drawn from oblique photographs from the ground and air and more detailed observations. Solid lines are accurate to 20-50 m while dashed lines are accurate to 50-100 m. 1988 photo sites are shown as black squares.



dashed lines, which show where photographic coverage was not adequate or where considerable dry rock debris overlies the ice, are accurate to 50-100 m.

The area of each glacier has been measured using their boundaries as mapped (Table 2). The largest is the Whangaehu Glacier which covers 0.76±0.04 square kilometres. The total extent of glacier ice on Ruapehu is close to 4 square kilometres (similar to that on the 2000-2400 m high peaks in the Waimakariri basin in the South Island) or about 0.5% of the area of Tongariro National Park. A conservative guesstimate of the volume of ice is 0.11 cubic kilometres.

The present elevations of the lowest ice on each of the glaciers is given in Table 3. This baseline along with corresponding information for 1961-1962 from Heine (1963) will be an additional basis for monitoring future changes in these glaciers. The information may also be useful for park interpreters for example during summer nature programmes.

The lowest ice on the volcano is at the snout of the longest glacier, the Whangaehu, at 2090m±20 m asl. The snout area is located under Clocktower Ridge which shades the area and provides a favourable situation for snow drifting and local generation of firn and glacial ice. Since 1962 up to 40 m of downwasting of ice, covered even then with moraine, has resulted in a thick blanket of rock debris over the ice which insulates it from the atmosphere and slows melting.

AREAS OF SNOW ACCUMULATION ON THE GLACIERS

The glaciers on Ruapehu appear to be more complex than South Island glaciers in their patterns of snow accumulation. On Ruapehu glaciers, snow accumulation and transformation into firn and ice does not have a simple relationship to elevation, although the normal situation of neve (snow accumulation area) in the higher parts of a glacier generally holds true on the mountain (eg Whakapapa, Mangaturuturu and Mangaehuehu Glaciers). Krenek (1959) used a term "inverted firnline" to describe the situation on Ruapehu where still covered lower parts of the glaciers in summer below higher areas which had bare ice exposed. Drifting of snow and accumulation in the lee of bluffs or ridges appears to produce local areas (Kells, 1970), near the snout on some glaciers (eg Whangaehu and Mangaehuehu), which may have a positive mass balance. The "Un-named" Glacier appears to be mostly derived by this mechanism as snow falling in north-westerly winds accumulates under Paretetaitonga Peak. Conversely, some of the upper parts of a few of Ruapehu glaciers are downwasting because summer melting exceeds the rate of snow accumulation (eg Whakapapa and Crater Basin Glaciers and the Summit Plateau ice field -see below).

Table 4 lists the approximate elevations of the equilibrium line on some glaciers. This is the mean elevation of the late summer snow line where gains and loses of mass in the glacier are equal. The lowest line is on the Whangaehu Glacier below the prominent south-facing-cirque under Cathedral Rocks. The highest line is above the Whakapapa Glacier on the north-west facing accumulation area under Pare Ridge. A light snow fall in mid March may have lead to a slight under-estimate in the elevations given in Table 4.

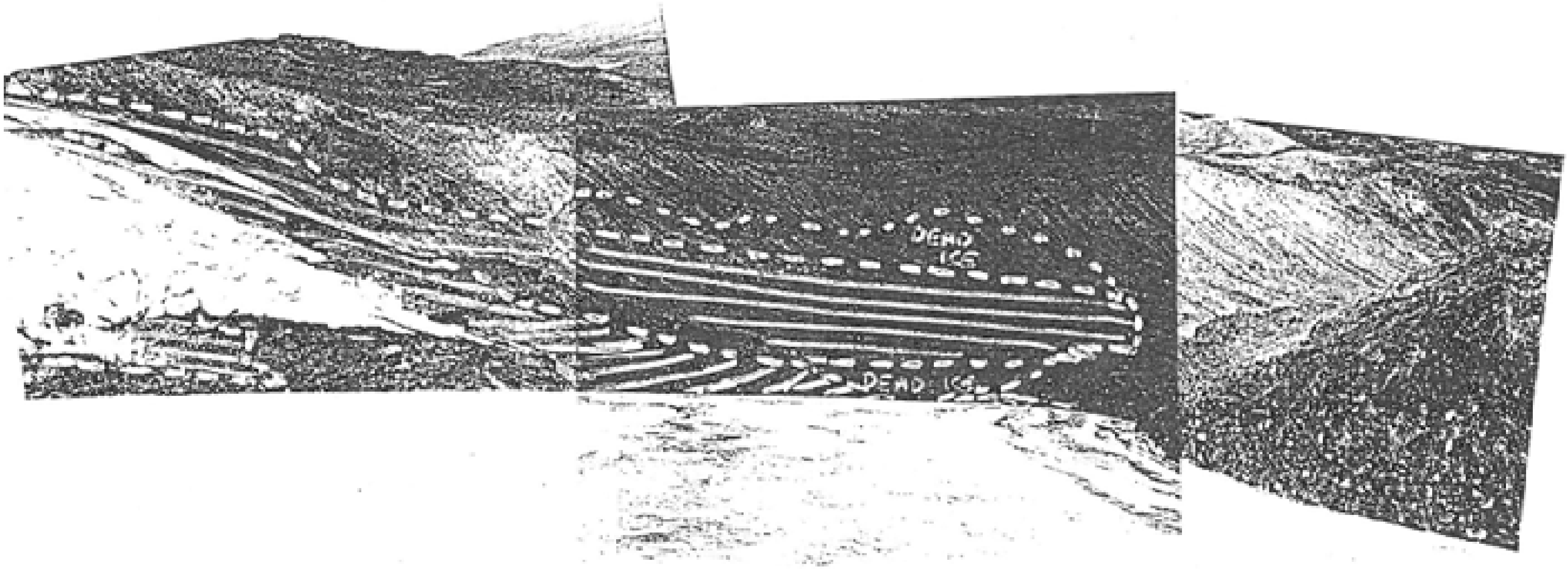
These equilibrium lines and areas of snow accumulation are likely to be sensitive to changes in precipitation, wind direction and/or strength, temperature and solar radiation. They will respond to climatically-induced changes in seasonal snow distribution. For this reason they might be mapped in more detail in future although this would require significantly more fieldwork. There is no information on how equilibrium line elevations have changed with time on Ruapehu though it is likely that they have risen since the periods with greater snowfall earlier this century.

MAJOR CHANGES IN THE GLACIERS BETWEEN 1961 AND 1988

The main changes evident in the data included here and the photos are the recession of all the glaciers except the "Un-named". Table 3 shows that the glaciers have retreated between 100 and 460 m in length back up their valleys since 1961/1962. The actual map distance retreated averages about 240 m. It does not appear to be appreciably different on any side of the mountain although it is obviously greatest for the Whakapapanui on the northern side. All of these glaciers have had negative mass balances (ie they have lost more mass due to melting, etc than they have gained from snowfall and accumulation) since 1962.

The 1988 photos a large amount of downwasting has occurred on glaciers, particularly the Whakapapa since the 1960s. The precise amount of glacier thinning is difficult to measure from photos alone but some patterns are evident. The ice at the present snouts of the Whakapapa, Mangatururuturu, Mangaehuehu (Figure 3) and Whangaehu Glaciers is about 30 m thinner in 1988 while that at the Mangatoetoenui is about 20 m thinner. The Whakapapa is most noticeably affected -the whole of its trunk has thinned by 20-30 m and now large areaa of bedrock are "emerging" as far up as 2600 m asl. Rapid retreat of its terminal appears to be imminent. These glaciers all tend to have concave surface longitudinal profiles especially at the snout, typical of slow-moving, decaying glaciers. Melting of up to 30 centimetres of sand covered ice at the terminal of the Mangaehuehu Glacier between 27 March and 26 April 1988 caused the snout to recede 55 centimetres up valley in that period (Lisle Irwin and Rob McCallum, personal communication).

FIGURE 3. Panorama of the terminal area of the Mangaehuehu Glacier taken from photo site 3 (Heine's photo point 25) on 27 March 1988, looking south (right) through east (left). Continuous white hand-drawn lines within dashed outlines show the position of the glacier in March 1961 in the foreground (above a 50 m high bluff) and in the valley between the lateral moraine walls (below the bluff). The dashed line on the far side of the former snout outlines an area of debris covered dead ice present in 1961. In 1988 the snout is out of sight below the bluffs, 250 m up valley from the 1961 position.



Some spot measurements suggest that the southern (north-facing) margins of the Mangatoetoenui, Whangaehu, Mangaehuehu and Mangaturuturu Glaciers have thinned by perhaps 10-20 m whereas the more northern margins of these same glaciers have thinned less, perhaps 5-10 m. The difference is probably due to greater snow accumulation and less melting along the northern margins, and accelerated melting due to dark rock material being washed or falling onto the southern margins. The Crater Basin Glacier has thinned by several of metres in the lake outlet area under Tahurangi which is continuing to lessen any buttressing effect of ice on the rim of the lake in this area.

Surveys made by Peter Otway and Robin Holdsworth have shown that up to 20 m of downwasting occurred on northern part of the Summit Plateau ice field during the 30 years to 1985 (Holdsworth, 1985). Downwasting has been greater over the southern end near Dome. The ice level has been lowered below the level of the plateau rim in places where ice used to flow from the ice field down into the Mangatoetoenui and Whakapapa Glaciers. In addition, a gently sloping ice covered ridge (an ice divide) has developed between Dome and Cathedral Rocks which represents the only substantial part of the plateau rim still buried by ice. Ice flow from the plateau into the Whangaehu Glacier has obviously lessened since 1962.

The "Un-named" Glacier has had a net positive balance since 1961 and earlier. It has thickened by 30 m at the snout which terminates, as it did in 1961, on the northern shore of the Crater Lake at 2550 m asl (Figure 4). The ice cliff that has developed along the lake shore since 1961 is 30 m high. At that time the glacier was starting to respond to the lowering of Crater Lake in 1953. By 1961 a thin mantle of snow (and possibly ice) had accumulated on the 200 m of lake bed exposed by the Tangiwai outburst. The glacier therefore, has effectively advanced by 200 m since 1953 (Williams, 1984), and terminates due to melting at and thermal radiation from the warm lake and calving of ice from the ice cliff. An impressive set of volcanic debris layers, probably annual including the 1969 and 1975 eruption deposits, is preserved in the ice and overlying firn of the cliff.

The positive mass balance of this glacier is moat likely due to unique combination of local topography, including its position in the lee of Paretetaitonga Peak and surrounded by other high peaks. (The thickening is a response to a sequence of events induced by the 1945 eruption, particularly the culminating one – ie the reattainment of the original lake level in 1953 - but it is not fundamentally caused by them.) At 2751 m, Paretetaitonga is one of Ruapehu's highest points and blowing and falling snow

FIGURE 4.
Figure 4a. Photograph of the "Un-named" glacier from Tahurangi, photo site 5. Dotted line shows the position of the section in Figure 4b below.

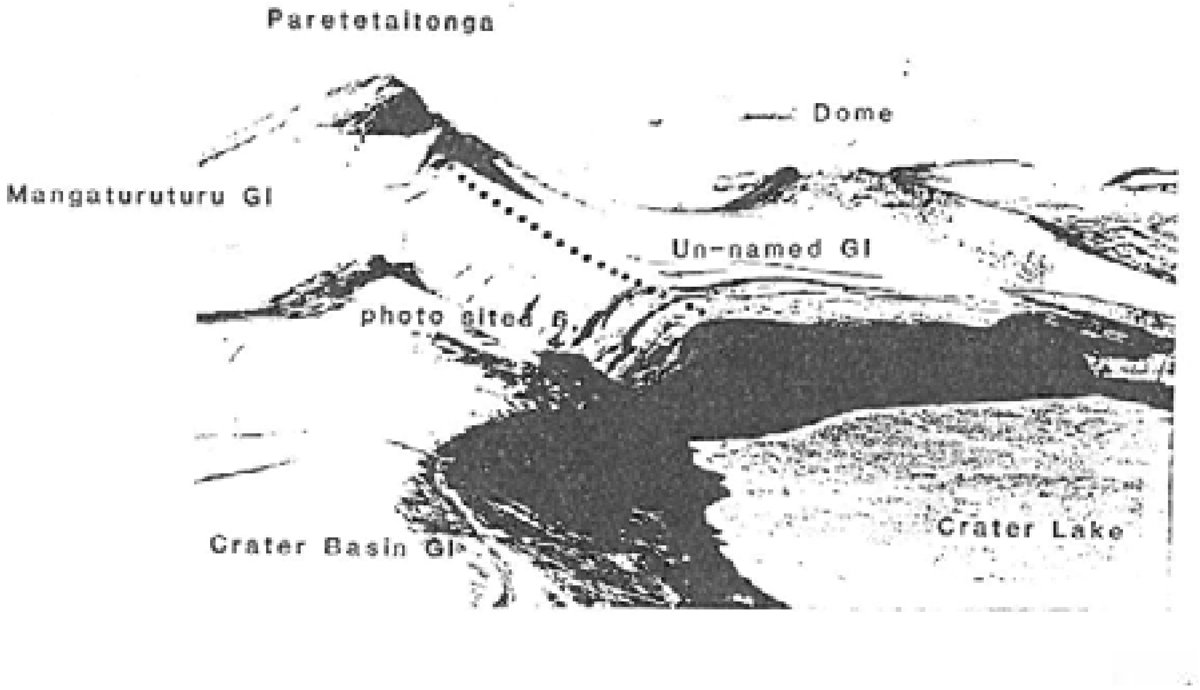
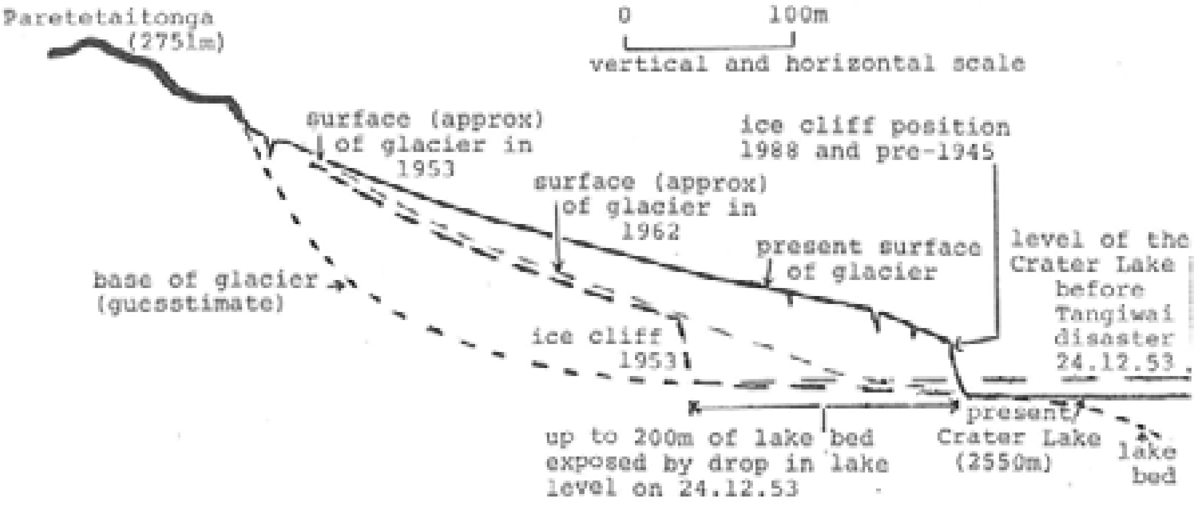


Figure-4b. Longitudinal section through the "Un-named" glacier along the main flowline SSE of Paretetaitonga Peak showing the present surface (from DOSLI, 1987), former surfaces (drawn from photos) and hence the thickening which has occurred between 1962 and 1988. No vertical exaggeration.



accumulates in large drifts to the south-east of it. These drifts having a south-easterly aspect are affected less by melting in summer than is snow on the opposite side of Crater Lake. Similar lee situations elsewhere on the mountain (eg Wahianoa Glacier) do not have topography that allows snow to accumulate to the same extent or are more susceptible to summer melting. A positive balance shows that Krenek' (1959) claim, that the line on Ruapehu is higher than the summit, refers only to a hypothetical regional equilibrium line. More importantly, it also means that this glacier is an ideal indicator for monitoring those effects of climatic change which would turn its mass balance from positive to negative.

Brief mention can be made of the extent of snow patches in the vicinity of the Turoa and Whakapapa Skifields. Some were photographed to compare with Heine's photos although such patches are governed more by topography and possibly by seasonal events rather than by climatic change. The same patches on Gliding Gladys and Clays Leap at Turoa were slightly smaller in March 1988 than in autumn 1961, whereas patches near Knoll Ridge at Whakapapa seemed slightly larger in 1988. Patches above the Mangaturuturu Shelter were significantly less extensive in 1988. Such changes if significant may affect vegetation and flush zones dependent on snowbanks.

The first major snowfalls of winter 1988 occurred later than in recent years leaving the mountain with perhaps less snow cover than normal in early May. Staff at the skifields (Dave Mazey and Andy Chapman, personal communication) did not believe there was significantly less snow above the two fields this autumn compared to previous years. It may be significant that the upper levels to which glacier ice is exposed in autumn do not seem to have risen much in 26 years (Table 4).

GLACIER FLOW RATES

An improved estimate of 24 m per year was obtained for ice movement in the Mangatoetoenui Glacier. The only other estimate of flow rates is that of Williams (1984) who used reported positions of an aircraft wrecked in 1951 on this glacier to calculate a flow rate of 10-20 m per year. In 1988 the highest wreckage of this Oxford aircraft was located (Figure 5) close to the central flow line of the glacier at m asl, 350 vertical m and 800 horizontal m below the 1951 position. This gives a flow rate of 24±5 m per year.

A similar rate may apply to the Mangaehuehu and Mangaturuturu Glaciers. They have similar surface slopes, well developed crevasses and equilibrium lines and therefore are likely to be similar dynamically. The Whakapapa and. Crater Basin Glaciers which are flatter and partly debris-covered will be less dynamic. The valley trunk of the Whakapapa is probably almost stagnant.

Lines of dirt ridges and cones on ice draining into the head of the Whangaehu Glacier between Cathedral Rocks and Dome (Figure 4a) moved about 200 m between 1961 and 1988. This represents an average flow rate of 7 m per year. Similarly, dirt ridges south-east of Dome between the Whangaehu and "Un-named" Glaciers have moved about 50 m or less than 2 m per year. Obviously little ice is draining from these places into the Whangaehu Glacier now.

SURVIVABILITY OF GLACIAL STRIATIONS

The scratches rasped in bedrock overrun by the glaciers were examined to determine the time taken for weathering to remove them, thereby revealing the extent and timing of bedrock exposure on ice retreat. The finest examples of striations were seen to the south of the Mangaturuturu snout and on western Reqtful Rocks above the Whakapapa Glacier, both areas of fairly fine grained and massive andesitic lava flows. Heine's photos show that these areas were uncovered by ice less than 27 years ago. Striations on bedrock below the 1961 terminal position of the Mangaehuehu Glacier had lost some of their fine detail but not nearly as much as on the moutonee that is located on the line of the youngest terminal loop moraine of this glacier. Historic photos in Williams and Bamford suggest that the glacier extended over the moutonee in 1900 but had retreated back from it by the 1920s. The striations there have been almost completely weathered away in about 70 years.

These age limits, although dependent to some extent on grain size in the host bedrock, can give some indication of how recently the glaciers have retreated off a given area elsewhere on the mountain. They suggest for example that much of Knoll Ridge, which has reasonably fine striations was covered by ice this century. They will be used to extend our knowledge of ice retreat in any future fieldwork.

THE FUTURE OF RUAPEHU'S GLACIERS

The automatic assumption made about the future for Ruapehu's glaciers is that they will disappear by the middle of next century if the climate warms by the 1.5 to 4.5 degrees Celsius predicted by Bolin and others (1986). This assumption is questionable.

Glacierization is controlled by a complex interaction of climatic and geographic variables, and temperature alone does not always have a dominant effect. Precipitation, as rain or snow, solar radiation and wind characteristics are very important factors in the energy and moisture budgets of glaciers, especially slow moving ones. These budgets and local topography determine whether a particular glacier will thicken, advance, thin or retreat.

The complexity of the relationship between glacier behaviour and climate is one of the main reasons for controversy over the relationship in New Zealand. Atmospheric circulation patterns (which control precipitation) and temperature are both important but their relative importance varies depending on the local situation (Fitzharris and Chinn, 1986; Hay and Fitzharris, 1988). Advances or retreats of the Franz Glacier on the western side of the Southern Alps have been attributed to periods with high or low precipitation respectively whereas on the eastern side the retreat of the Stocking Glacier is correlated with monthly temperatures (Salinger and others, 1983). To predict the actual effect of climate change on specific glaciers on Ruapehu, we need to isolate the fundamental variable causing glacial retreat there.

A mass balance which is negative for most of Ruapehu's glaciers is the overall cause of their recession. It has been shown that thinning and terminal retreat of small, slow moving glaciers on Mt Kenya is primarily controlled by the local (in situ) mass balance rather than the flow of ice (Hastenrath, 1987). Similarly, the recession of what appear to be dynamically and physically similar glaciers on Ruapehu is likely to be due to a decrease in the average localized mass balance. This is different from glaciers like the Franz Josef where variations in ice flow represented by waves or bulges of ice moving down glacier result in changes in the level and extent of the ice in the valley.

The glaciological data that are immediately available are insufficient to determine unambiguously which climatic variable controls mass balance for any of Ruapehu's glaciers. Using mainly climatic data between 1954 and 1957, Krenek (1959) concluded that the amount of snow accumulating in winter controlled the mass balance. Kells (1970),on the basis of hydrological budget measurements over the 1968-69 budget year, considered that winter precipitation and temperature were both important on the Whakapapanui. Heine (1962), analysing temperature and precipitation records between 1957 and 1962 concluded that air temperatures in spring and summer were important. Air temperatures at the Chateau may have warmed slightly between 1940 and 1969 (Napper, 1986) but records are incomplete after 1972. In addition, there is some doubt about whether New Zealand air temperature records show a warming trend which could be related unequivocally to Ruapehu glacier recession. Further examination of temperature and precipitation data is outside the scope of this report.

Clearly there is uncertainty but a dominant role for precipitation can not be ruled out, especially in view of the presently positive mass balance of the "Un-named" glacier. Speculative comparisons with the Franz Josef and Stocking Glaciers might suggest that the glaciers more exposed to snow-bearing winds from the westerly quarter ie the Whakapapa, Mangaturuturu and ‘Un-named’, were more sensitive to precipitation than temperature. Glaciers on the eastern side of the massif, particularly the Mangatoetoenui and Wahianoa, could be more sensitive to temperature changes. The southerly aspects of the accumulation areas of the Mangehuehu and Whangaehu Glaciers may also make them more sensitive to precipitation rather than temperature changes.

It is possible therefore that climate warming, which may be accompanied by increased precipitation and more seasonal snowfall could actually cause of Ruapehu's glaciers to thicken, at least initially. If precipitation stays the same but there is a rise in the elevation of the average freezing level (ie at any given spot on the mountain more precipitation falls in liquid rather than solid forms) then the recession will continue. However, if climatic warming causes a decrease in precipitation in the central North Island then the recession of the glaciers will accelerate. These last two scenarios would have serious implications for Ruapehu skifields, similar perhaps to the way in which the Manganui on Taranaki has become marginal recently.

The present equilibrium lines on Ruapehu's southern and eastern glaciers are probably too low to be elevated above the peaks of the mountain by temperature warming alone. The equilibrium line elevations given in Table 4 are 200 to 400 m below the various peaks above them. Robin quoted a relationship:

$$dH = +77 \times dT$$

where dH is the change in elevation of an equilibrium line (in metres) accompanying a change of temperature dT (in degrees Celsius), other being unchanged. By this relationship, a temperature increase of 1.5 to 4.5 degrees would raise the equilibrium lines by 120 to 350 m, less than the heights given above. This would mean that these glaciers would still have areaa of permanent snow accumulation. In addition, any increase in net cloudiness will tend to depress the equilibrium line by a small amount, perhaps in the order of 4 m per 1/10th increase in cloud at constant temperature (Robin, 1986).

The Whakapapa Glacier will not survive in its present valley form for many more years. If it continues to downwaste, the areas of bedrock that are appearing through it will enlarge and probably create isolated pockets of ice. Separated from their accumulation areas on the side of Pare Ridge these pockets will become "dead ice". However, the lahar and other debris covering them will probably delay their final melting for some years although the terminal will rapidly recede up valley. The bedrock that has appeared through lower parts of the Wahianoa and Mangatoetoenui Glaciers (eg Figure 1) may also be fortelling a similar recession.

Continued downwasting of the Summit Plateau ice field will create a deepening depression. The ice is at least 130 m thick in the northern half (Holdaworth, 1985) so a significant crater could develop. Hazardous situations could develop if large volumes of water get impounded and a crater rim collapses or if the crater walls pose dangers (ie rock fall). The potential for catastrophic failure of the south-eastern rim of the Crater Lake, which could be initiated by continued downwasting of Crater Basin Glacier, is being monitored by Peter Otway of DSIR (personal communication).

FUTURE WORK

The future of this project is dependent on the priority and funding it receives and will be reviewed later this year. Subject to this review, it is intended to repeat the photography next year using a tripod to mount the camera. The elevations in Table 1-3 would be checked with an altimeter. Some new photo sites would be established using our experience this year to increase the precision of any surveys made in future decades and to increase photo coverage (eg from Paretetaitonga). Selected areas of snow accumulation and glacier thinning noted this year may be meaaured more precisely. Air temperature and precipitation data may be analysed. An article is planned for the Tongariro Journal this year and for a scientific journal next year.

CONCLUSION

The survey this year has achieved the main goal of determining the present day extent of glacier ice on Mt Ruapehu. Ice at present covers four square kilometres or 0.5% of Tongariro National Park. The elevations of the glacier terminals have been measured and the lowest ice located at 2090±20 m asl at the snout of the Whangaehu Glacier on the eastern side of the volcano.

Most of the glaciers have retreated, on average about 240 m since 1961 and 1962 and thinned by up to about 30 m. However, the "Un-named" Glacier under Paretetaitonga has actually thickened by up to 30 m in this period, which makes it climatically and glaciologically significant.

A baseline of ice elevations and a renewed network of photo sites have been established so that any effects of climatic warming can be detected or monitored. The "Unnamed Glacier" with its current positive masa balance and its clear north-west to south-east orientation related to snow drifting and wind patterns maybe the best to monitor. In addition, the Mangaturuturu, Mangaehuehu, Mangatoetoenui and Whakapapa Glaciers at least ahould also be monitored to give a geographically and glaciologically representative spread.

A rate of flow of 24±5 m per year has been determined for the Mangatoetoenui Glacier, close to its central flowline. Such a slow rate of flow is significant because it indicates that the recession of these glaciers is more likely to be due to a decrease in the in situ mass balance over time rather than specifically to changes in ice flow regimes on the mountain. It is possible therefore that climate warming, which may be accompanied by increased precipitation and more seasonal snowfall could actually cause some of Ruapehu's glaciers to thicken, at least initially. Furthermore, modelling, while very preliminary and simplistic, suggests that warming temperatures alone will not destroy the glaciers. This would be contrary to what most people would expect.

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FIGURE 5. Rob McCallum (DOC, Ohakune) with wreckage of the Oxford aircraft which used to determine the rate of flow of the Mangatoetoe Glacier.

TABLE 1 Photo survey sites, Ruapehu.

Photo site no.	Description of photo site	Elevation (metres)	Panorama extent
Mangaehuehu Glacier			
1	Mangaehuehu Valley 200 m below terminal on polished bedrock with boulders.	2080±10	Glacier width
2	At top of change of slope beside stream on western side of glacier on ski route.	2200±10	Lowest ice
3	Heine's point #25 on north side above "Glacier Entrance" ski route. Heine's 3 orange circles still visible.	2320	Glacier except lowest ice
4	Heine's point #26 on point on main Tahurangi-Girdlestone ridge 200 m south of summit	2745	Down glacier
Crater Basin and "Unamed" Glaciers and Summit Plateau			
5	Summit of Tahurangi. Heine's point #27	2797	Te Ata Ahua to Clocktower
6	On knob overlooking lake, below NZGS survey peg.	2570±10	Icecliff.Lake outlet to Te Ata Ahua
7	By survey peg	2580±10	Valley between CB and "U" Gls.
Mangaturuturu Glacier			
8	Below and SW of terminal on lava ridge. Cairn built.	2230±40	Most of glacier
8	Heine's point #23 on knob west of site 8. Original cairn gone but orange rock remains.	2180	Less of glacier than 8.
Whakapapanui "glacier"			
9	Heine's point #3 on Knoll Ridge.Red cross still visible.	2200	Lower firn patch

10	Heine's point #4 on Knoll Ridge. Red circle still visible.	2210	Lower firn patch
11	Highest rock on Knoll Ridge, SW of bull wheel	2250±5	Lower firn patch
12	On low mound above Whakapapa firn patch	2390±10	"Whakapapaiti"
13	Bedrock point on ridge overlooking Whakapapa Gl	2480±10	Whakapapa Glacier
Whangaehu Glacier			
14	Heine's point #18 on top of black bouldery mound near stream.***	1930±20	Small part of lower glacier
15	Heine's point #17 on black lava, slightly rounded knob.***	2010±20	Former terminal area.
16	On bouldery ground 50 m up slope from top of moutonee in mid valley.	2140±10	Pyramid to debris covered ice to east.
17	Cairn built 15 m to SE above col between Whangaehu and Mangatoetoenui Gls. Cairn built on flat area.	2510±10	Pyramid to neve below Cathedral Rocks.
Mangatoetoenui Glacier			
17	On col as above	2510±10	Whole glacier.
18	Heine's point #19 on ridge above former terminal lake. Original cairn gone, so rebuilt with pole from Oxford wreckage.	2165±10	Whole glacier, terminal area.
Wahianoa Glacier			
4	Tahurangi-Girdlestone ridge as above	2745	Eastern part of glacier.
5	Summit as above	2797	Down glacier.

*** Former photo points and surrounding area modified by erosion of loose rocks and some bedrock (during lahars in 1969 and 1976).

TABLE 2. Areas of glaciers and guesstimated volumes of ice.

Glacier	Present area (sq km)	Mean thickness (m)	Volume (cubic km)
Mangaehuehu	0.38	23*	0.0087
Mangaturuturu	0.42	23*	0.0097
Whakapapaiti	0.22	10**	0.0022
Mangatoetoenui	0.55	23*	0.013
Whangaehu	0.76	23*	0.018
Wahianoa	0.47	15*	0.0074
Crater Basin	0.35	15*	0.0052
"Un-named"	0.19	25**	0.0048
Summit Plateau	0.64	70**	0.045
Te Heu Heu patch	0.03	-	-
Whakapapanui patch	0.02	-	-
dead ice patches	0.04	-	-
TOTALS	4.07***	-	0.11

* Mean thicknesses estimated as being 1.5 times the deepest crevasse.

** Mean thickness estimated from Holdsworth (1985), Figure 4 and known topography.

*** Error in this total is approximately ±10%

TABLE 3. Elevations and recession of glacier terminals based on comparison of seasons work and Heine's data (1963).

Glacier	Present elevation of lowest ice (m asl)	Elevation in autumn 1961 and 1962(masl)	Recession of snout since '62 (m)
Mangaehuehu	2130±10	2070	250
Mangaturuturu	2260±20	2190	240
Whakapapanui	2420±20	2260	460
Whakapapaiti	2400±20	2380	100
Mangatoetoenui	2190±10	2100*	320±70
Whangaehu	2090±20	2040	120±40
Wahianoa	2240±40	2170	160±70

* Heine lists this as 2130 m but mapping gives 2100 m.

TABLE 4. Approximate elevations of equilibrium lines and uppermost exposed glacier ice on some glaciers.

Glacier	Equilibrium line (m asl)	Uppermost exposed ice 1988 (±20 m asl)	Uppermost exposed ice 1961/2 (±15 m asl)
Mangaehuehu	2400-2500	2580	2590
Mangaturuturu	2450-2600	2600	2580
Whakapapaiti	2550-2650	2650	2620
Mangatoetoenui	2400-2500	2600	- -
Whangaehu	2340-2440	2600	2610