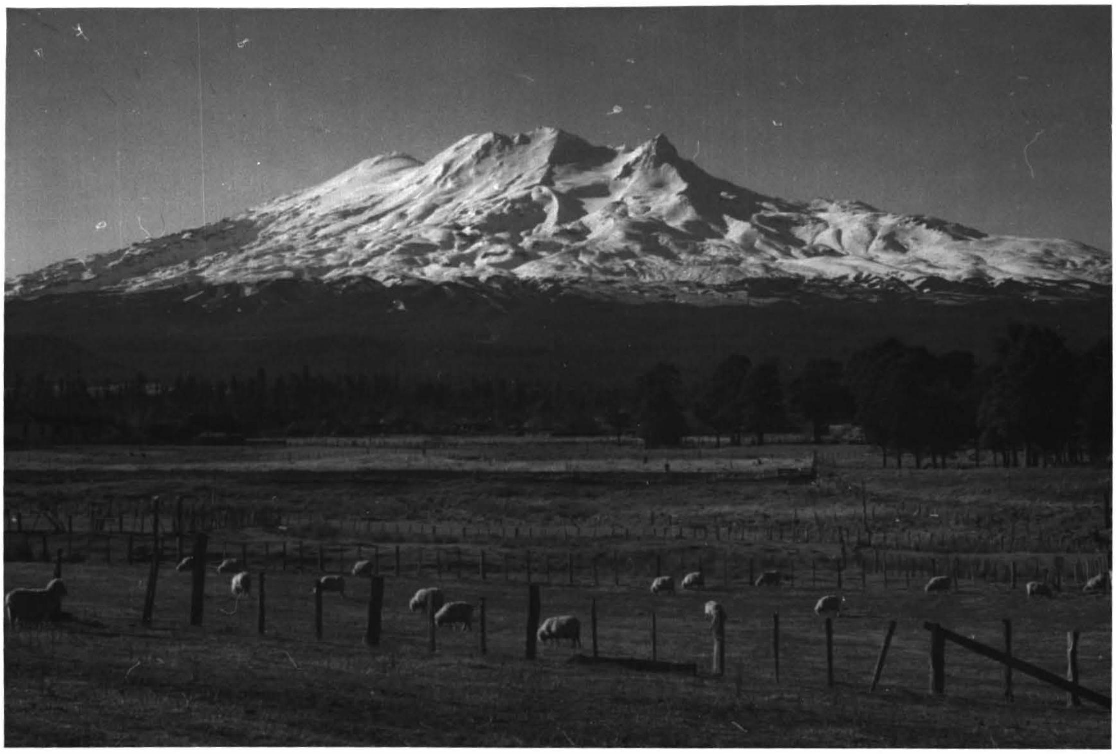

MT. RUAPEHU

CONTRIBUTIONS TO THE GEOLOGY OF MT. RUAPEHU, NEW ZEALAND

A thesis presented for the degree of M.Sc. and Honours in Geology, by B.E. O'Shea; Victoria University College, 1957.

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PART I

GEOMORPHOLOGY OF MT. RUAPEHU WITH PARTICULAR REFERENCE TO THE TANGIWAI RAIL DISASTER

(Published as 'Ruapehu and the Tangiwai Disaster' 1954: N.Z.J. Sci. Tech., B36:174 - 189)

SUMMARY

This paper deals with the cause of the Whangaehu River flood (a lahar) that led to the Tangiwai rail disaster. Changes in the Crater Lake, the nature and origin of the outlet, and the course followed by the Whangaehu River are described. The views of earlier writers on previous Whangaehu River floods, and the geomorphology of the summit of Ruapehu are also discussed.

INTRODUCTION

During the passage of the lahar, shortly after 10 o'clock on Christmas Eve 1953, a portion of the Whangaehu River rail bridge at Tangiwai was demolished by a raging torrent of mud and boulders which originated from the Crater Lake of Mt. Ruapehu, nearly twenty miles distant. This mudflow, or lahar, damaged the railway bridge piers and the Wellington-Auckland express plunged into the torrent. As a result, one hundred and fifty-one people lost their lives.

During tramping and ski-ing trips over the past five years the writer has become well acquainted with the National Park area. Close inspection of the Crater Lake was made on 1 January 1954, and again on 22 January. On the latter date the writer was accompanied by two chemists from the Chemistry Department, Victoria University College, and one from the Dominion Laboratory of the Department of Scientific and Industrial Research, who collected samples of the lake water. On 24 January, the Whangaehu River was followed from the Desert Road to where it emerges from a deep gorge on the lower slopes of Mt. Ruapehu. A number of braided channels were examined on the alluvial fan that extends east from the outlet gorge almost to the Desert Road. On the same day the scene of the disaster at Tangiwai was also inspected

MT. RUAPEHU

The zone of active volcanism in New Zealand, or "Taupo Zone" of Hochstetter (1864), is bordered to the west by the N.N.W. - trending axis of the Auckland Peninsula, and to the east by the more conspicuous N.N.E. - trending axis of the upthrust Kaimanawa block. This fact was also noted by Thomas (1888-9) and Henderson (1924). In the acute angle formed between these axes lies the Ruapehu-Ngauruhoe-Tongariro centre of volcanic activity dominating the central plateau of the North Island.

? map

? exactly where with respect to Crater Lake?

cf. p.10

The writer considers the broad summit of Mt. Ruapehu to be a caldera (as defined by Cotton, 1944, p.295, after Williams), or an "explosion caldera" (Cotton, 1944, p.302), if the "explosion hypothesis" is accepted. Early writers have described Ruapehu as truncated by simple explosion (Speight, 1908). Although many investigators are satisfied with the theory of "explosion" on a grand scale to account for the caldera, the lack of scattered fragments from the destroyed portion of the mountain suggests the alternative thoery of collapse and engulfment of the summit. This would follow the explosion stage of volcanicity, "explosion-collapse" theory (Cotton, 1944, pp.302-5, after Williams, Van Bemmelen, Van den Bosch, Dana, and others), and appears

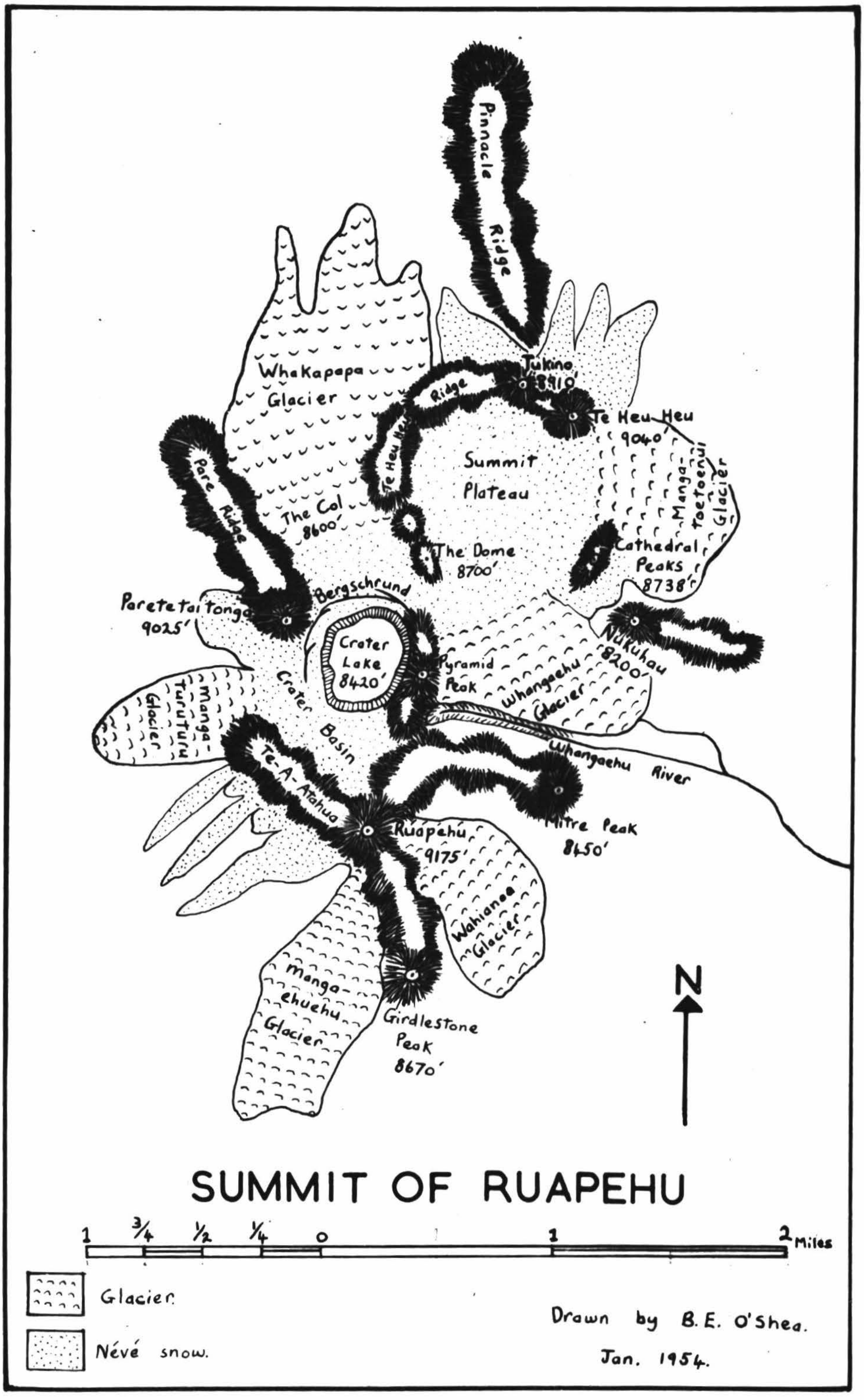


Fig. 1.

Sketch map of Ruapehu summit, based on Automobile Association Road Map and Geological Map of the Tongariro National Park Subdivision.

applicable to Ruapehu. In this view the Ruapehu caldera occupies the site of the summit of a formerly higher volcanic cone. The notches in the caldera rim are not due simply to erosion since the formation of the caldera. These notches, many of which contain the heads of small glaciers, indicate that the flanks of this higher cone were cut by large consequent valleys arranged in a radial pattern.

Grange and Hurst (1928-9) stated that at one stage the top was blown off or collapsed to the 7,000 ft. level and regained its former height and form by the addition of more recent lava flows darker in colour than the earlier grey hypersthene-andesite flows.

The caldera is bordered by precipitous scarps, with "an obsequent (antidip) relation to the inclination of the ash beds and lava tongues of the mountain side" (Cotton, 1944, p.295), which are remnants of the once higher summit. These scarps form a number of prominent rocky peaks, Te Heu Heu (9,040 ft.) and Tukino (8,910 ft.) to the north, Pare-te-tai-tonga (9,025 ft.) to the west, and the highest peak Ruapehu or Tahurangi (9,175 ft.) to the south.

As aptly described by Friedlander (1898), the summit of Ruapehu "is a vast oblong almost level plain covered with névé." He regarded the summit as consisting of two adjacent craters, the "North" and "South" craters ("West" and "East" of Grange and Williamson). The two craters or vents have been active intermittently in the past.

? diagram or map not clear

The snowfields or névés of the summit give rise to six glacier tongues of small dimensions. The most southerly is the Mangaehuehu Glacier which descends immediately below Ruapehu Peak, and to the west is the Mangaturuturu Glacier fed by the snowfield between

Ruapehu and Pare-te-tai-tonga. The Whakapapa Glacier flows north; on the north-east slopes is the Mangatoetoenui Glacier; and farther south the Whangaehu and Wahianoa glaciers originate (Fig.1). Around the Crater Lake, crescentic crevasses develop in the névé basin during the summer months, and at the cliffed margin of the icefield calving blocks descend to the lake below.

CRATER LAKE

The North Crater is dormant and is covered with névé to form the plateau. Recent revival of volcanic activity close to the south-east side of the South Crater has resulted in the building of an embryonic composite cone. It is the crater of this cone that contains the present lake. Friedländer (1898) stated: "This cinder cone is active as a solfatara, but the lake acts as a steam condenser and hides as it were to some extent the activity of Ruapehu."

? map

Early observers regarded Ruapehu as extinct, and it was not until 1886 that Cussen reported the lake as boiling. The water is usually lukewarm, but during eruptions it may boil. On rare occasions it has been observed frozen (Park, 1886; Thomson, 1926).

The icefields of Pare-te-tai-tonga and Ruapehu slope down steeply towards the lake edge and terminate abruptly as ice cliffs, about 200 ft. high on the south, west, and north sides. The visible east side of the crater, which is the only part indicative of a growing ash cone, displays typical cone-building features (Figs. 2, 3 and 4). Internal sliding of ash and coarser material has been and still is frequent. This debris has settled on the lake floor to be explosively ejected during succeeding eruptions. The east and north-east walls are composed mainly of masses of scoria and ash, and constitute the

Fig. 2.

Crater Lake in winter 1952. Note steam rising from the lake.

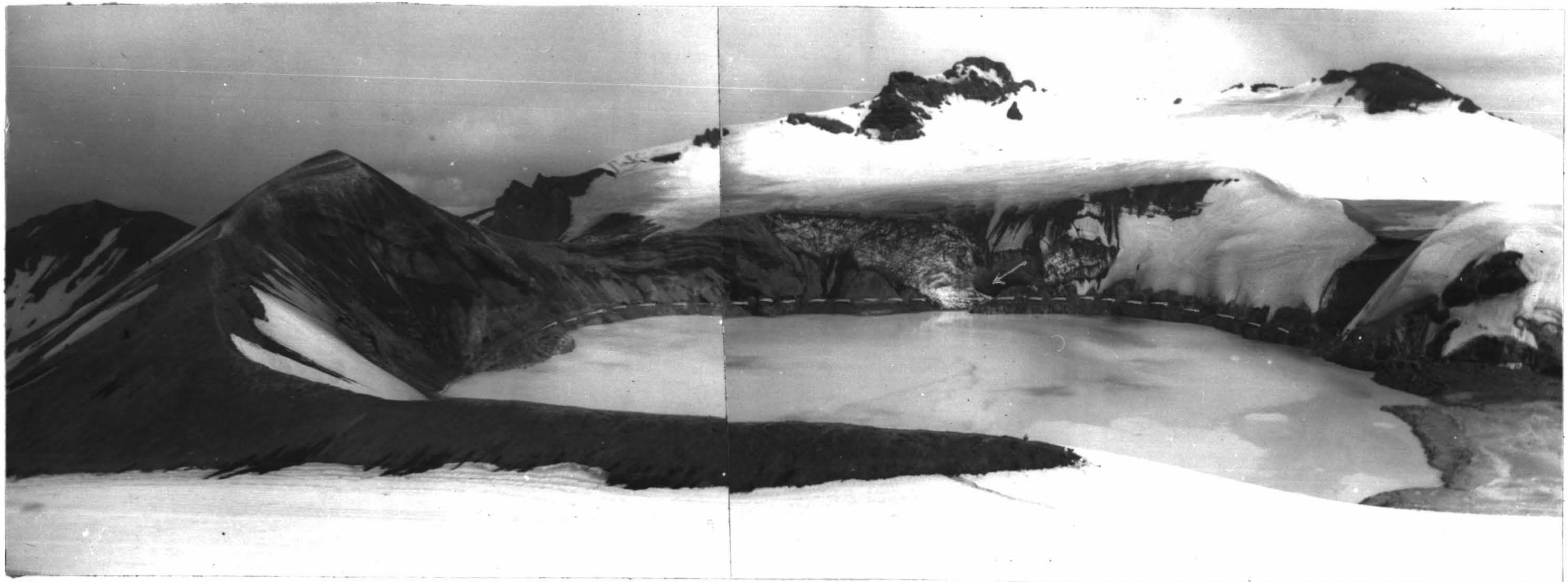


Fig. 3.

Same view as Fig.2.taken on 1 January 1954, showing ice tunnel (arrow) in ice wall under Tahurangi (Ruapehu) Peak. Pyramid Peak to left, and exposed lake floor on right. Dotted line indicates lake-level prior to 24 December 1953.

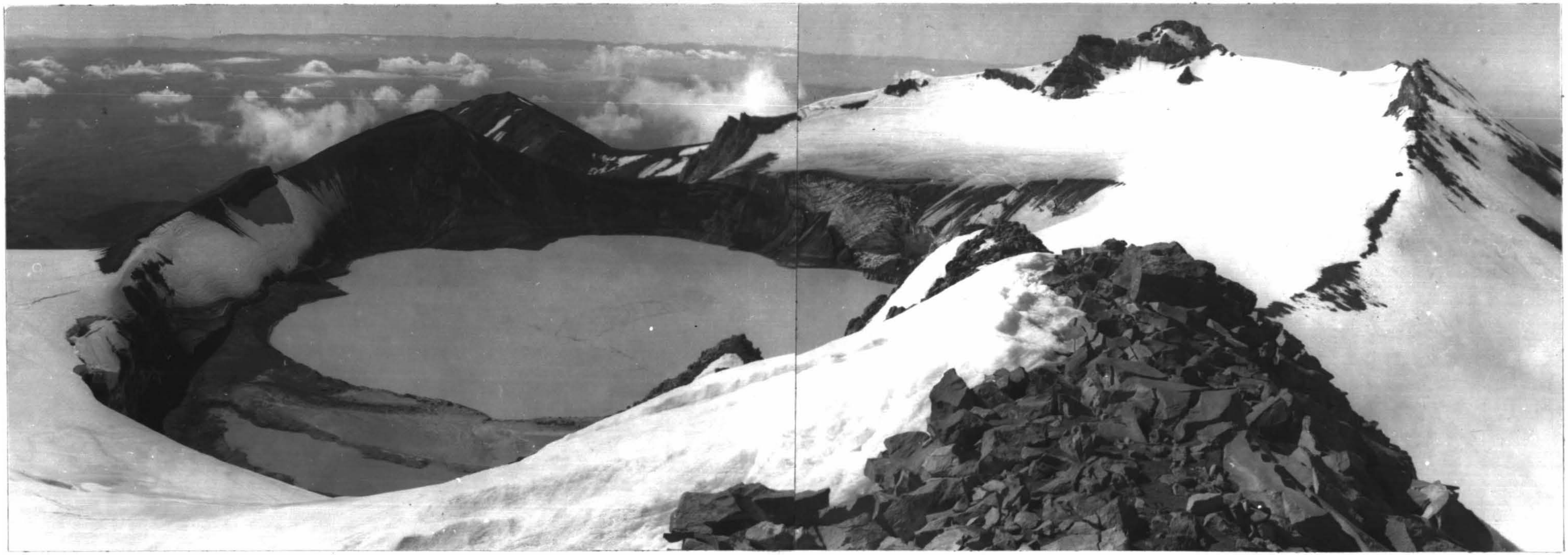


Fig. 4.

View of the crater lake looking east from Pare-te-tai-tonga, January 1,1954. Tahurangi (Ruapehu) distant right and Pyramid Peak to left of lake. Kaimanawa Range in the distance.

narrowest part of the rim. The highest point on this section of the rim is at Pyramid Peak, about 250 ft. above lake-level, and the lowest general level is on the south-east side, where the rim falls to within approximately 150 ft. of the water.

During the 1945 eruption, Cotton (1946) drew attention to the fact that it seemed possible that the south-east wall of the crater rim above the Whangaehu headwaters might give way, for there it is comparatively thin and appears frail.

As a result of landsliding, the inner slopes of the south-east portion of the rim are exceedingly steep.

THE WATER-TABLE

The level of the water-table within Mt. Ruapehu may normally be low, perhaps several thousand feet below the summit, due to the permeable nature of the andesitic material of which the mountain is composed. Cotton (1944, p.31) quoted figures from H.T. Stearns on the water-table gradient on the island of Oahu. Stearns stated that the ground-water level rises inland from the sea margin at a gradient of not more than three feet per mile. Although these figures apply to basalt, the gradient of the water-table in andesitic lavas, and tuffs especially, may be even lower. In the absence of other factors, a volum of water such as that in the Crater Lake could not exist, because of the rapid percolation through such permeable material. There are, however, other factors which might result in a perched water-table, separated from the main water-table by partly saturated formations in the zone of aeration. A body of ground-water with a highly irregular water-table profile could be confined at a high level, within a system of intersecting dikes and sills, as is common on Ohau Island (Tolman, 1937, pp.545-50), or by impervious strata. Its water-table could intersect the crater basin to form the lake. Cotton (1944, p.329) remarked: "Commonly, high-level crater lakes do not overflow . . . Generally if small they are both fed by and drain into the ground-water system, without overflow."

Alternatively, a thick deposit of mud may seal the lake floor, preventing percolation to the ground-water system. Subcapillary openings are dominant in muds, clays, and silts, and water cannot be forced through or out of them by ordinary subsurface hydraulic gradients (Tolman, 1937). On 22 January 1954, the exposed portion of the lake floor was studied. A large area consisted almost entirely of blue-grey mud displaying conspicuous dessiccation polygons, and recent soundings of the lake floor by Mr. D.J. Mason (1954) have shown it to be covered by this fine mud.

THE OUTLET FROM THE CRATER LAKE.

The fact that the Crater Lake is fed during the summer months by large quantities of melt water from the surrounding icefields, and its level normally remains more or less constant for considerable periods, suggests the possibility of a natural outlet for water, apart from seepage into the ground-water system. The mineralized and coloured nature of the water in the Whangaehu River suggested a close connection with the lake water, and, although Hill (1891) disputed it, the majority of observers have considered the Whangaehu to be the natural outlet. Beetham, in his narrative on the first ascent of Ruapehu in 1879, stated "The waters of the pool (Crater Lake) broke out at a much lower level below the crater and formed the source of the Whangaehu River." Hill (1891) made close studies of the Ruapehu region, and his conclusion regarding the Whangaehu River reads: "From what I have seen of this river (Whangaehu), I am satisfied that it has no connection whatever with the hot lake . . Its taste and colour may be accounted for by the fact that its waters are forced to pass through rocks which are undergoing rapid decomposition by means of chemical and physical agencies." Friedländer (1898) regarded the Whangaehu as receiving its waters by percolation from the lake. This probably occurs to a small degree where the water-level has risen to any permeable strata outcropping within the crater rim. In fact, a number of small rock caverns on the east wall above present lake-level seems to indicate that seepage has taken place.

The writer believes that the major outlet is and always has been in the form of an ice tunnel or ice-bridged ravine, usually obscured by the huge overhang of the ice walls that border the lake on the south. An outlet in the form of an ice tunnel was probably first observed in January 1922 by Mr. L.M. Lennard (in evidence to the Tangiwai Board of Inquiry, 1954) and others. In 1937 Mr. Roy Sheffield, a Chateau guide, swam and crawled under the ice cliffs to a subterranean passage, where he observed a waterfall feeding the Whangaehu River (Pascoe, 1952). In January and April 1939, the outlet was again entered, this time by Mr. L.M. Lennard. He noticed that from the lake the water flowed over a rock sill and over a number of small waterfalls before finally emerging from under the ice of the Whangaehu Glacier.

During the 1945 eruption of Mt. Ruapehu, steam and hot water near the head of the Whangaehu ravine appeared to be emerging from a passage connected to the Crater Lake. Mr. A.M. Prichard, then Chief Pilot for the Ministry of Works, while flying over the area on 28 July 1945, estimated that fifty cusecs of hot water was gushing from the outlet instead of the usual two or three cusecs. Cotton (1946) concluded that the lake water was displaced by the spreading tholoid, and that the outflow of hot water ceased suddenly because the intake became blocked by lava.

Beck (1950), in describing the later phases of the 1945 eruption, stated: "By the 16th September, part of the crater floor had collapsed about ten feet. The surface of the plug dome (tholoid) was a little lower than the surface of the former lake, and an ice cave, the means of exit of the lake water to the Whangaehu River, was present on the south wall of the crater."

By late 1945, the ice wall adjacent to the outlet had receded about four to five chains. In the years following the eruption, it advanced again towards its former position on the southern lake edge, but with no trace of an outlet.

Water flows from the distal end of the outlet tunnel down a steep narrow ravine, cut in comparatively loose scoria. The head of the ravine is covered for a short distance by a sheet of thin ice, which is a southern extension of the Whangaehu Glacier. The water finally emerges a few hundred yards downstream.

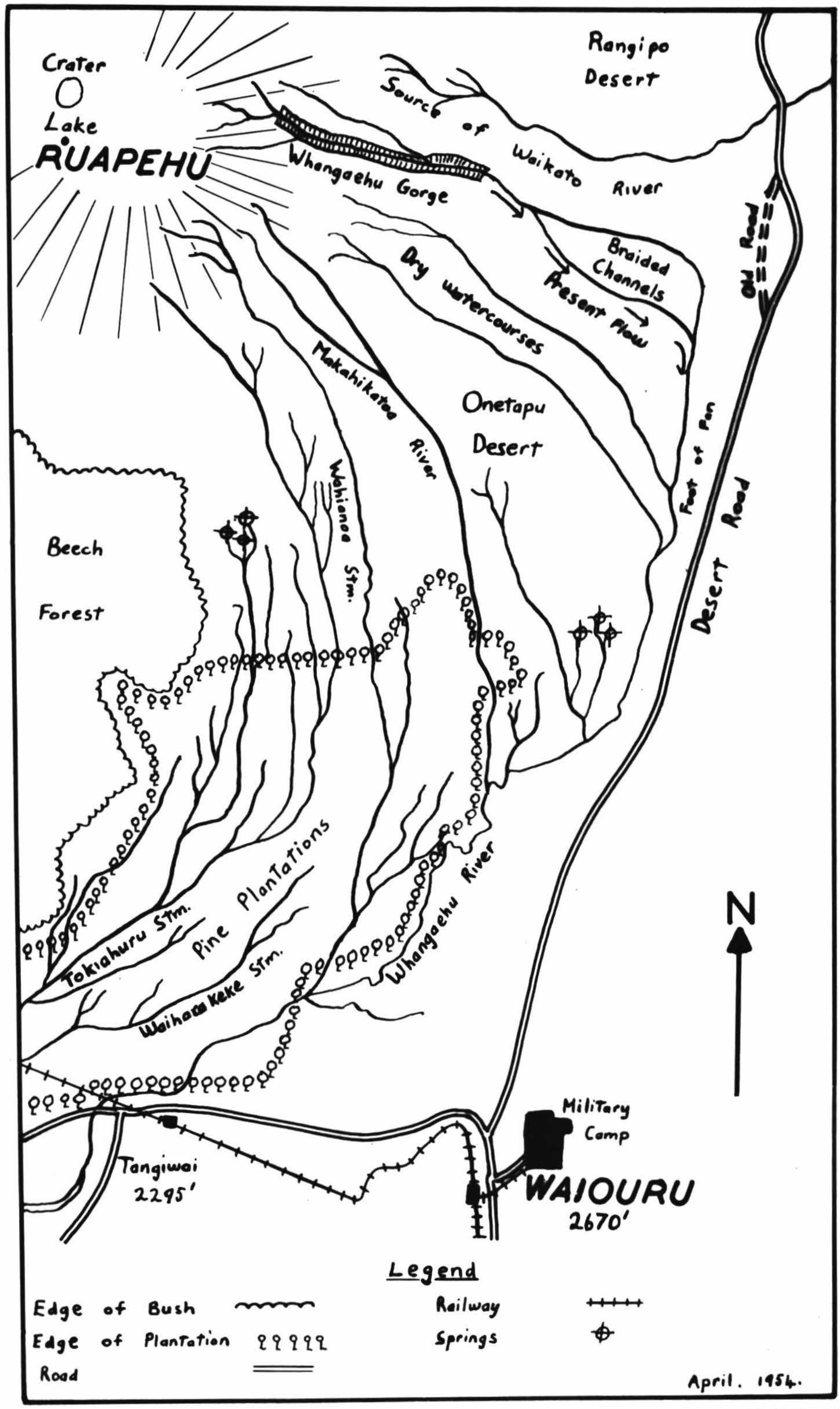
ORIGIN OF THE OUTLET.

4. p.3

The South Crater (Friedländer, 1898), or caldera, of Mt. Ruapehu was breached on the east side, probably by explosion in the distant past. In the gap thus formed, renewed activity built a secondary cinder cone in which the present lake is situated. To the east the drainage pattern on the outer ash slopes was distributed into innumerable rills, which eventually gathered into a single consequent stream. With further activity and ash cone building, this stream may have been diverted slightly southward until barred by the original south wall of the South Crater that now forms the highest peak, Tahurangi (Ruapehu). There, no longer able to migrate, the stream gained mastery and cut a deep ravine or barranco (outlet gorge) into the secondary crater, thus tapping the Crater Lake if it existed at that time. The valley of the Whangaehu in its upper reaches may therefore be described as a deeply eroded, major consequent.

Later, névé accumulated on the shelf bordering the present crater on the south and west, and terminated abruptly as ice cliffs at the Crater Lake margin. The ice in the south-eastern section of the snow-field was directed into the barranco, blocking the lake outlet.

In general, the water drained from the lake through an ice tunnel which probably followed the former course of the barranco. The resemblance is close to the subglacial melt-water stream of a glacier, which emerges from an ice tunnel. The barranco is represented at the present time by a sharp dip on the south-east side of the crater rim, over which water flows to enter the ice tunnel.



? Scale

Fig. 5.

River pattern of south-east of National Park, based On Automobile Association Road Map of Tongariro National Park.

WHANGAEHU RIVER

Whangaehu River (Fig.5) emerges from a steep, deeply-eroded consequent gorge, on the lower slopes of Mt. Ruapehu, to flow on the gentle slopes of its large alluvial fan. This fan constitutes part of the Onetapu Desert, a southern extension of the Rangipo Desert, on the eastern side of Mt. Ruapehu, and, being composed of unconsolidated material, forms an ever-changing topographic feature. On the left bank of the Whangaehu in its upper reaches, the long rocky ridge called Nukuhau separates the northerly drainage of the Waikato from the southerly drainage of the Whangaehu .

During past eruptions of Mt. Ruapehu, the ash and scoriaceous material ejected has been blown by the prevailing north-west winds and deposited on the eastern slopes of the mountain. Heavily loaded with this volcanic debris, the rivers have been forced to aggrade. A considerable proportion of this bouldery waste has been supplied by volcanic mudflows (lahars), which occurred at frequent intervals in geologically recent times.

Towards the head of the fan, (Fig. 6) where the grade is uniformly steep, the Whangaehu flows in a single aggraded channel; but farther down on the broad convex surface it flows in braided channels which unite at the foot of the fan (Fig. 7). From this point the Whangaehu flows as a single stream on the floor of an aggraded valley, and is bounded on either side by an extensive flood plain. The direction of drainage changes suddenly at this point, from east to south, and the river follows the semi-circular margin of the fan.

Fig. 6.

Whangaehu River emerging from its gorge onthe lower slopes of Mt Ruapehu-24 January 1954.

Fig. 7.
Alluvial fan formed by Whangaehu River on east side of Ruapehu near Desert Road.

Fig. 8.
Evidence of recent scouring in one small channel near the foot of the fan. On 24 January 1954 the water of this stream seeped out of the alluvium a few hundred yards upstream from this point.

Fig. 9.
Recent scouring where two channels join near the foot of the fan.

Fig. 10.
Evidence of scouring in one of the now dry braided channels. Flood level at this point is indicated by the figures hand.

Fig. 11.
Portion of one of the larger channels showing typical alternation of mud deposits and coarse material with boulders - 24 January 1954.

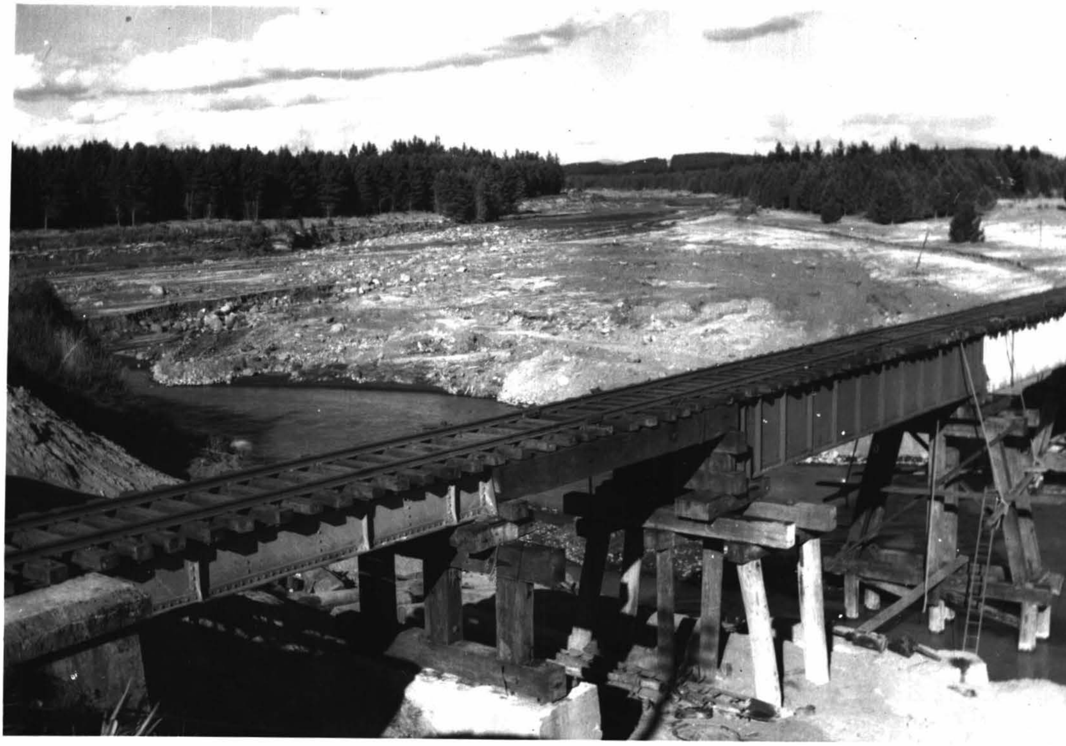


Fig. 12.

Reconstructed temporary Tangiwai rail bridge. Railway embankment is out of photograph to right of flood plain.

Fig. 13.

Outlet of Crater Lake from north side of Pyramid Peak. Note reconstructed dam of fallen ice and rock-1 Jan. 1954.

On the fan, much water sinks into the alluvium in dry weather, and the streams are greatly reduced. The percolating ground water emerges as springs at the fan margin, especially in the southern areas, and these flow as tributaries to the Whangaehu. On the surface of the fan, vegetation is scanty, for all parts are subject to flooding.

Beyond the fan, the Whangaehu receives two main tributaries, the Makahikatoa River, which is frequently dry in its upper reaches, and the Wahianoa Stream, which carries the melt-water from the Wahianoa Glacier on the south-east slopes of Mt. Ruapehu.

On 24 January the channels of the braided portion of the fan were dry, except for the lower reaches, where water seeped out of the alluvium to form small creeks, (Fig. 8). The main flow of water from the Crater Lake and the Whangaehu Glacier followed a course farther south, avoiding the higher braided portion and joining the confluence of the smaller channels about a mile to the south.

Evidence of the Tangiwai lahar could be seen in all the channels, (Figs. 9 and 10), and the lahar appeared to have covered an extensive area of the fan. The sides of many channels had been corraded and the tussock grasses of the flood plain had been bent in a downstream direction. In one of the larger channels the lahar reached a height of nearly ten feet, as indicated by mud lines, and the widest part of this channel was approximately 100 ft. Along the course of two channels examined, areas of coarse material with boulders up to about 1 ft. in diameter alternated with areas of mud deposits, and much fine waste was deposited in areas of overflow on the low interfluves (Fig.11). The mudline on these interfluves was quite distinct; and in the channels themselves a yellow deposit of sulphur indicated origin from Crater Lake.

At Tangiwai, the river has a winding course,(Fig.12) and on one of the bends is situated the Tangiwai railway bridge; a short distance downstream is the road bridge. On the convex bank and partly extending across the flood plain is the railway embankment leading to the bridge.

At the time of maximum flood, the lahar, which otherwise would have spread over the flood plain, was partly blocked by the railway embankment and directed to the narrow channel under the bridge. Constriction due to the embankment, and perhaps the bridge piers themselves, led to a ponding above the rail bridge. It is difficult to determine whether the bridge piers were undermined or were removed bodily by the accumulated pressure from the ponding above the bridge. Healy, in evidence to the Tangiwai Board of Inquiry, 1954, maintained that the lahar had sufficient density and velocity to carry the two central piers forward bodily, and that the scouring effects took place only after the first wave of the lahar had passed. Healy suggested that of the 70,000,000 cubic feet of water that drained from the lake, about one-sixth came down in the lahar of density 1.6, and the remainder came down in gradually diminishing amounts immediately afterwards. He estimated that the peak wave of the lahar took ten to fifteen minutes to pass. From evidence presented to the board, it is believed that the peak discharge was approximately 30,000 cusecs and the mean discharge approximately 23,000 cusecs. The average speed of advance of the crest was calculated to be 10 miles an hour.

Downstream, at the road bridge, it appears that the abutment on the left bank was let down as it was undermined by the torrent; for the bridge was not displaced laterally. Healy, however, stated that the greater mass of water in the peak wave did not flow under the road bridge, but swept over the right bank and across the highway, thus avoiding the bridge. The scouring commenced only after the peak wave had passed.

PREVIOUS FLOODS IN THE WHANGAEHU RIVER

A report of flooding in the Whangaehu River appears in a short description by W. Skey (1868) as follows: "An avalanche of ice and mud forced its way down the Whangaehu from Ruapehu to the sea in 1863, scouring out the bed of the river, destroying a bridge, and doing great damage to the native cultivation . . . The cause of the avalanche may no doubt be attributed to a sudden escape of vapours from the same volcanic source that gives origin to the mineral waters."

He ended his description with a very general analysis of the Whangaehu water: "The water is persistently turbid, from the presence of clayey matter, and the taste is very sour. It contains the constituents of potash alum with the addition of a little chloride of magnesium and protochloride of iron."

The Provincial Geologist, J.C. Crawford, made similar observations in 1869, while on a trip to Taupo. He attributed the main flood to damming up of the water downstream, and his description reads: "Our guide, Tuakau, pointed out to us the marks of the avalanche which fell from Ruapehu, and ultimately destroyed the bridge of the Whangaehu. The avalanche, after descending the mountain, was carried by its impetus for some miles across the plain into the bed of the Whangaehu. The left bank of that river, being the highest, stopped the further progress of the avalanche, which consequently formed a dam. The river ran dry below and formed a lake above, until the accumulated waters carried the debacle before them to the sea, sweeping the Whangaehu bridge away, some forty or fifty miles below.

"We could perceive distinctly the marks of the progress of the avalanche across the plain. The ground had been bared and large patches of bushes swept away."

Richard Taylor, in his Journal (Typescript in Turnbull Library), noted the flood as occurring on 13 February 1861. In his book, Te Ika A Maui, he referred to this flood, but dated it 1859: "The flood which occurred in the Whangaehu River on the 13th December 1859, and carried away the bridge which had only been recently erected, was of an extraordinary kind . . . To account for this unexpected flood, which occurred in fine dry warm weather, it is most likely that a long continuance of heat detached a portion of a great cliff (in headwaters) sufficient to arrest the course of the river and form a temporary lake, which, gradually rising in height until its barriers were no longer able to resist the pressure, gave way . .

"The flood overflowed its banks, depositing vast quantities of ice, snow, and drift along the entire course, until it reached the bridge . . . There the trunks and blocks of ice collected in such quantity that they were level with it, and formed such a compact mass that an observer said it would have been quite possible to walk along the top of it across the river . . . The poor bridge creaked, opened, and was swept away . . . The flood came down at about 6 a.m. and in little more than two hours it subsided, leaving large masses of ice, snow, and mud, filled with crystals of ice, on the banks . . . the ice and snow were remarkably compact, very black, and emitting a strong sulphureous smell, and in such masses as actually to remain for nearly a week under the mud."

A record of the flood may also be found in the New Zealand Official Year Book, 1899, p.536, and in the New Zealand Spectator, Wellington, 16 February 1861.

It must be remembered that the existence of a crater lake was not known at that time, for the first ascent to the summit was not made until 1879 by Beetham and Maxwell.

During a period of eruption in August 1889, the Crater Lake ejected its waters, with a resultant sudden flood in the Whangaehu. Hill (1891), who denied any connection between lake and river, attributed the flood to welling over of lake water over the crater lip.

Cowan (1927) referred to remarks made by Mr. Ross, proprietor of the then Terraces Hotel, concerning a period of intense activity in March 1895: "There was an enormous discharge of hot water from the lake, the Whangaehu was flooded, and even the Wanganui River was greatly discoloured. After all the water had been discharged the steam escaped with a thundering roar."

A similar flood to that of Christmas Eve 1953 accurred in January 1925, accompanied by an unexplained drop in lake-level. Later investigation of the Crater Lake revealed an enlargement of the ice tunnel, a drop of many feet in lake-level, and the exposure of a boulder-strewn bench around the lake edge (from photographs).

CHANGES IN LAKE LEVEL

It seems likely that in the past blockage of the outlet tunnel has resulted in a rise in lake-level. In January 1925, the lake was drained suddenly through the outlet. An extract from the "Annual Report of the Tongariro National Park Board," 1925, reads: "The Ranger at Whakapapa states that the Crater Lake on Mt. Ruapehu has been lowered considerably in depth, due chiefly to the ice cave outlet being enlarged, and for the time being flooding the sulphur stream on the south side of the mountain."

Between 1925 and 1945, the outlet apparently became partly blocked by ice, and the lake rose to its former level. During the erupti n of 1945, the lake actually disappeared as the spreading tholoid displaced the lake water (Cotton 1946). By January 1946, pools of water had appeared on the crater floor, and by 1948 the lake was re-established.

In an addendum (1949) to his 1946 paper, Cotton noted: "In June 1948, and probably earlier, the lava in the crater was entirely submerged; a crater lake was re-established in every way resembling that which was in existence prior to 1945, though perhaps at a somewhat higher temperature."

In a report to the Tangiwai Board of Inquiry investigating the Tangiwai railway disaster, Mr. D.J. Mason, President of the New Zealand Canoeing Association, gave particulars obtained during a number of sounding surveys of the Crater Lake.

On 1 March 1950, an expedition led by Mr. L.S. Vause noted that the lake-level had been rising, for a rock previously twelve inches above the water had in one month become submerged. The soundings taken at that time on a north-south line were 60 feet increasing steadily to 138 feet and then suddenly plunging steeply to 264 feet. There was no trace of the old ice tunnel or of a new outlet, but Vause suggested that there must be considerable seepage through the retaining wall to act as a source for the Whangaehu River.

In January 1951, the lake was at a still higher level. The water, with a temperature of 76 $^{\circ}$F, tended to undermine the ice cliffs to the north and west, so that the ice had receded at least three chains.

On 13 and 14 February 1954, further soundings were taken by Mr. Mason. Near the centre of the lake the depth was 218 ft. He estimated that the lake had risen 50 to 60 ft. since 1950 and had dropped 26 ft. since Christmas Eve 1953. There has therefore been a rise of approximately 70 ft. in the lake bed, which now consists of very soft mud. He accounts for the rise as being due to deposition of rock and ash material from the surrounding icefield or perhaps to a minor eruption. The range of temperature of the water was from 72° to 76° F.

From the above evidence and from personal observations since 1949, the lake-level has continued to rise since the 1945 eruption, and by 24 December 1953 was at a considerable height above the lowest point of the rock rim, the water being merely held back by the ice face of the icefield above the barranco. The writer believes it possible that the ice tunnel was re-forming under the ice cliffs and was heading back towards the ice face.

On 24 December 1953, a stage may have been reached when the ice wall between the re-forming tunnel and the lake could no longer hold back the mass of lake water at such a high level. Consequently, it gave way suddenly, and the water above the rock rim rushed out, enlarging the tunnel as it passed.

CHANGES IN THE CRATER LAKE

The present ice tunnel was first reported as being just visible, during October 1953, by Mr. J. Blyth, of Taranaki. On 24 December, only eight hours before the disaster, it was observed by a party of climbers.

From approximately 8.03 p.m. to shortly after 9 p.m. on Christmas Eve 1953, a local tremor of very small amplitude was recorded at the Chateau Tongariro seismic station. According to Mr. G. Eiby, of the Seismological Observatory, Wellington, the gradually increasing disturbance was totally unlike a normal local earthquake, and did not show the signs usually shown prior to a volcanic disturbance. It was merely a tremor of extremely small amplitude; a vibration and no more. Considering the time and duration of the disturbance, it is generally believed to be due to the large mass of water that burst forth suddenly through the formerly blocked outlet and thence down the mountainside.

On 1 and 22 January 1954, the Crater Lake and Whangaehu head-waters were closely inspected. The outlet (Figs. 3, 4 and 13) is marked by a large circular hole, about 150 ft. in diameter, in an ice wall to the south-east side of the crater. The visible portion of the tunnel has been enlarged by collapse of its ice walls, but at a short distance within the tunnel the diameter decreases suddenly. During investigations on 1 January, water was observed flowing from the lake to the tunnel through a small dam of ice and rubble. On 22 January, the dam was still being built by the addition of falling blocks of ice, and the water appeared to be seeping through. On 14 February, the flow of water through a small cave in the dam was estimated by Mr. Mason to be four cubic feet per second.

At the distal end of the tunnel, the water emerges to flow down a narrow rocky ravine roofed over by a thin sheet of ice. The escaping lake water seems to have scoured away scoria and ash, causing the overlying ice to collapse in places. A large circular "sink-hole" in the ice, exposing bare rock beneath, is now visible in the Whangaehu head-waters about 200 ft. below the crater rim, (Fig. 14). This spot coincides approximately with the bare rock patch observed in 1945 by Mr. Pritchard, in which hot water and steam were gushing from a subterranean passage (from photograph).

Overlying ice has also collapsed at the ultimate outlet down-stream, and much of the narrow rocky ravine is now exposed, flanked on either side by remnants of the ice sheet. Between the "sink-hole"

Fig. 14.

'Sink-hole' in ice, on site of distal end of tunnel outlet, Whangaehu River headwaters.

Fig. 15.
Lake floor and foot of ice cliffs exposed after fall in lake level - 22 January 1954.

Fig. 16.

Exposed lake floor on west and north side of Crater Lake - 22 January 1954.

and the ultimate outlet an ice bridge remains, severely cracked and appearing frail.

Within the crater, the water level has dropped nearly 28 ft. resulting in the exposure of the crater wall beneath the north-west and northern ice cliffs, (Fig. 15). A narrow beach to the east is also exposed, as well as an extensive flat area to the noth and west (Fig. 16). The writer believes this to be the remnant of the pre-1945 floor, the remainder of the floor having dropped to a greater depth when the tholoid subsided towards the end of the 1945 eruption. During that time, Oliver (1945) noted: "The margin of the tholoid on the south-west side was separated from the wall of the crater lake basin by a remnant of the crater lake mud on the exposed lake bottom."

From a contour map based on aerial photographs, Healy (1954) estimated the lake area prior to 24 December 1953 to be 72 acres, and the present area as on 8 January 1954 to be 47.4 acres. The present volume of water he estimated to be 320,000,000 cubic feet.

Apart from the unmistakable odour of SO_2 gas which appeared to be effervescing from the lake water in several spots, there was no sign of volcanic activity during these investigations. Samples of lake water were obtained by a chemist from Dominion Laboratory in the party of 22 January, and these were subsequently analysed with the following results:-

pH	...	...	...	1.4
SO_4	...	...	...	6420 parts per million
Cl	...	...	...	3920 parts per million

On the same date, samples of mud from the exposed portion of the lake floor, and sulphur from the northern edge of the lake were collected and subsequently tested by Mr. T.A. Turney, Chemistry Department, Victoria University College, who reported as follows:-

"Sulphur was taken from the north side of the lake. It appeared to have been floating up from a point in the crater lake and was being washed across to the side. A yellow scum was apparent on the surface. The sulphur washed to the side consisted of a yellow fibrous mass which had the appearance of plastic sulphur. The material was full of gas bubbles. The material was insoluble in carbon disulphide, which is consistent with the material being plastic sulphur. The material as it dried out lost its plastic form to form rhombic sulphur. This was soluble in carbon disulphide. On burning, the material left a slight residue of mud which was not examined. The dried material could not again be made plastic, and this precluded the possibility of the plasticity being due to the mixture of mud and sulphur. Chemical examination showed no selenium or tellurium.

"A sample of mud from the floor of the crater was also examined. This mud in the wet state was yellow in colour. The mud contained sufficient free sulphur to ignite.

"The presence of naturally occurring plastic sulphur does not appear to have previously been reported. Plastic sulphur is formed from sulphur in the liquid state by quenching with water. As sulphur has a melting point of 115^{o} C, the presence of plastic sulphur would suggest temperatures at the lake bottom at least high enough to cause the extrusion of liquid sulphur. Of further interest is the probable presence of sulphur dioxide evolved in bubbles from the lake surface. This was not tested for chemically, but the smell is characteristic, and both Mr. W.B. Martin and the writer consider the gas was sulphur dioxide. There was no smell of hydrogen sulphide, but this would not be expected when there was a large amount of free sulphur dioxide."

ACKNOWLEDGEMENTS.

Thanks are expressed to Mr. T.A. Turney and Mr. W.B. Martin, Chemistry Department, Victoria University College, for identification of the sulphur, and to Mr. M.T. Te Punga for criticism of the manuscript.

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PART 2

THE CALDERA OF MOUNT RUAPEHU

SUMMARY

This paper deals with the events leading up to and following the formation of a caldera that replaced the summit of the once higher Mt. Ruapehu.

Following a period of intense activity with deposition of the extensive 'Tongariro Ash Shower', the summit of 'Old Ruapehu' subsided and a caldera was formed. Later activity from two vents within the caldera built up the topographical features of the present day Mt. Ruapehu.

INTRODUCTION

During the summer months of early 1955 and 1956, ablation of névé and glaciers on Mt. Ruapehu exposed large areas of rock and ash. During these exceptionally dry seasons, it was possible to make more detailed observations on the caldera that occupies the summit.

RUAPEHU CALDERA

Morphological details of the large comparatively flat expanse on the summit of Mount Ruapehu appear to conform closely to Williams' interpretation of the term caldera (1941 P. 242). It is a volcanic depression, more or less circular in outline, measuring nearly two miles by half a mile, and containing within its boundaries two vents (Fig. 18).

Although the rim has been considerably modified by erosion, it is well preserved in a few places. The inner slope of these summit remnants present sections of lave flows which appear to converge to, and radiate out from, a common source at a higher level than the present summit. These flows are well exposed on Te Heu Heu and Tukino Peaks to the north and on Paretetaitonga and Tahurangi to the south. The only apparent caldera rim remnant to the east is Cathedral Peaks. (Figs 19 and 20).

The remaining portion appears to have been destroyed by deep erosion, possibly by glacial action, but more probably by headward erosion by consequent streams on the outer slopes. Notches in the rim also seem to indicate the presence of extensions of major radial consequents to a higher source.

Thus 'Old Ruapehu' appears to have been partially replaced by a caldera (Fig. 17).

EXPLOSION OR "EXPLOSION COLLAPSE"?

It may appear that the topographical features of the summit of Mount Ruapehu are due to the building up processes of two or more adjacent vents to produce a multiple volcano, as suggested by its elliptical shape. However the writer believes that the present summit topography is due mainly to caldera-making processes and erosion.

Early theories of caldera-formation postulated simple explosion on a grand scale. It was suggested by Speight (1908) that the summit topography of Ruapehu originated in this way

Fig. 17.

Mt. Ruapehu as seen from summit of Mt. Ngauruhoe. Note caldera occupying summit of Ruapehu. Note also the bifurcating Whakapapa Glacier and radial consequent valleys.

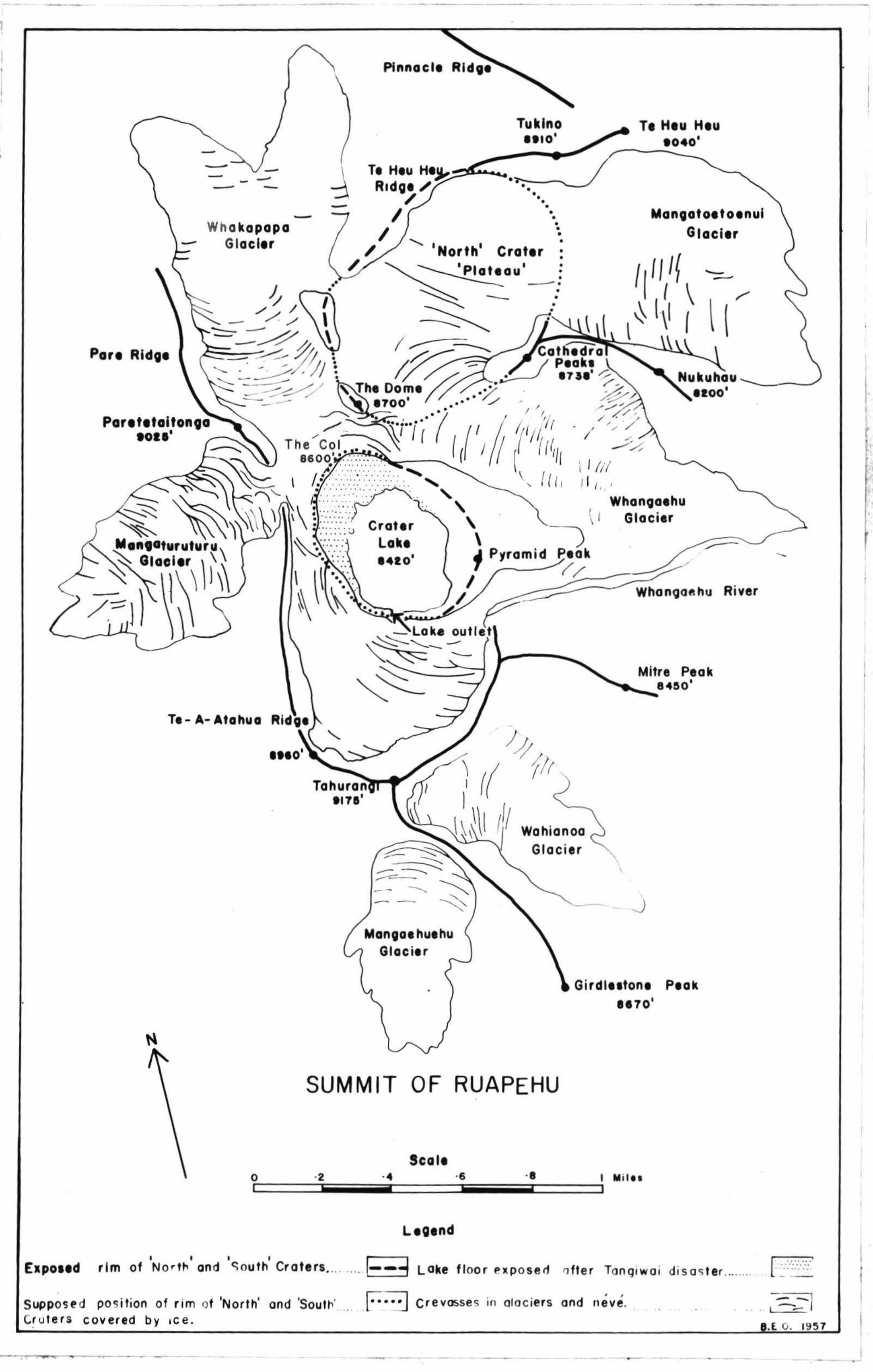

Fig. 18.

Map based on aerial photographs showing summit features of Mt Ruapehu.

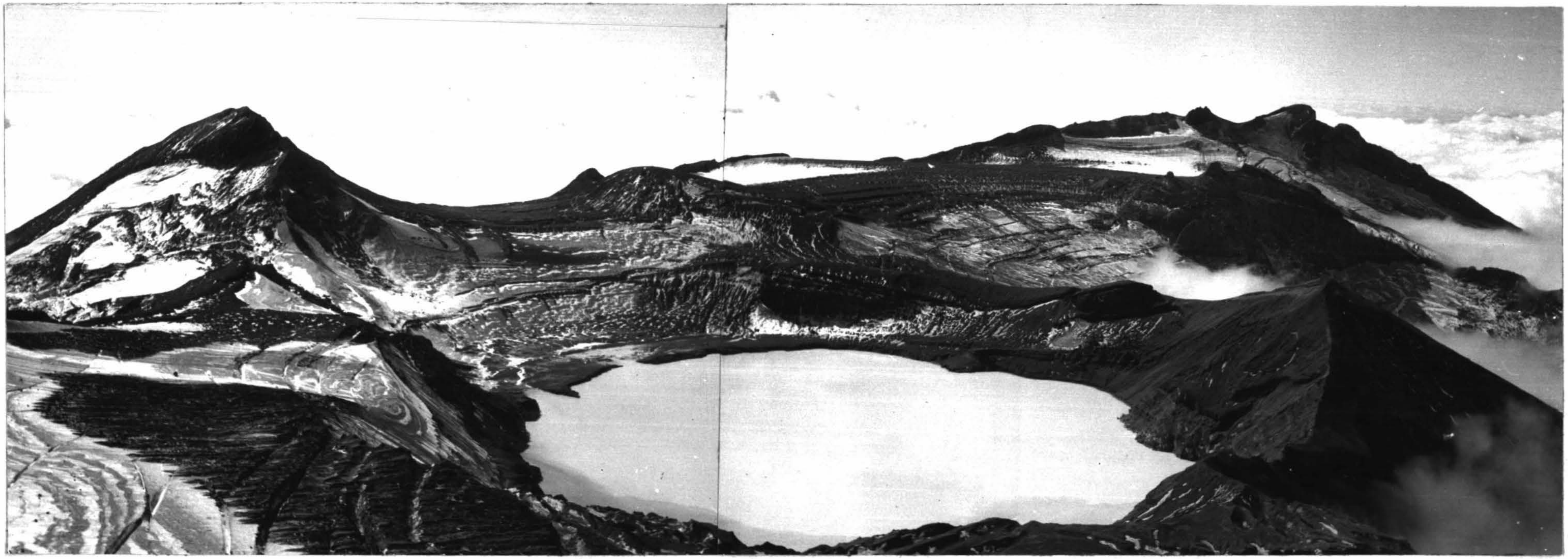

Fig. 19.

View of Ruapehu caldera looking north from Tahurangi, the highest point on the caldera rim.

Fig. 20.

View of Te Heu Heu Ridge and 'North Crater' (Plateau) of Ruapehu from Paretetaitonga. Cathedral Peaks distant right and 'The Dome' right foreground.

as did the present topography of Mount Tongariro, eleven miles to the north-north-east.

The weakness in this theory as applied to Ruapehu (and others named by Williams) is the lack of angular fragments from the destroyed summit which would be expected to cover the plain about the mountain.

Williams (1941p. 253) using Krakatau as an example, suggests a mechanism of explosion-collapse for formation of that caldera. His 'Krakatau' type (P. 246) seems to be particularly common on composite volcanoes built of andesitic material, and seems applicable to the Ruapehu caldera. The evolution of a 'Krakatau type' caldera had been divided by Williams (p. 336, after Van Bemmelen) into six stages. The present writer believes that these stages can be distinguished in the case of Ruapehu.

Tongariro Ash Shower (Stages 1,2 and 3) - According to Williams these stages are represented by repeated and usually short lived periods of voluminous discharge of pyroclastic ejecta, chiefly in the form of pumice and/or juvenile ash. Explosions are at first mild, but culminate in more violent explosions which hurl the ejecta high into the air. During these stages the magma level in the magma chamber drops.

These stages are represented, in the case of Ruapehu, by an extensive and fairly widespread andesitic shower preceeded possibly by emission of nuée ardente flows.

Reference to this shower has been made by previous writers and a number of sections have been studied by the present writer in the National Park region.

Grange and Hurst (1928-29) describe a typical cutting on the Desert Road between Waiouru and Turangi:-

(1) "White rhyolite pumice from Taupo. (4 feet)

(2) Thinly bedded dark grey andesite ash containing leaves. (1 ft. 6 ins.)

(3) Fine brown andesite ash (3 ft. 6 ins.)

(4) Layers of andesite lapilli. (1 ft. 6 ins.)"

The fine brown andesite shower extends over the whole of the Tongariro Subdivision. The succeeding shower, he states, has been carried north and east from its source and is 9 inches think on the Kaimanawa Range, but absent from Waiouru and West Ruapehu.

A similar section is described by Grange (1931) from a section on the National Park - Turangi Road:

(1) "Fine brown andesite ash. (2 feet)

(2) Andesite lapilli. (up to 1 inch) (1 ft. 6 ins.)"

Further north on the Taupo - Napier Road (1.2 miles S.E. of The Terraces' Hotel), Baumgart (1954) describes the Taupo Ash sequence exposed at this locality. He divides the sequence into 26 members and at the base of the sequence (member 26) are: "22 inches of even grained dark brown ash, pumiceous and andesitic (Tongariro); broadly mottled with traces of organic matter, with many small flecks of carbon, apparently fragments of roots and stems; few pumice lapilli up to $\frac{1}{2}$ inch near the base."

The section lies directly upon a firm fine grained pink pumice breccia of the Waitahanui Series (Grange 1937, p. 69).

By radioactive carbon dating of the andesite layer, it appears that this was deposited about 9000 years ago (Baumgart 1954).

Another section has been studied by the writer on the National Park - Turangi Road (18 miles from National Park).

(1) Variable thickness of Taupo Ash.

(2) Fine dark brown andesitic ash (5 feet)

(3) Coarser deposits of ash and andesitic lapilli up to $\frac{3}{4}$" in diameter grading into fine ash above. (4 feet)

(4) Coarse black ash and small angular fragments of andesite up to $\frac{1}{2}$ inch in diameter. (1 foot 3 inches)

(5) Agglomerate of rounded andesite boulders in a brown deeply weathered clayey matrix.

From the Taurewa Post Office (on the National Park - Turangi Road) a private milling road running 12 miles into the bush offers two excellent sections of the 'Tongariro Ash Shower'.

A section, (Fig. 21) called by the writer the Taurewa section (6 miles from Taurewa Post Office) shows:-

(1) Buff coloured Taupo Ash and pumice lapilli. (35 - 40 feet)

(2) Fine dark brown andesitic ash. (3 feet)

(3) Water-laid deposits consisting of small rounded andesite fragments, a single layer of andesite boulders three inches in diameter and light grey to brown pumiceous sand and silt.

Half a mile further on, a quarry exposes extensive deposits of Taupo Ash (Fig. 23), and half a mile further, 3 feet of andesitic ash lies directly on a weathered surface of dark grey mudstone. Taupo Ash overlies the andesitic ash.

As there appears to be only one extensive horizon of andesitic ash, the showers described above probably belong to the same period of activity (pre-caldera phase of Williams).

Although these showers are referred to as the 'Tongariro Shower' by Grange and Baumgart, there is no reason to suppose that they actually came from Tongariro alone. There appears to be no reason why both Tongariro and Ruapehu should not have erupted large quantities of andesitic ash simultaneously, for both mountains were probably connected to the same magma chamber, due to their close proximity.

Microscopic study of the 'Tongariro Shower' has revealed a mineral content similar to that of the Ruapehu andesites themselves; viz. glass, plagioclase felspar, iron ore, hypersthene and augite.

Near the mountains, especially to the west and south, the ash deposits rest on fluviatile conglomerates and agglomerates of lahar origin, which suggests a period of quiescence and deep erosion before the explosive period, although the oncoming of the explosive period itself may have been the cause of the lahars. Nuées ardentes were possibly the motivating cause behind the lahars.

Most of the sections in the National Park region show the fine ash lying directly upon the agglomerate of ill-sorted andesite boulders and clay (boulder clay of Park, 1887). Typical sections of this type were observed on the main road to Raetihi, south of National Park.

Near the Makatote railway viaduct (3 miles south of Erua) a Public Works quarry exposes about 40-50 feet of the agglomerate underlying 6-7 feet of fine andesitic ash.

Beneath the viaduct itself, the Makatote River has cut down through approximately 260 feet of the agglomerate, and at the south end of the viaduct on the railway line, 6-7 feet of fine dark brown ash is clearly observed above the agglomerate (Fig. 24).

Further south (13 miles south of Erua) 6 feet of ash overlies water-laid grey ash which in turn overlies the agglomerate. Five miles south of Raetihi near the new Mangawhero River bridge on the Para Para Road to Wanganui and again 21 miles south, the agglomerate and ash can still be observed although considerably thinner (Fig. 22).

Fleming (1953, p. 277) refers to the Whangaehu and Mangawhero valley fill consisting of ill-sorted andesite debris, as being of minor lahar origin. Similarly, the Hautapu Valley agglomerate to the south-east of Ruapehu described by Te Punga (1952 p. 32) is regarded as being of the same origin.

Thus we have evidence of a period of continuous explosive activity, and apparently the only one of its kind, from Ruapehu and Tongariro. As no soil layers or other evidence of quiescence are apparent within the ash beds, it seems safe to suppose that the explosive stage was rather brief and continuous.

Other showers were undoubtedly emitted by the volcanoes before this outburst; but they were insignificant and are not preserved in sections.

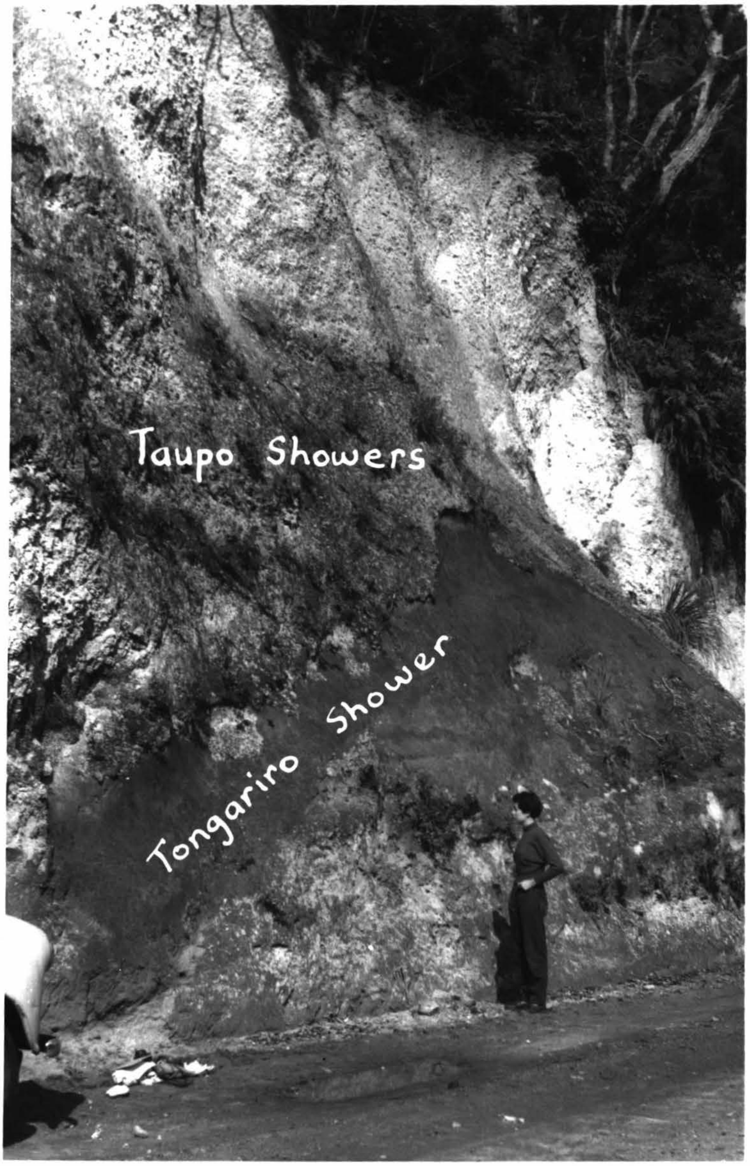

Fig. 21.

Section showing Tongariro Shower and Taupo Ash
6 miles along private road from Taurewa P.O.

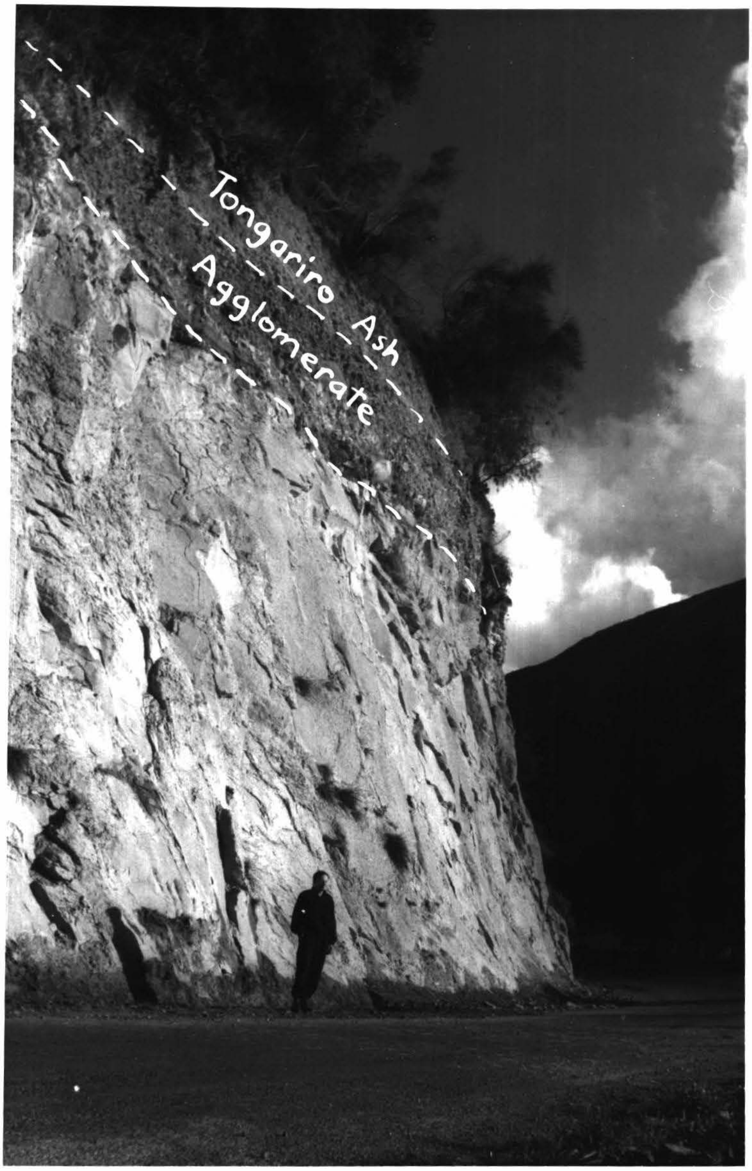

Fig. 22.

Tongariro Ash lying on agglomerate of Ruapehu andesite and ash, 21 miles south of Raetihi on the Para Para Road.

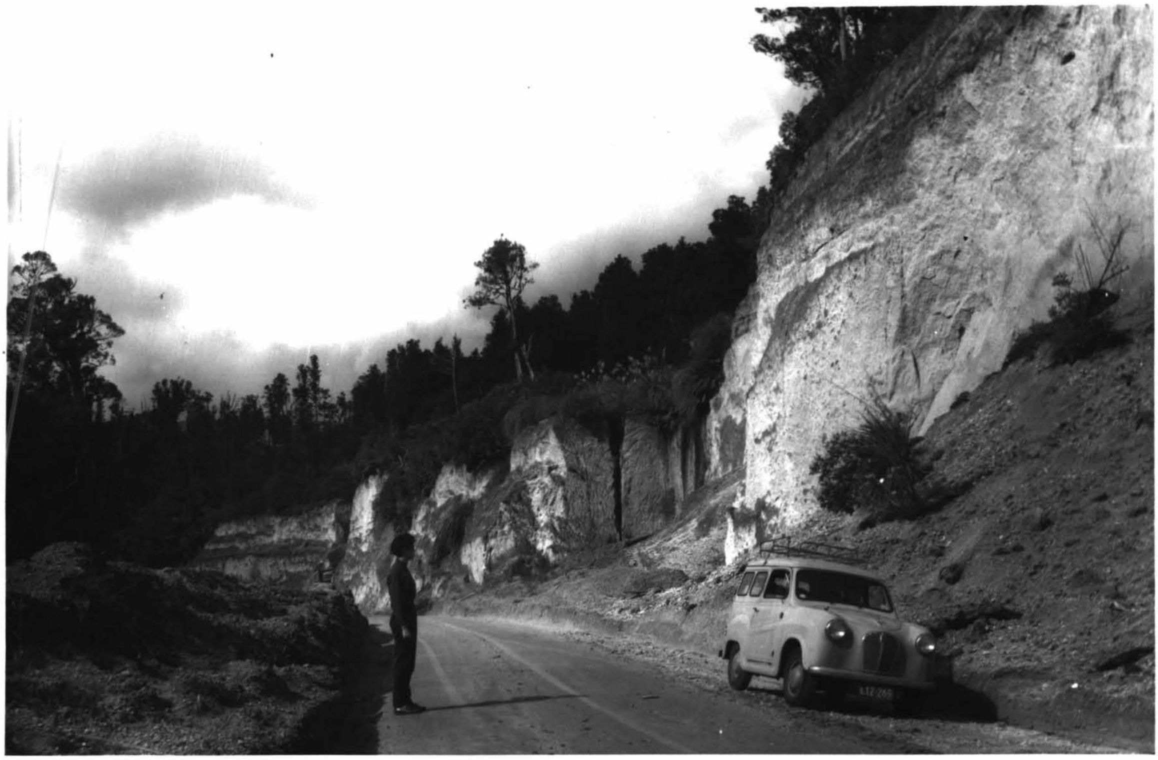

Fig. 23.
Thick Taupo Ash deposits that overly the Tongariro Ash Shower $6\frac{1}{2}$ miles from Taurewa P.O. on private road.

Fig. 24.
Tongariro Shower overlying a typical agglomerate section near the Makatote Viaduct.

STAGE 4

Engulfment follows this period of repeated and short-lived explosions of ash. Thus the former higher summit of Ruapehu, lacking support from below by withdrawal of magma, collapsed and formed the caldera.

Although the Ruapehu caldera is not as large as some of those described by Williams (1941), the sequence of events is essentially the same. The engulfment of the summit need not have been catastrophic as in the case of Krakatau, but the summit may have subsided more quietly.

STAGES 5 & 6

"After a period of quiescence and erosion, new cones appear on the caldera floor, especially near the rim .... Young cones rise above the caldera rim and pour lavas down the outer slope." (Williams 1941 p. 336).

By study of the present topography of the summit, it seems that later activity was confined to two vents, a "North" and "South" crater (Fig. 18). The "North" crater is covered with névé, but during the late summer of 1954/55 and 1955/56, the remains of the crater rim were well exposed. The North crater (Plateau) is bounded to the north and north-east by Te Heu Heu and Tukino Ridge which represents the old caldera wall (Fig. 20). This merges with a comparatively narrow and low rim of scoria and ash which turns eastward along the north-east side of the Whakapapa Glacier and eventually disappears beneath the Whangaehu Glacier to the east.

The highest point on this portion of the rim is the "Dome" (8700 ft) which overlooks both the "North" and "South" craters. The "North" crater rim to the east is non-existent as far as can be observed, except for a small remnant of the caldera rim at Cathedral Peaks (8738 ft.). To the north and south of Cathedral Peaks the rim has been breached and the open spaces form the cols of the Mangatoetoenui and Whangaehu Glaciers respectively.

The "South" crater is still active and contains a small cone within which is situated the crater lake (O'Shea 1954). It is bounded on the west and south by Paretetaitonga (9025 ft), Te-A-Atahua Ridge and Tahurangi (9175 ft), which represent the more massive lava remnants of the south portion of the caldera rim.

To the east, Pyramid Peak is the highest point on a composite rim of scoria, ash and minor flows (O'Shea 1954). This rim bounds the southern upper reaches of the Whangaehu Glacier and disappears under ice filling the col of the Whakapapa Glacier to the north. The two lowest points of the "South" crater rim are to the south-east, south of Pyramid Peak, and potentially at the Whakapapa col if the ice was removed (Fig. 19).

During the period of quiescence after the caldera formation erosion continued on the mountain flanks, and during this period also glaciers redeveloped.

Later, the two vents were opened out by renewed activity and lava was erupted profusely, especially from the larger "North" crater. The later lava tongues flowed into and filled to a certain extent the radial valleys which had been formed before the caldera, and which had been eroded further during the quiescent period.

Thus the lavas of 'Old Ruapehu' were covered by newer eruptive materials. Grange and Hurst (1928-29) observed these more recent flows which are darker in colour that the earlier lighter grey flows. They considered that "Ancient Ruapehu" had regained its former height and form by the addition of these more recent lava flows, after the top had been blown off or collapsed to the 7000 ft. level.

Recent work undertaken by the writer in the Whakapapnui Gorge region on the northern slopes shows that these later flows lie unconformably on the earlier lava and agglomerate. The latter is the characteristic rock on Pinnacle Ridge, which bounds the Whakapapanui Gorge to the east.

Heat from these later lava flows which overspread the snow and névé in the caldera, possibly gave rise to the more recent lahars that formed the lahar mounds on the north-west slopes of Ruapehu (Grange 1931). A crater lake may have existed in either or both craters during this period of activity, the waters of which may have been released during intermittent activity, also giving rise to lahars.

Renewal of activity has taken place to the present day from the "South" crater. But even so, this appears to mark a "period of decadence and old age". (Williams, 1941, p. 241 after Reck).

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PART 3

PETROLOGY OF THE WHAKAPAPANUI GORGE ANDESITES, MOUNT RUAPEHU

SUMMARY

Petrological study of the andesite flows bordering the Whakapapanui Gorge, on the northern slopes of Mt. Ruapehu, has revealed very constant mineralogical composition in all flows. However, the rocks can be classified according to textural differences based on the nature of the groundmass. The older Pinnacle Type of andesite is generally more crystalline than the more recent Whakapapanui Series which are characterised by very glassy groundmasses.

INTRODUCTION

Dominating the central plateau of the North Island, New Zealand, are three active volcanoes; Tongariro, Ngauruhoe, and Ruapehu. The lavas emitted by these volcanoes have been referred to as "Tongariro basalts and andesites" (Grange, 1937) and cover an area of nearly 350 sq. miles at the southern extremity of the volcanic zone ("Taupo zone" of Hochstetter, 1864, pp. 92-5). This zone extends from Ohakune near Ruapehu in the south to White Island or beyond in the north (Fig. 25).

The highest and most massive of the three volcanoes is Mt. Ruapehu, reaching a height of 9175 ft. above sea level or 5000 - 6000 ft. above the central plateau. In plan it is roughly elliptical measuring about 13 by 10 miles. This multiple volcano has been in existence since late Pliocene times (Fleming and Steiner, 1951), but has been active only intermittently during historic times.

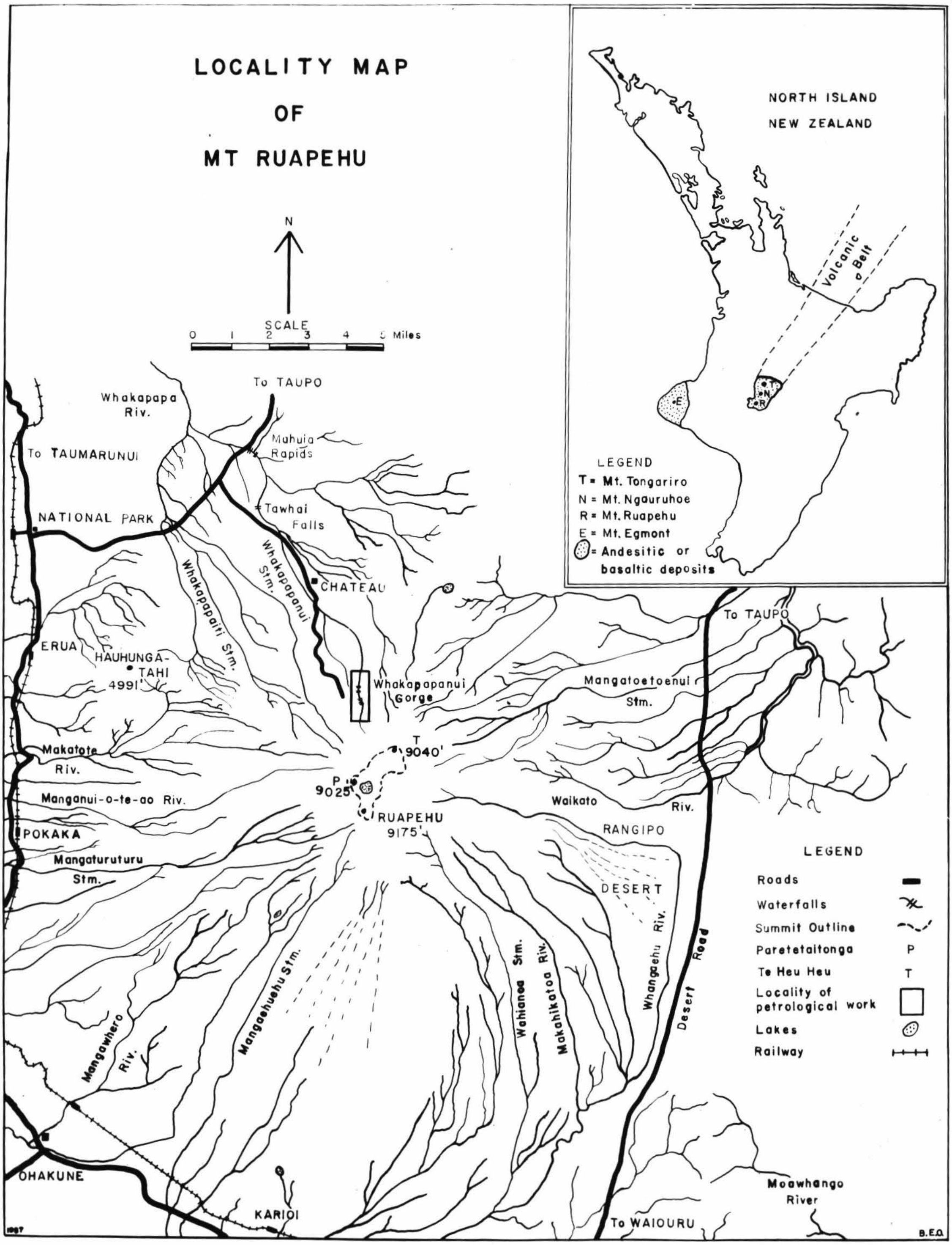


Fig. 25.

Locality map of Mt. Ruapehu and inset of North Island showing volcanic belt. Based on Automobile Association Road Map of Tongariro National Park.

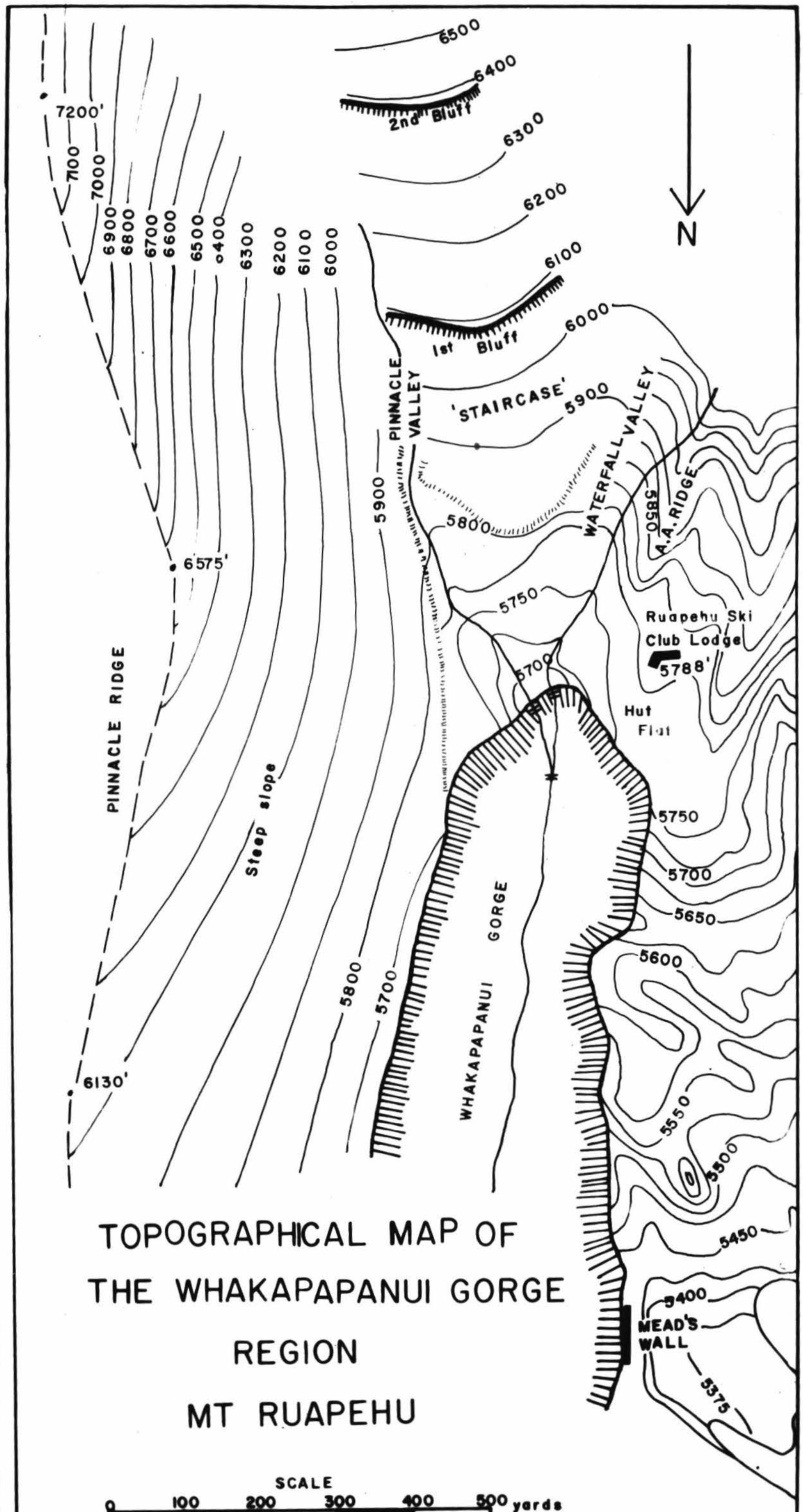


Fig. 26.

Topographical Map of the Whakapapanui Gorge Region, Mt. Ruapehu. Based on Lands and Survey Map of Mountain Hut Area and Lower Ski Grounds on Mt. Ruapehu.

The volcano is well dissected by a radial pattern of consequent streams (Fig. 25). Deeply eroded consequent gorges are a characteristic feature of Mt. Ruapehu and it is in one of these gorges that this petrological study has been undertaken.

LOCATION

The area under consideration is a small area bordering the Whakapapanui Stream on the northern slopes of Mt. Ruapehu. The area extends from an altitude of about 5400 ft. to 6400 ft. above sea level, and is approximately $\frac{1}{4}$ mile wide.

The lower half of the area is confined to the Whakapapanui Gorge, known locally as "Skippers", whereas the upper portion comprises the popular ski-field known as the "Staircase". The gorge is about ten minutes walk northward around the mountain from the road end; $4\frac{1}{2}$ miles by road above the Chateau Tongariro Tourist Hotel.

A conspicuous dyke (Mead's Wall) marks the lower boundary, and the top flow (Flow 9 on the 2nd Bluff) overlooking the "Staircase" marks the upper boundary. (Fig. 26)

The section extends through approximately 1000 vertical feet.

METHOD AND PURPOSE OF INVESTIGATION

This work was completed by the writer as part of an M.Sc. thesis in Geology at Victoria University College.

The Whakapapanui Gorge ("Skippers") was selected for study because it affords many fresh exposures of lava flows, as well as a few minor intrusions. Accessibility also played an important part in its selection.

The writer considers the area as an excellent representative section of Ruapehu; as the section comprises nine comparatively recent flows and three dykes, lying on an older basement of lava and agglomerate (Figs. 27, 28 and 32)

Field work was carried out during the summer months of early 1956. A number of specimens were collected from each flow and were sectioned. A detailed petrographic study has been carried out on these flows in order to determine any appreciable differences in composition or texture.

For comparison, specimens were collected from the basement of older lava, from older flows at Mahuia Rapids and Tawhai Falls and also from Paretetaitonga at 9,025 ft.

The younger flows of the Whakapapanui Gorge and surroundings have been referred to as the Whakapapanui Series, and successive lava flows have been distinguished by numbers from the bottom up. The basement, comprising agglomerate and lava slightly lighter in colour than the above flows, is referred to as the Pinnacle Type because of its widespread occurrence on Pinnacle Ridge which borders the area to the east and because it is texturally different from the later flows.

PREVIOUS PETROLOGICAL WORK

Little detailed petrology has been published on Mt. Ruapehu rocks. The first reference to them is by Hochstetter (1867,P.67). From field observations he classed the rocks as trachytes. Similarly Crawford (1868) and Cussen (1886) referred to them as trachytes. Referring to Tongariro, Ruapehu and Egmont, Crawford states: "These are the three principal trachytic cones of the Northern Island."

More detailed field observations were made by Park (1886-7). He describes rocks seen during an ascent of Ruapehu from Karioi. "... at the top edge of the bush there occurs a great lava-flow of black compact dolerite, which contains numerous cavities lined with calc-spar. Proceeding up the mountain the next rocks met with are finely vesicular trachy-dolerites, of a deep red colour... At 5500 feet and 6000 feet the rocks are phonolites or clinkstones of a grey colour ... Above the phonolites appear dark-grey porphyritic trachytes which continue up to 7500 feet and form the high precipitous peak facing Karioi. On the north side of this peak there is a great boss or dome of dark smooth pitchstone in which the lines of fluxion are well marked." Near the top of Paretetaitonga he found a coarse vesicular trachyte.

Thomas (1887) remarks: "The more recent lavas of the great volcanoes Ruapehu, Ngauruhoe and probably Tongariro, appear to consist of the basic rocks known as augite-andesites." He describes augite-andesites from Ngauruhoe and also from Tongariro (1888).

The first detailed microscopic examination was undertaken by Hutton (1889). He describes a hornblende-andesite collected from the eastern base of the mountain, an augite andesite from the southern slopes, and enstatite andesite from the south-east, south and western slopes.

The next observations were by Hill (1891): "The rocks composing Ruapehu are principally made up of basic and intermediate lavas, the only trace of truly acidic rocks on the mountains being the pumice trachyte, which is found on certain slopes in the vicinity of the Crater." He also refers to heavy basalts on the north-east slopes, and to heavy black lavas of phonolite and clinkstone near the Whangaehu River. Later (1895) he speaks of Ruapehu trachytes.

Marshall (1907) remarks: "Ruapehu and its neighbours are entirely formed of hypersthene-augite andesite, so far as I know ... I have found no hornblende .... no examples of phonolites, basalts or trachytes ...."

not in bibliography

Later writers (Speight 1908, Grange 1928) all regard the Ruapehu rocks as andesite or hypersthene andesite. Grange and Hurst (1928-29) differentiate the rocks as follows:

"Dark andesite flows, scoria and ash from Ruapehu, Tongariro and Ngauruhoe (Recent and Pleistocene). Grey andesite flows and agglomerates from vents beneath Ruapehu and Tongariro (Pleistocene)".

Microscopic examination by Te Punga (1952) of the Hautapu Valley agglomerate (origin Ruapehu) showed the following types of andesite to be present:-

(1) Highly vesicular augite andesite, and hypersthene andesite.
(2) Feldspar-rich andesite with a trachytic groundmass.
(3) Slightly vesicular augite-hypersthene andesite.
(4) Hypersthene andesite with a microcrystalline groundmass.
(5) Hypocrystalline augite-hyperthene andesite with a glassy base.
(6) Feldspar-rich hypersthene andesite with a microcrystalline groundmass.
(7) Non-vesicular types of augite-hypersthene andesite and hypersthene-augite andesite.

Battey (1949) refers to hyalopilitic hypersthene - augite andesite forming the lava flow from Ngauruhoe 1949. He is probably the first to make any detailed optic observations of any National Park rocks.

GEOLOGICAL SETTING

The area studied has been sub-maturely dissected by the Whakapapanui Stream flowing in a steep-sided radial consequent valley. As a result of steep and somewhat uneven declivities, melt-water from the Whakapapanui Glacier and winter snows has had sufficient velocity and corrasive power to expose successive lava flows. This has resulted in a structural escarpment and terrace type of landscape that appears rather characteristic of dissected composite volcanic cones. (Cotton, 1944, pp.375-6) (Figs. 28, 29, 30 and 32).

Rock disintegration by freeze and thaw action is prevalent at these high altitudes and sheets of coarse waste cover the flows below. Streams of these angular fragments are present below nearly all lava flow outcrops and the excess waste has caused the Whakapapanui Stream to aggrade; especially in the lower reaches (Fig.31).

Thus the northern and western lower slopes of Ruapehu tend to merge and be covered gradually by the alluvial deposits of the Waimarino Plain. Because of the large amount of debris on the lower slopes, few outcrops of solid andesite are actually visible below about 3500 feet.

The older lavas of Ruapehu, referred to in this account as the Pinnacle Type, have been covered by newer eruptive materials, the Whakapapanui Series. These more recent lava tongues have flowed into and have filled to a considerable extent the former deeply eroded radial valleys of "Old Ruapehu".

The southern slopes of Pinnacle Ridge represent a pre-existing valley wall against which the Whakapapanui lavas abut. (Fig. 27).

by deduction only, according to Fig 27.

As may be expected, inversion of relief has occurred. The convex-surfaced lava flows of the Whakapapanui Series have become in places radial consequent divides.

The former drainage in the area was displaced so that the present line of drainage occupies the angle between the convex lava flows to the south and the pre-existing valley wall (Pinnacle Ridge) to the north. With most of the drainage in the area confined to the Whakapapanui Stream it was able to cut back into the mountain slopes by rapid headward retreat of falls, leaving a gorge below.

The Whakapapanui Gorge (known locally as "Skippers") is a narrow steep-walled trench with an amphitheatre-like head, caused by such retreat of falls (Fig. 32). Consequent waterfalls occur therefore on the edge of lava flows, each successive flow acting as a fall maker. (Fig. 44). In many places the cap rock is overhanging so that blocks fall away periodically leaving the edge of the flow sharp and fresh.

Below the falls, the outcropping edge of the fall-making flows can be seen in the walls of the gorge. In places the Pinnacle Type of "Old Ruapehu" can be seen underlying unconformably the Whakapapanui Series (Fig. 43). ? flowing uphill?

Above the gorge the main stream is confined to Pinnacle Valley, but tributary streams flow across the surface of the lava flows and have exposed fall-making flows at places.

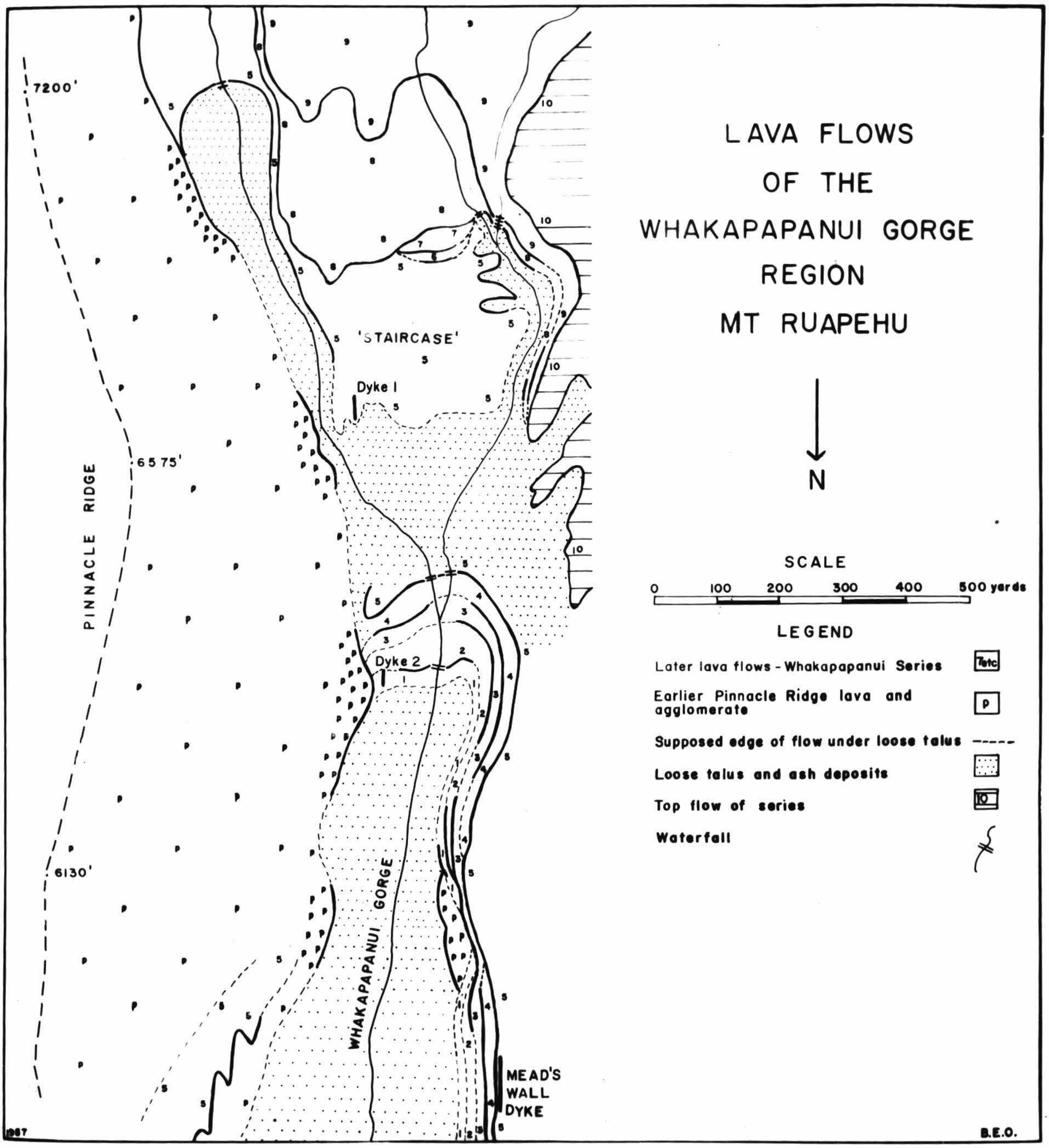


Fig. 27.

Map of the lava flows of the Whakapapanui Gorge Region, Mt. Ruapehu. Based on Lands and Survey Map of Mountain Hut Area and Lower Ski Grounds on Mt. Ruapehu.

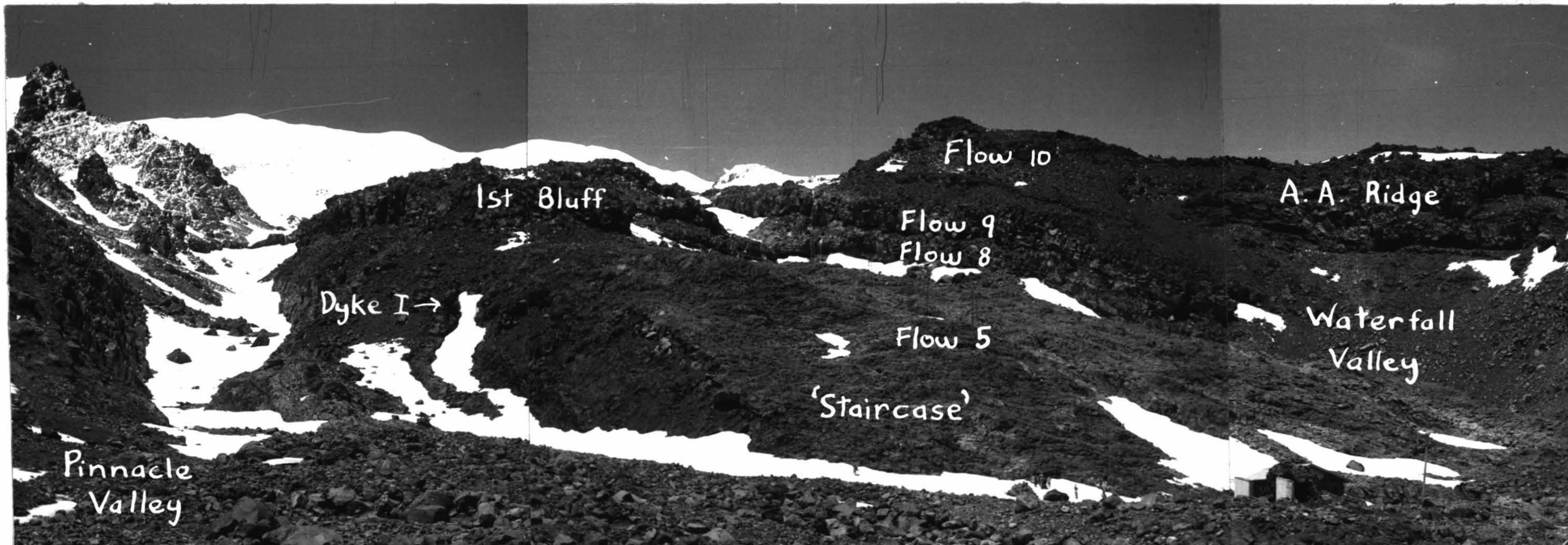


Fig. 28.
Panorama of 'Staircase' locality showing Flow 5 and the flows above. Pinnacle Ridge and Valley on extreme left, A.A. Ridge and Waterfall Valley on extreme right, and Dyke I on left below 'Ist Bluff'.

Fig. 29.
Panorama of 'Staircase' locality showing, with aid of numbers, hand specimen localities. Pinnacle Ridge on left and A.A. Ridge on right.

Fig. 30.
Terrace and structural escarpment type of landscape due to deep erosion of the radially consequent Whakapapanui Stream. View taken from Mead's Wall Dyke shows Whakapapanui Gorge in foreground, 'Staircase' in distant centre and Pinnacle Ridge on left.

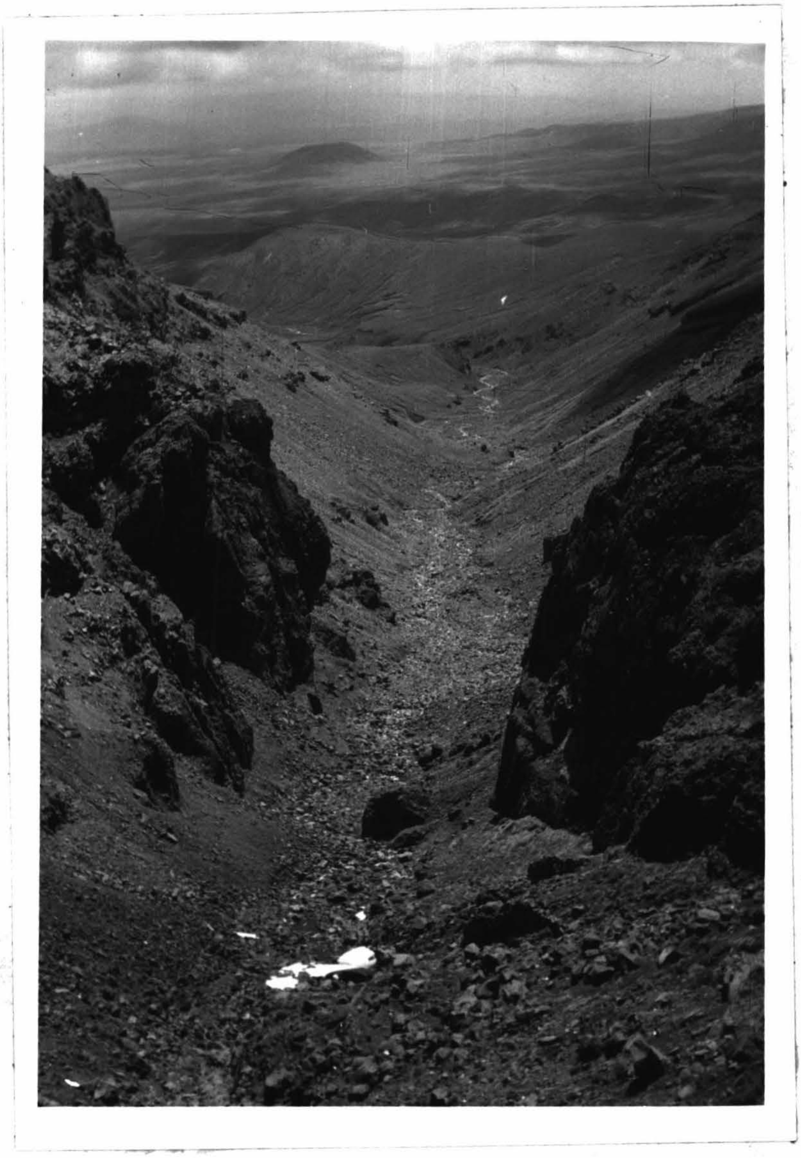


Fig. 31.
Aggradation of the Whakapapanui Stream in its lower reaches. View looking down Whakapapanui Gorge towards the Waimarino Plain.

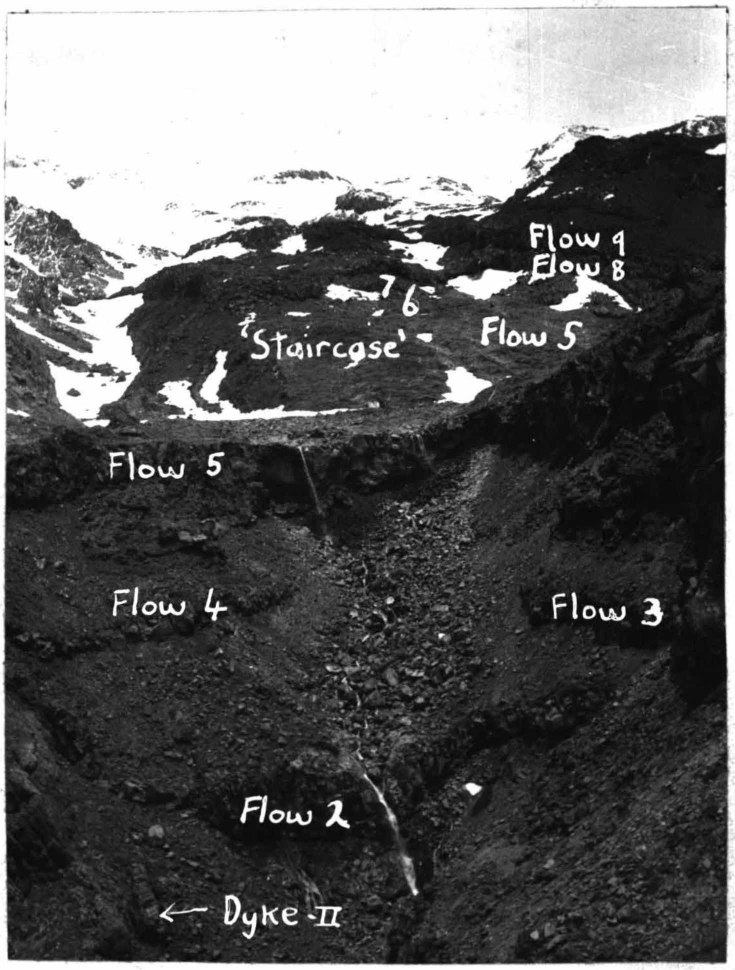


Fig. 32.
Amphitheatre - like head of the Whakapapanui Gorge showing flows and Dyke II below Flow 2. 'Staircase' and flows above are in the distant centre.

WHAKAPAPANUI SERIES

FLOW 5:-

Flow 5 has been studied in considerable detail and has been used as a basis for comparison of all other flows. The flow has been selected because of the widespread exposures, both on the "Staircase" and in the Whakapapanui Gorge.

Four fresh specimens were collected on the "Staircase". At this locality a wide expanse of the upper surface of the flow is exposed to form the "Staircase". The overlying flows have been stripped off and the surface has been worn smooth (Figs. 28 and 29).

The eastern edge is well exposed and overlooks Pinnacle Valley and Dyke I. The thickness of this edge is about 30 feet and the scoriaceous lower surface of the flow rests directly on pyroclastic material at this point. The thickness of the flow decreases gradually to the western margin bordering Waterfall Valley, and decreases further to a feather-edge at the foot of the "Staircase" near A.A. Ridge.

The top of the "Staircase" slopes at about 15° and the lower half at about 25° in a northerly direction. The flow continues down the valley where it is well exposed as the top flow in the Whakapapanui Gorge (Fig. 32). Its slope here is about 15°, still in a northerly direction.

The smooth character of the upper surface of Flow 5, where exposed on the "Staircase", and to a lesser extent the variable thickness of the flow, appears to be due entirely to erosion by running water, especially melt water from winter snows. There is no evidence of glacial erosion.

Further down the flow, adjacent to the Whakapapanui Gorge, the upper surface is highly scoriaceous and clinkery. The flow has apparently not been subjected to the same erosional conditions as it has on the "Staircase", and appears to be considerably thicker.

Direct contacts with underlying flows, and overlying flows where present, are not readily observable because of the scoriaceous nature of the upper and lower surfaces of the flows. Where contacts may be present, they are obscured by talus deposits. Normally the flows are separated by pyroclastic material. What type?

TABLE I

Flow 5 Specimens

Specimen Number	Altitude	Locality
3	6050 ft.	Lower 'water-fall' on western edge of 'Staircase.'
17	6000 ft.	Eastern edge of 'Staircase'.
19	6000 ft.	Centre of 'Staircase' slope.
10	5875 ft.	Feather-edge near foot of 'Staircase'
22	5700 ft.	Western waterfall at head of Whakapapanui Gorge ("Skippers")
23	5700 ft.	Eastern waterfall at head of Whakapapanui Gorge.
24	5700 ft.	'Skippers chimney' on right bank at head of Whakapapanui Gorge.
29	5700 ft.	Left bank at head of Whakapapanui Gorge.

MEGASCOPIC CHARACTERISTICS

All the specimens from Flow 5 are porphyritic andesites. The exposures of massive lava are remarkably fresh, but the scoriaceous areas are weathered into a rusty, brown or red coloured rock which is often crumbly. Most specimens are of a uniform medium grey colour, but specimens 17 and 19 are slightly darker. Specimens 17 and 19 are also the only two vesicular specimens, whereas all the others of Flow 5 are massive.

The vesicles are irregular in shape and size and display no directional tendencies. They are not lined with secondary minerals in any of the flows studied. Flow structures are not obvious in Flow 5, but curved shrinkage joints are common.

White tabular phenocrysts of plagioclase up to about 2 mm or more in length are observable, although they are not as conspicuous as in some of the other flows. It was observed that the darker the rock the more glossy is the groundmass, and the felspar phenocrysts are more conspicuous. Usually they have a glossy appearance but in the darker rocks they appear white. Black plates of pyroxene are also present, being somewhat more abundant and conspicuous in those specimens from the Whakapapanui Gorge. The groundmass is glassy to very fine grained and predominates (Table V).

MICROSCOPIC CHARACTERISTICS OF "STAIRCASE" PORTION OF FLOW 5

Specimen number 19 was studied in detail, and the other specimens are essentially the same.

The texture is typically porphyritic with phenocrysts of plagioclase felspar, augite, hypersthene and small magnetites set in a subvitreous to hyalopilitic groundmass.

Between the felspathic microlites of the groundmass, is a comparatively large amount of brown coloured glass, giving a hyalopilitic texture, characteristic of Ruapehu andesites (Fig.33). Pyroxene in the groundmass appears to be predominately augite. Throughout the groundmass, small specks of black magnetite are conspicuous. Apatite occurs as an accessory mineral also, both in the groundmass and occasionally as small inclusions in felspar phenocrysts.

The principal constituents are plagioclase, hypersthene and augite.

PLAGIOCLASE.

Plagioclase appears to occur in two generations. The first and oldest generation consists of euhedral tabular crystals varying in size from about 1.7 mm by 0.8 mm down to about 0.2 mm by 0.05 mm. The size and shape of the first generation varies considerably between these two extremes so that continuous crystallisation of plagioclase phenocrysts must have taken place (Fig. 33).

The largest plagioclase phenocrysts (megaphenocrysts) and the smaller phenocrysts (microphenocrysts) are together the dominant phenocrysts in the rock.

The second and youngest generation comprises the lath-shaped felspar microlites of the groundmass. Their length is usually about 0.02 mm or less.

The composition of the felspar phenocrysts was determined by using curves (after F.E. Wright) showing extinction angles of combined Carlsbad-albite twins, and was verified by universal stage methods (Turner, 1947). It varies from An_{62} and An_{68} (basic Labradorite). The composition of the felspar microlites was not determined because of the lack of suitable twinned microlites.

Zoning of the plagioclase phenocrysts is rather common and it is of the normal type.

The phenocrysts are usually twinned on albite, Carlsbad and combined Carlsbad-albite laws.

Inclusions of brown glass are found in a few plagioclase phenocrysts of the first generation (Figs. 33 and 36).

More commonly they are rather large, oval or even irregularly shaped, and are generally uniformly distributed throughout the crystal. They are, as a rule, aligned parallel to the crystal boundaries.

A clear outer border indicates that later enlargement of the felspar has taken place. Resorption and corrosion of the original crystal does appear to have taken place in a few cases.

Sometimes the inclusions are confined to a narrow zone near the margin. These phenocrysts in particular show evidence of resorption and corrosion prior to later enlargement.

Sometimes a crystal will have only a few isolated inclusions scattered through it.

It has been observed that generally, the andesites with a more crystalline groundmass have more glass inclusions in the felspars than the andesites with a more glassy groundmass. However there are exceptions.

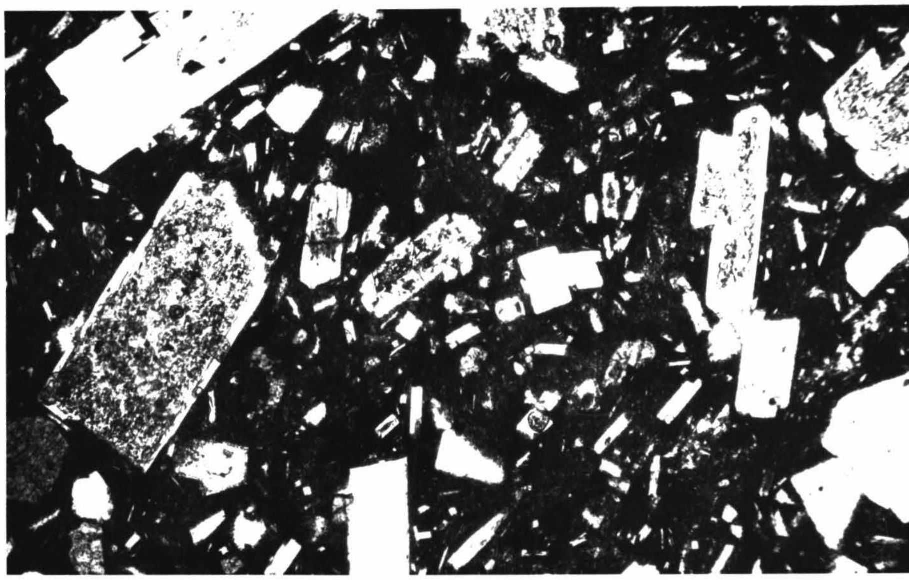


Fig. 33.
Photomicrograph of section 10, Flow 5 ('Staircase') showing hyalopilitic textureof groundmass. Note glass inclusions, especially in the larger plagioclase phenocrysts. Plane polarised light. x 25 (approx).

Fig. 34.
Crystal of augite with outer rim of hypersthene. Section 19, Flow 5 ('Staircase'). Crossed nicols. x 75.

No other inclusions in felspars were observed in this part of the flow except for a few small apatites. On the whole, the plagioclase phenocrysts are very fresh.

PYROXENES

Pyroxenes occur as subhedral phenocrysts of hypersthene and augite. Hypersthene shows distinct pleochroism from very pale green to pale brown or red. The phenocrysts tend to have a prismatic habit, although some are irregular in shape and they vary in size (Table VI). By using the universal stage, $2V_X$ was determined as 60°.

Augite has a similar habit and occurs usually as separate crystals, although glomerophenocrysts of considerable size (Table VI) are fairly common. Generally, however, the crystals are about 0.3 mm in diameter ranging down to smaller crystals .05 mm in diameter.

Conspicuous zoning is present in one crystal, augite forming the core and hypersthene the mantle (Fig. 34 and Table VI).

The augite is pale brown in colour and slight pleochroism is sometimes seen. Twinning was observed in many cases; parallel coloured bands appearing between twins with crossed nicols. Use was made of the twinned augites to determine the extinction angle, $Z \wedge C$ (Turner, 1942) .

It was found to be 45° and the optic angle, $2V_z$ was $50^\circ \pm 2^\circ$. β refractive index ($n\beta$) was between 1.685 and 1.69. From 2V and $n\beta$ measurements, the composition of the augite, as determined from curves (Hess, 1949), is diopsidic augite, $Ca_{42}Mg_{44}Fe_{14}$.

Augite is also common in the groundmass, occurring as small irregularly-shaped flakes.

Iron Ore

Magnetite occurs as scattered, irregularly-shaped grains in the groundmass and as small magnetites also of irregular shape (Table VI).

WHAKAPAPANUI GORGE ("SKIPPERS") PORTION OF FLOW 5

Although the same flow as the "Staircase" portion, a distinct textural difference is apparent (Fig. 35).

The first generation consists of phenocrysts of plagioclase of variable size. There appears to be gradation between two extremes of size (Table VI), but the larger phenocrysts seem to be predominant with few of the really small phenocrysts so characteristic of the "Staircase" flow.

The second generation of plagioclase consists of numerous microlites in the groundmass. They are more abundant than in the "Staircase" groundmass, so that the groundmass tends to be more of the intersertal type of texture rather than pilotaxitic. The term intersertal suggests, as does the slide itself, that there is too much glass between the microlites to be pilotaxitic but not enough to be typically hyalopilitic.

The microlites show a marked fluidal arrangement in places.

Inclusions of glass are present in a few phenocrysts, as in the "Staircase" rocks. In addition to a narrow zone of glass inclusions near the border, one large plagioclase phenocryst (section 29), possesses two hypersthene inclusions (Fig. 36).

The composition of the plagioclase is the same as that for the "Staircase" rocks.

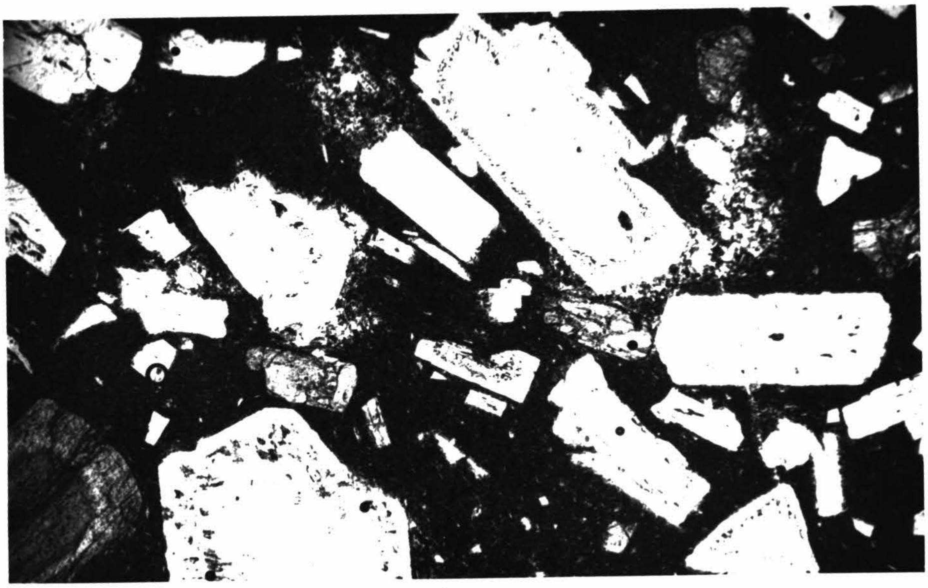


Fig.35.
Photomicrograph of section 23, Flow 5 ('Skippers') showing groundmass with intersertal texture and predominantly large phenocrysts. Plain polarised light.
x 30 (approx).

Fig. 36.
Photomicrograph of a plagioclase phenocryst with two hypersthene inclusions. Note also narrow inner zone of glass inclusions. Section 29, Flow 5 ('Skippers'). Plane polarised light.
x 75.

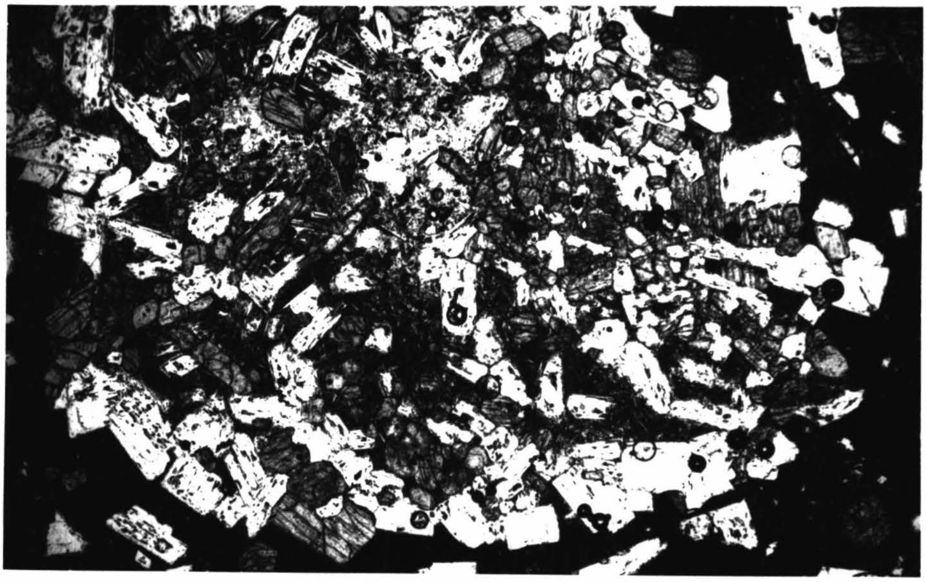


Fig. 37.
Photomicrograph of section 24H(A), Flow5 ('Skippers'),
showing clot of hypersthene and plagioclase crystals.
Plane polarised light.
x 30 (approx).

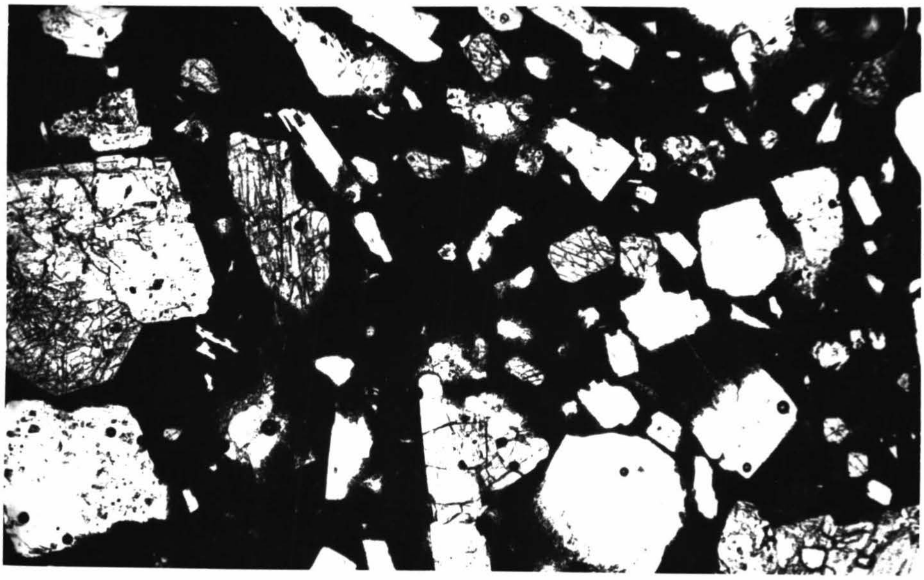


Fig. 38.
Photomicrograph of section 9, Flow 9, showing glassy
groundmass without any microlites. Plane polarised light.
x 25 (approx).

The pyroxenes are the same as the "Staircase". Typical hypersthene tabulae are about the same size as those in the "Staircase" rocks. In slide 24 H(A), small phenocrysts of hypersthene and plagioclase are mixed together in a most irregular fashion to form a clot or glomeroporphyritic aggregate of hypersthene and plagioclase (Fig. 37).

Augite is common, and generally the phenocrysts are larger than in the "Staircase" rocks (Table VI). The optical properties of the augite are the same as for the "staircase".

Magnetite does not appear to be as abundant as in the "staircase" rocks. The few larger irregular grains are usually associated with pyroxenes. The groundmass is peppered with numerous minute grains of magnetite.

In both the "staircase" and Whakapapanui Gorge rocks, what appear to be xenoliths of felspar are common. A typical xenolith (section 29) measures 1.7 mm. by 0.7 mm. and is composed of small rounded granules of felspar 0.02 mm or more in diameter.

Another section (24 H (B)) has an irregularly-shaped aggregate of radiating felspar laths. The laths are long and narrow (Table VI) show no twinning, have parallel extinction and show slight sericitisation. They appear more highly potassic than the felspar of the phenocrysts. Roughly encircling the felspar laths are masses of small felspar (and possibly some quartz) granules. These in turn are roughly encircled by comparatively large quartz granules (Table VI) that together closely resemble a quartzite.

Flow 9

The uppermost flow in the area studied forms a prominent feature at the top of the "staircase" at 6,400 ft., called the "2nd Bluff" (Figs. 28 and 29). The flow outcrops along the precipitous eastern slopes of A.A. Ridge, which extends in a northerly direction along the western boundary of the "staircase" (Fig. 39).

Megascopically, the flow is similar in all respects to Flow 5. Near the head of Waterfall Valley, the flow lies directly upon Flow 8 (Fig. 40) but further down A.A. Ridge it is separated from Flow 8 by talus or pyroclastic material.

MICROSCOPIC CHARACTERISTICS OF FLOW 9

Phenocrysts of plagioclase, hypersthene and augite are set in a groundmass consisting almost entirely of dark brown or grey glass showing only incipient crystallisation (Fig. 38).

The plagioclase phenocrysts in section 7 are of variable size, but the general order of size is about the same as for the "Skippers" portion of Flow 5 (Table VI).

In sections 1, 8 and 9, the smaller phenocrysts are the more numerous. The overall texture is somewhat similar to Flow 5 ("Skippers") except for the glassy groundmass and more numerous small phenocrysts.

As for Flow 5 plagioclase, the composition is basic Labradorite varying from between An_{62} and An_{68}. Glass inclusions are very few and those that are present seem to have no regular arrangement.

The optic properties, arrangement and size of pyroxene phenocrysts is much the same as for Flow 5.

In one phenocryst of hypersthene there are two plagioclase inclusions which have apparently been resorbed into roughly rounded shapes (Fig. 41).

Further along A.A. Ridge the groundmass texture of Flow 9 changes. Section 12 has a brown glassy groundmass with numerous small microlites. The section approaches Flow 5 ("Skippers") type, but the microlites are generally shorter and there is more glass between them.

Section 13 is similar to 12, but is probably even more like the "Skippers" type. The microlites tend to be larger and more numerous than in section 12. Although the groundmass is almost pilotaxitic, glass which is darker in colour does occur between the microlites and thus the groundmass texture is classed as intersertal.

These sections (12 and 13) are essentially similar to the other sections of Flow 9, except that the groundmass is more crystalline.

TABLE II

SPECIMENS FROM FLOW 9

Specimen Number	Altitude	Locality
1	5900'	Half way along A.A. Ridge overlooking Waterfall Valley.
7	6100'	From position near to where Flow 9 lies directly upon Flow 8. (Fig. 40)
8	6300'	Near top of "Staircase" on "Upper Waterfall".
9	6300'	Further east on 2nd Bluff
12	5825'	Near north end of A.A. Ridge at foot of "Staircase"
13	5850'	Further up A.A. Ridge

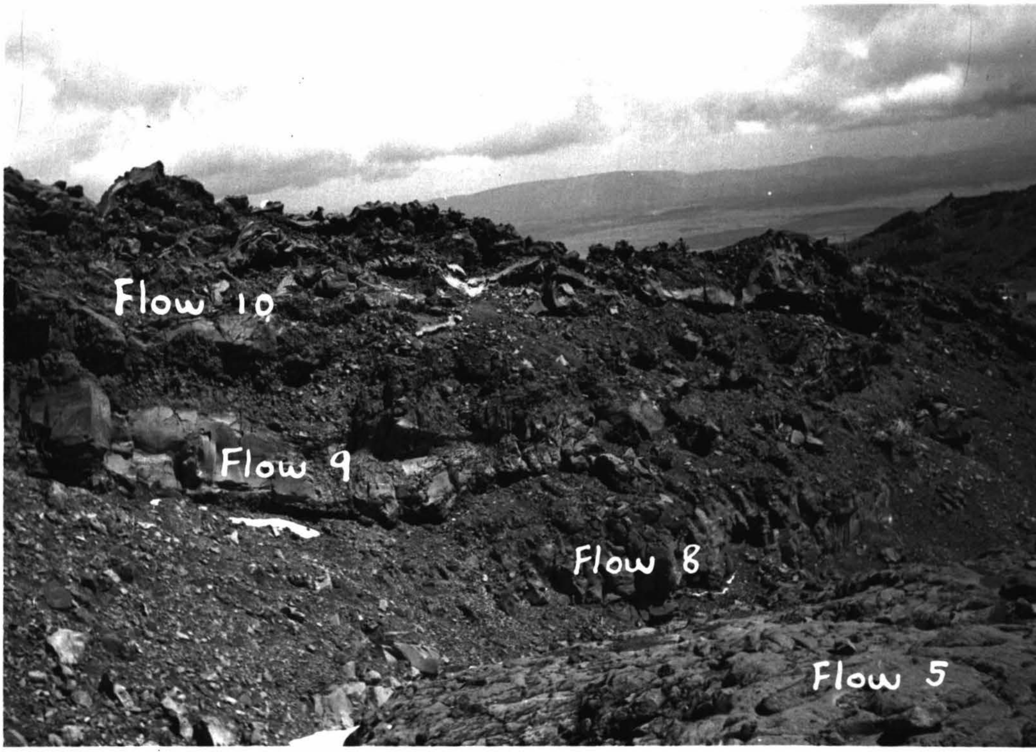


Fig. 39.
Eastern slopes of A.A. Ridge near foot of 'Staircase', showing Flows 8 and 9. Flow 5 and Waterfall Valley in foreground.

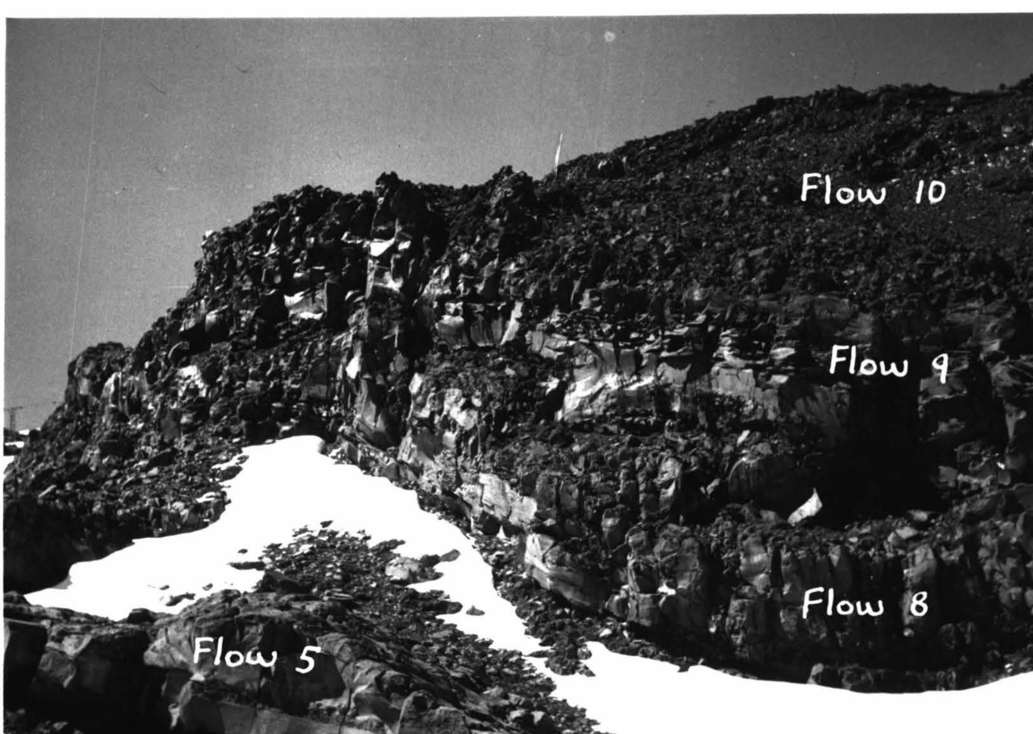


Fig. 40.
Close contact of Flows 8and 9 at head of Waterfall Valley. Flow 5 ('Staircase') remnant in foreground.

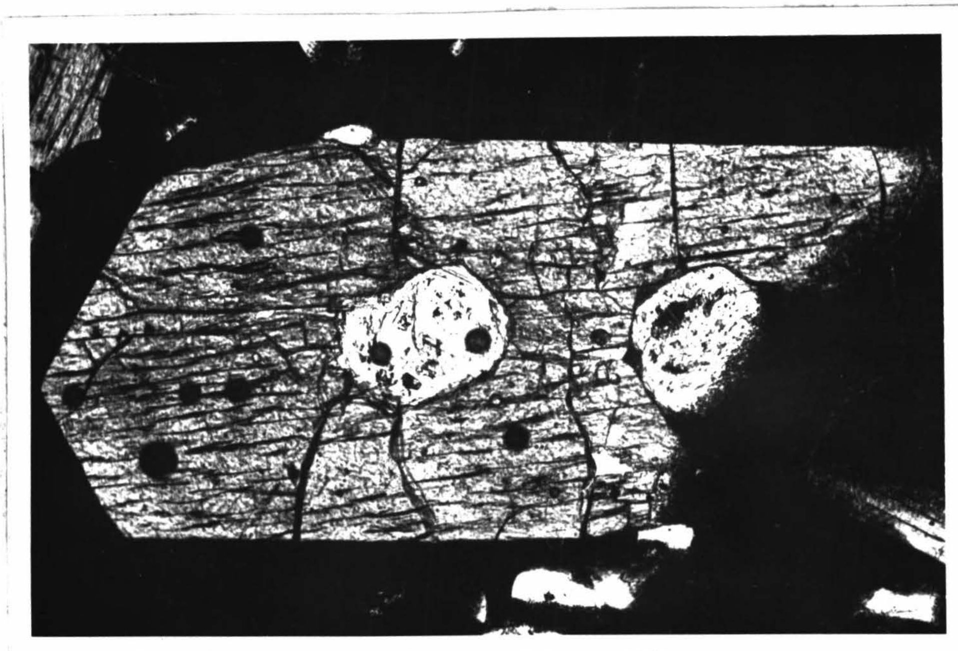


Fig. 41.
Photomicrograph of hypersthene crystal withtwo plagioclase inclusions. Section 7, Flow 9. Plane polarised light.
x 75.

Fig. 42.
Photomicrograph of two groundmass textures within the same section. Glass groundmass on left and more crystalline on right. Note sharp boundary. Section 20, Flow 8.
Plane polarised light.
x 25 (approx).

Flow 8

This flow lies immediately below Flow 9 and outcrops along the eastern side of A.A. Ridge (Figs. 39 and 40). Halfway up the "staircase" the flow forms the prominent "1st Bluff" (Figs. 28 and 29).

MICROSCOPIC CHARACTERISTICS OF FLOW 8

Similar to Flow 9 above but glassy groundmass shows definite signs of incipient crystallisation. In section 20, microlites of felspar are generally present but not in great numbers. Most crystallisation of felspar in the groundmass has taken place in the form of minute specks or laths of felspar.

Light patches in the rock, which are clearly visible in hand specimens, indicate a portion of the groundmass where crystallisation has taken place to a greater extent. The boundaries between glassy and partly crystalline groundmasses are extremely sharp in some cases. (Fig. 42). endogenous xenoliths?

In section 21 there are no dark regions of glassy groundmass whereas in section 4 the groundmass is all dark and glassy. Section 5 shows both glassy and more crystalline groundmasses, although the glassy type predominates.

In section 11 from A.A. Ridge, irregular patches of brown glass occur. The boundaries between light and dark areas are not as sharp as in the other sections. The lighter coloured groundmass is more crystalline than the light areas of the other sections and there appear to be slightly more microlites in the groundmass.

All the other features of Flow 8 are the same as Flow 9.

TABLE III

SPECIMENS FROM FLOW 8

Specimen Number	Altitude	Locality
21	6100'	Eastern edge of flow overlooking Pinnacle Valley. Thickest portion of flow appears to be at this point.
20	6075'	Further west overlooking "Staircase"
5	6075'	Chimney-like feature called the 'nose dive', overlooking the middle of the "staircase".
4	6050'	Further west above Waterfall Valley.
2	6025'	Still further west, approaching A.A. Ridge. Slaty cleavage in flow at this point.
11	5825'	A.A. Ridge; lowermost flow exposed on ridge.

Flows 6 and 7

Two outcrops of what appear to be remnants of two flows are exposed below Flow 8 and above Flow 5 near the "Nose Dive" (Figs. 29 and 32). They are very similar to Flow 5 ("Staircase") and may actually be remnants of the latter.

Section 6 (Flow 7) is similar to Flow 5 ("Staircase") except that the microlites may be more numerous and larger. Glass is of the typical brown colour and is abundant. The smaller plagioclase phenocrysts are probably less common than in Flow 5 ("Staircase"). Glass inclusions are conspicuous in plagioclase phenocrysts of all sizes.

Section 18 (Flow 6) is even more like Flow 5. The flow is vesicular, rather like sections 17 and 19 of Flow 5. Deep brown glass is characteristic and is possibly more abundant. Glass inclusions in plagioclase phenocrysts are present in a few only.

Optic angle ($2V_X$) measurements for hypersthene in Flow 7 were $66^\circ \pm 2^\circ$. One zoned hypersthene showed 62° in the inner zone and 69° in the outer zone.

$2V_Z$ for augite remained the same as for the other flows, i.e. 50°.

Flows 4, 3, 2 and 1

The lowermost flows of the Whakapapanui Series show no significant differences to the flows already described above.

Flows 4, 3 and 2 are well exposed at the head of the Whakapapanui Gorge ("Skippers") and along the west bank of the gorge where the outcrops form high precipitous escarpments. The flows can be followed a considerable distance downstream (Figs 32,43 and 44).

Flow 1 outcrops at one locality only, on the left bank near the bottom of the gorge, and it lies unconformably on rocks of the Pinnacle Type (Fig. 43).

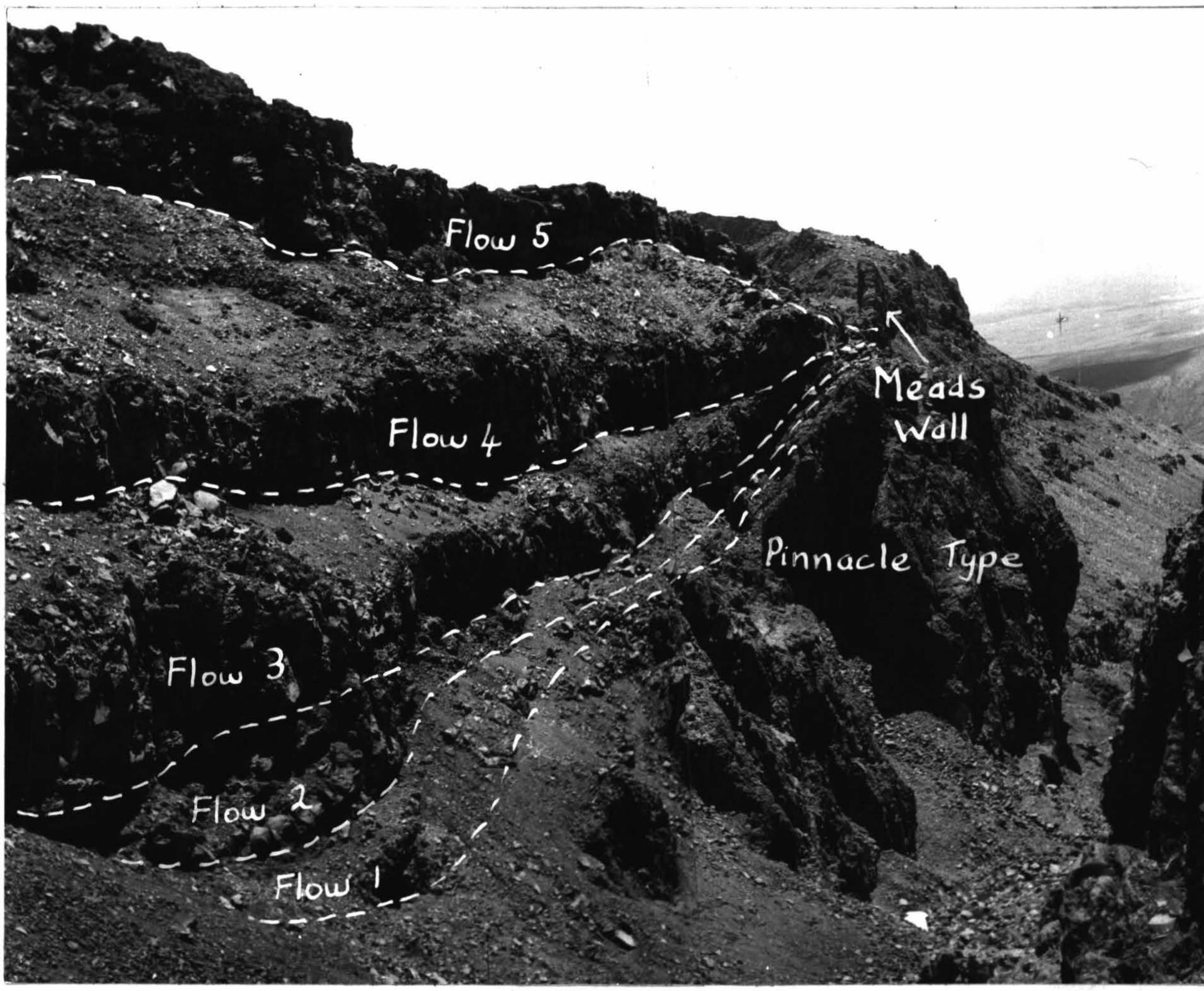


Fig. 43.

Left bank of the Whakapapanui Gorge showing flow outcrops, Mead's Wall and Basement rock of Pinnacle Type.

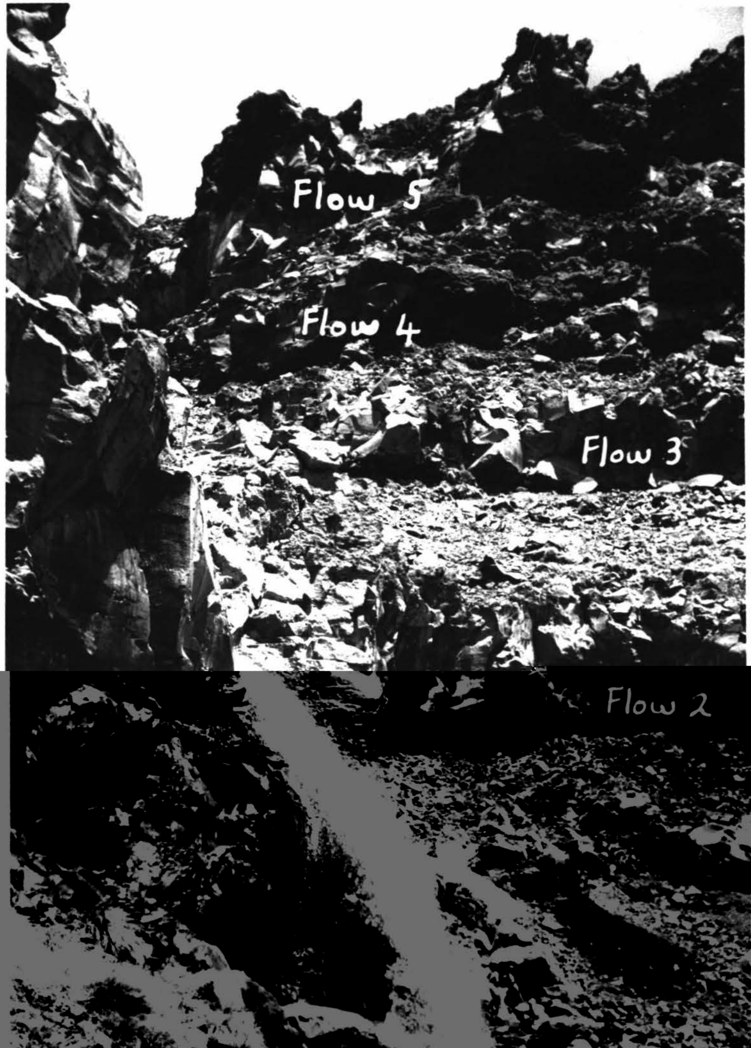


Fig. 44.

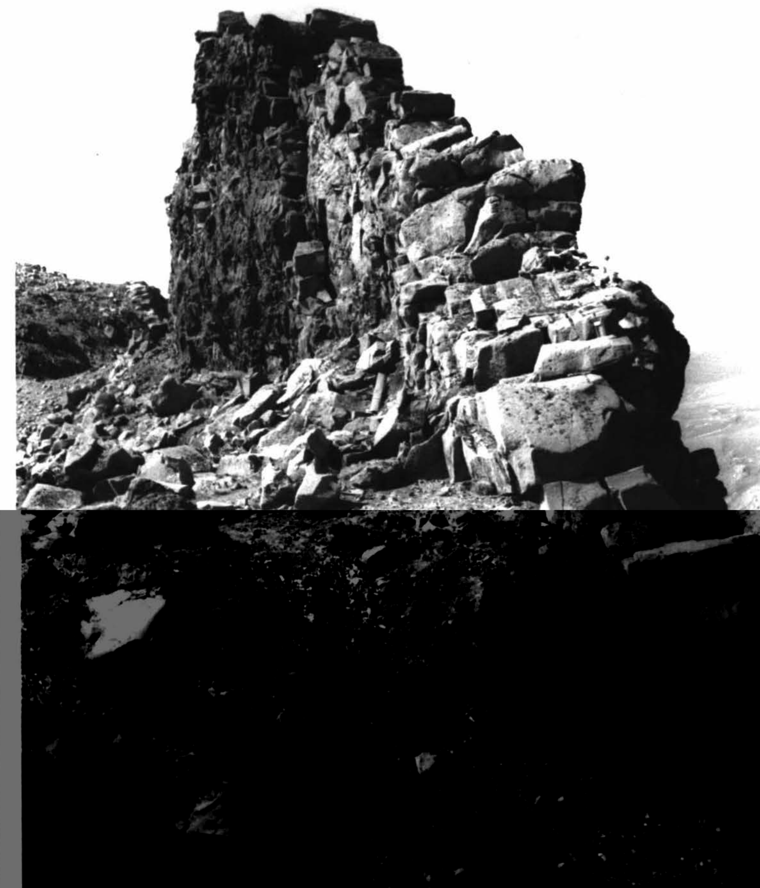


Fig. 45.

Left- Flow out-crops, head of Whakapapanui Gorge.

Right- Mead's Wall Dyke.

TABLE IV

SPECIMENS FROM FLOWS 4, 3, 2, and 1

Specimen Number	Altitude	Locality
Flow 4 38	5650'	Right bank, head of Whakapapanui Gorge below "Skippers Chimney".
34	5650'	Left bank head of gorge
33	5625'	Left bank further downstream
Flow 3 26	5625'	Right bank, head of gorge
27	5625'	Head of gorge - centre
28	5625'	Left bank, head of gorge
32	5600'	Left bank, downstream
Flow 2 37	5550'	Right bank, head of gorge
36	5550'	Head of gorge - centre
35	5550'	Left bank, head of gorge
Flow 1 31	5500'	Left bank of gorge, downstream & overlooking Pinnacle Type rock.
Paretetaitonga 40	9025'	Top of third highest peak Paretetaitonga on caldera rim of Ruapehu

MICROSCOPIC CHARACTERISTICS OF FLOWS 4,3,2 and 1

Flow 4

Groundmass is very glassy and deep brown coloured with incipient crystallisation, microlites are fairly common in section 38 but are very small. The general texture is similar to Flows 8 and 9.

In section 33, the groundmass is glassy with no microlites but with some incipient crystallisation. It is somewhat similar to Flow 9. Hand specimens 33 and 34 are a little darker which follows from the fact that they have a more glassy groundmass.

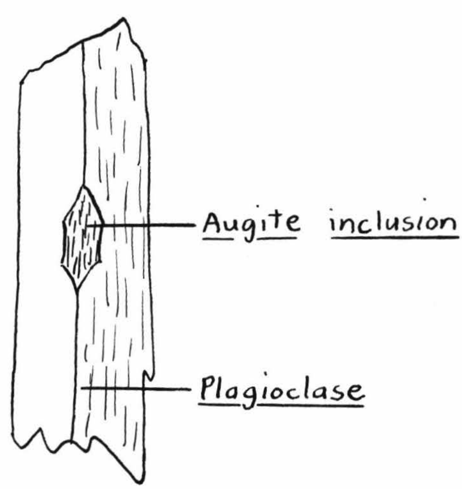
There are very few glass inclusions in the plagioclase phenocrysts.

The optic angle (2V) for hypersthene is (-) 60°, and for augite (+) $50^{\circ} \pm 1^{\circ}$ as for Flow 5.

Flow 3

Deep brown glassy groundmass similar to Flow 5 ("Staircase"). Small irregular patches of deep brown glassy groundmass are common.

In section 32 an augite inclusion occurs in plagioclase.



Glass inclusions are fairly common in plagioclase phenocrysts.

Optic angles for augite and hypersthene are as for Flow 5, but $Z \wedge c$ for augite did vary in a few phenocrysts. In these cases $Z \wedge c$ is 41° or $41\frac{1}{2}$°.

?

Flow 2

Similar to Flow 3 (and Flow 5, "Staircase") but with slightly more numerous small felspar phenocrysts. $Z \wedge c$ for augite is more commonly 45°, but one did measure 42°.

Flow 1

Glassy groundmass with incipient crystallisation and rare microlites. Similar to glassy sections of Flows 8 and 9.

LAVA ON PARETETAITONGA

On the tope of Paretetaitonga (9025 ft.), the lava is the same as Flow 5 ("Staircase") in appearance. Under the microscope the groundmass seems to be very glassy with incipient crystallisation and a few microlites.

There are very few glass inclusions in the felspar phenocrysts and in general, the phenocrysts are rather small. The lava is vesicular and is much the same as Flow 5 ("Staircase").

INTRUSIONS IN THE WHAKAPAPANUI SERIES

Only three minor intrusions, in the form of dykes, were observed in the area studied.

The largest dyke, Mead's Wall, is situated on the western edge of the Whakapapanui Gorge at about 5450 feet, and is at the southern-most margin of the area (Figs. 43 and 45). It strikes north-south.

It is slightly lighter grey in colour, rather similar to the

Pinnacle Type. It is vesicular in parts and appears fairly coarse grained.

Dyke I is considerably smaller and is situated at the foot of the "Staircase" near Pinnacle Valley (Figs. 28, 46 and 47). The western face appears scoriaceous and may actually be a flow remnant resting at a steep angle. It extends south up Pinnacle Valley towards the eastern edge of the "1st Bluff" (Flow 8).

Dyke II is the smallest of the three, on the right bank of the Whakapapanui Gorge near its head (Fig.32). It is bounded on all sides by loose talus material and does not appear to have penetrated Flow 2. It also lies north-south. The groundmass is very dark grey and very fine grained with large conspicuous white phenocrysts of felspar, some measuring about 3 mm by 1 mm.

MICROSCOPIC CHARACTERISTICS OF INTRUSIONS

(1) Mead's Wall: (Specimens A, B, C and D)

Finely crystalline groundmass with numerous microlites. Pyroxene phenocrysts are large and conspicuous and plagioclase phenocrysts have abundant glass inclusions. The overall texture is very similar to Flow 5 ("Skippers") which it intrudes.

(2) Dyke I: (Specimens 14, 15 and 16)

Same as Flow 5 ("Staircase") in all respects. In section 16 there is a conspicuous xenolith of felspar granules with associated biotite and magnetite. Glass inclusions are fairly common in felspar phenocrysts.

(3) Dyke II: (Specimen 39)

The groundmass predominates (Fig. 48). There are numerous felspar microlites giving a groundmass approaching the intersertal type. There are only a few phenocrysts but those that are present are fairly large. The groundmass is more glassy than Flow 5 ("Skippers") and the phenocrysts are fewer. There are very few or no glass inclusions in the felspar phenocrysts.

The largest single phenocryst of plagioclase observed, measures 3 mm by 0.8 mm, but usually they are of the same order of size as the larger phenocrysts of Flow 5 ("Staircase") (Table VI). Often, the plagioclase phenocrysts are aggregated to form glomero-phenocrysts.

Lath-shaped microlites are very long and numerous (Table VI).

Pyroxenes are usually also aggregated to form glomerophenocrysts and plagioclase phenocrysts are often associated with them. The largest glomerophenocryst observed was about 3.3 mm in diameter.

Single augites are common and are similar to Flow 5. Smaller grains occur in the groundmass.

Oval-shaped vesicles show rough fluidal tendencies.

There is little or no magnetite.

Comparatively large xenoliths of felspar granules are present as in all other flows of the Whakapapanui series (Table VI).

Optic properties and composition etc. of the three intrusions are the same as for the Whakapapanui flows.

Figs. 46 and 47.
Dyke I at foot of
'staircase'.

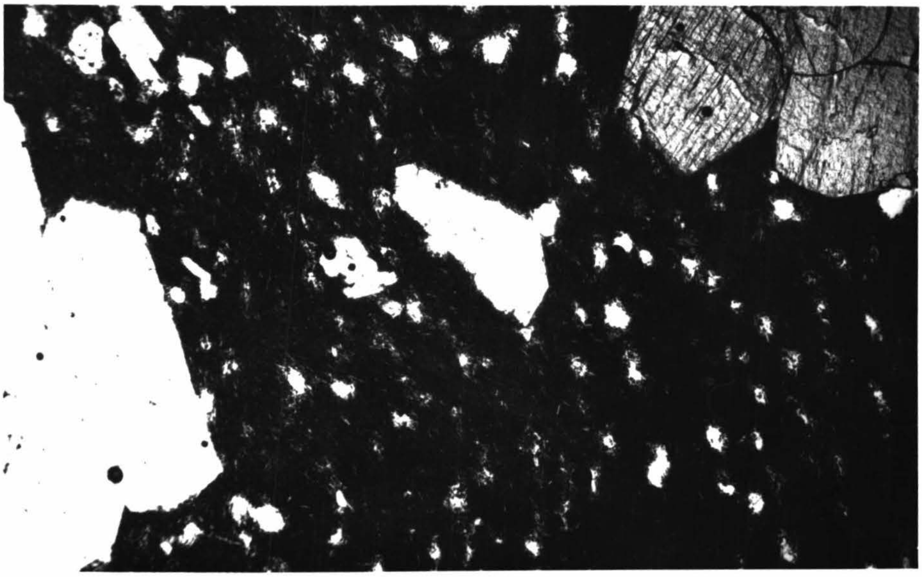


Fig. 48.
Photomicrograph of section 39, Dyke II, showing texture.
Oval white dots are vesicles. Plane polarised light.
x 35 (approx).

Fig. 49.
View along Pinnacle Ridge taken from the summit of the Great Pinnacle (7260 ft.), Massive lava in foreground but agglomerate further along the ridge.

PINNACLE TYPE OF RUAPEHU ANDESITES

The more recent Whakapapanui series of andesites appear to lie unconformably on older, usually more crystalline andesites. They are called the Pinnacle Type because of their widespread occurrence on Pinnacle Ridge which bounds the area studied to the east.

Two specimens were collected; number 25 from a flow on Pinnacle Ridge itself (Fig. 49), and number 30 from an outcrop in the Whakapapanui Gorge below Flow 1 of the Whakapapanui series (Fig. 43).

The rocks are a little lighter in colour than the flows immediately above and they tend to be slightly more coarse grained. Mafic phenocrysts are more conspicuous than in the other flows. The flows are usually associated with old agglomerate (Figs 50 and 51); number 25 rests directly on agglomerate and number 30 lies underneath agglomerate.

Section 30:

The basement rock of the Whakapapanui Gorge, section 30, has a more crystalline groundmass with numerous microlites of felspar (Fig. 52). The phenocrysts are on the whole more numerous and larger than in the flows above. The mafic phenocrysts are frequently very large.

Two generations of felspar are apparent as in Flow 5 ("Staircase"). The largest phenocrysts of plagioclase pass through all intermediate sizes down to those of smaller size and are of the same order of size as Flow 5 ("Skippers"). As in Flow 5, the microlites probably represent the second generation of felspar.

Figs. 50 and 51 - Close view of typical Pinnacle Ridge agglomerate.

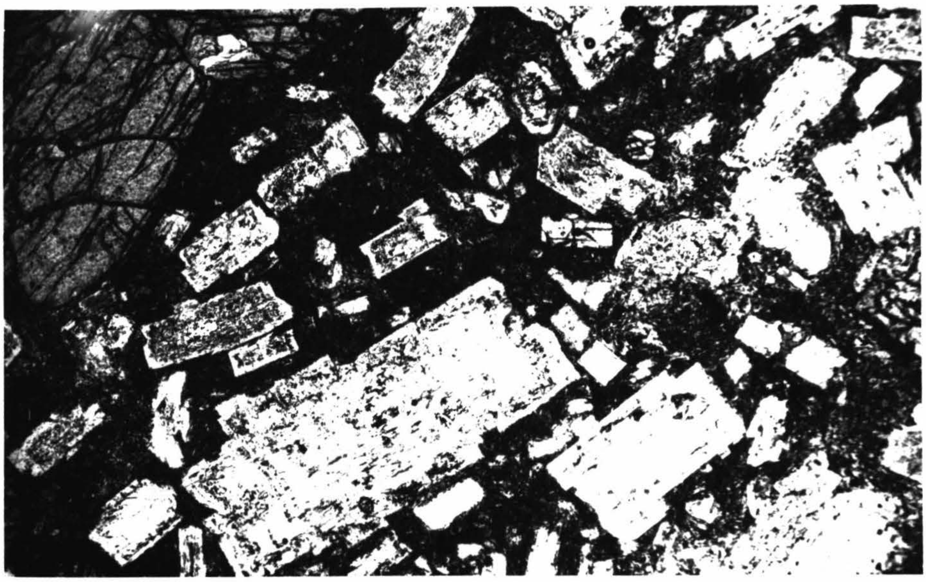


Fig. 52.
Photomicrograph showing texture of Pinnacle Type basement, section 30. Note numerous glass inclusions in plagioclase phenocrysts. Plane polarised light. x 24 (approx).

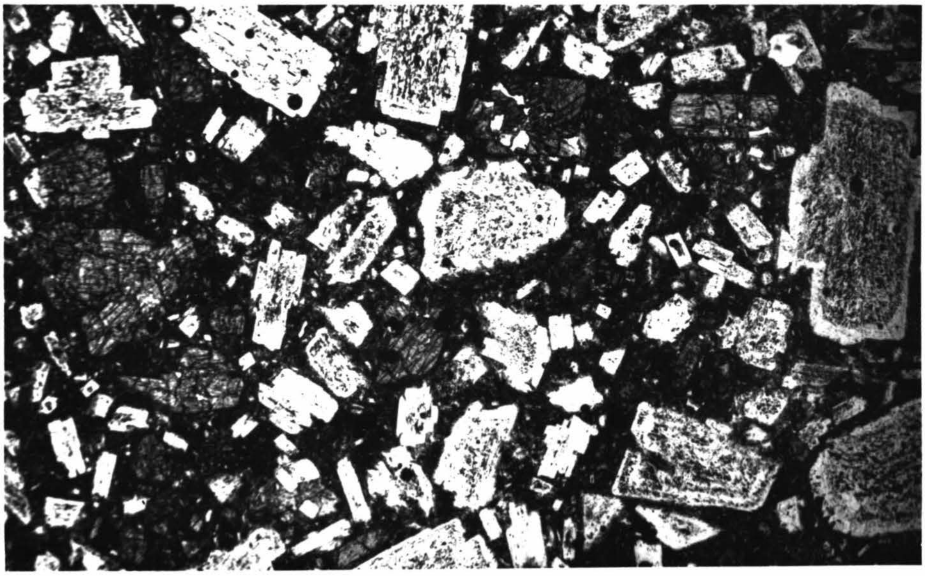


Fig. 53.
Photomicrograph of section 25 from a flow on Pinnacle Ridge. Note more crystalline texture. Plane polarised light. x 28 (approx).

There do not appear to be as many phenocrysts of small size as in Flow 5 ("Staircase"), but microlites in the groundmass are certainly more numerous and give a more crystalline rock than any of the flows studied so far, with the exception perhaps of the "Skippers" portion of Flow 5.

The microlites as a rule are much larger and broader than those in the Whakapapanui Series.

All of the plagioclase phenocrysts have numerous glass inclusions throughout. The composition is the same as for the Whakapapanui Flows above.

A notable feature of the section is the large size of some of the pyroxene phenocrysts (Table VI). One perfect eight-sided section of augite measured over 2mm in greatest diameter.

Hypersthene is usually in the form of fairly large tabulae or as glomeroporphyritic aggregates.

The optic angle ($2V_Z$) for augite is $50^\circ \pm 2^\circ$ as for the other flows. β refractive index is also the same, being between 1.685 and 1.69, probably nearer the latter.

$2V_X$ for hypersthene is 76°, somewhat higher than observed in the flows above.

Large irregularly-shaped grains of magnetite are common, together with smaller grains in the groundmass (Table VI).

Section 25:

Section 25 from a flow on Pinnacle Ridge is rather similar to section 30 except that the numerous phenocrysts are, on the average, smaller (Fig. 53). The groundmass is crystalline with irregularly-shaped granules of felspar and very few typical microlites.

Augite is also abundant in the groundmass as small granules.

The plagioclase and augite phenocrysts are generally smaller than the phenocrysts of section 30 (Table VI). Typical rectangular sections of hypersthene are common and are about the same size as section 30.

Magnetite is common also, the grains being smaller than in section 30. The smaller grains in the groundmass are present too.

The optic angle ($2V_Z$) for most of the augites is $50^\circ \pm 2^\circ$, but two pleochroic crystals were observed with $2V_Z$ of 58° and 59°. $Z \wedge c$, was for most crystals 45° but one of $43\frac{1}{2}^\circ$ was measured.

$2V_X$ for hypersthene was in two crystals studied, 81° and 84°.

A reaction rim around a xenocryst of quartz was observed showing evidence of reaction between the quartz and surrounding andesite lava. The quartz, probably picked up accidentally by the lava at depth, is surrounded by a zone of brown glass which in turn is encircled by a zone of small augite prisms.

Holgate (1954) uses this type of reaction as his chief line of evidence to show the former existence of immiscible liquids in rocks.

MAHUIA RAPIDS AND TAWHAI FALLS

Although not in the Whakapapanui Gorge, specimens were collected from these localities on the Waimarino Plain, for comparison with those already described.

Both features are developed on massive, compact flows of

'Old Ruapehu' (Figs. 54, 55 and 56) which were erupted from the summit of Ruapehu, a distance of about 9 miles.

MAHUIA RAPIDS

In appearance, the rock from Mahuia Rapids (section 41) is similar to the Pinnacle Type of the Whakapapanui Gorge. It is light coloured and coarse grained, but with one notable difference, in that it has a higher proportion of ferromagnesian crystals, including a few light green phenocrysts of olivine.

In section, one large olivine phenocryst measured 3.6 mm by 1.3 mm. However, of the few phenocrysts present, most are much smaller (Table VI).

The groundmass, which predominates, is almost holocrystalline, being composed of second generation felspar in the form of crowded lath-shaped microlites of fairly large size (Fig. 57). Some rectangular-shaped laths are larger than typical microlites.

Glass inclusions are characteristic of the plagioclase phenocrysts. Augite phenocrysts are very common, as are the flecks in the groundmass.

Only about three or four grains of iron ore were observed but scattered specks are present throughout the groundmass.

The chief difference between this rock and the Pinnacle Type of the Whakapapanui Gorge, is the slightly more crystalline groundmass with fewer phenocrysts, the higher ferro-magnesium percentage and the presence of a little olivine.

The optic properties of augite are the same although a few $Z \wedge c$ values measured 41° and a few optic angle ($2V_Z$) values were a little lower, $47^\circ \pm 1^\circ$.

TAWHAI FALLS (sections 42 and 43

The flow forming the Tawhai Falls is totally unlike any other flow studied in this report. The nearest approach possibly is Dyke II. It is a very dark (almost black) massive and compact fine grained rock with only a very few small phenocrysts. Specimen 43 is almost black and consequently the few phenocrysts present stand out well as small white specks. Specimen 42 is a little less dark because of the slightly more crystalline groundmass.

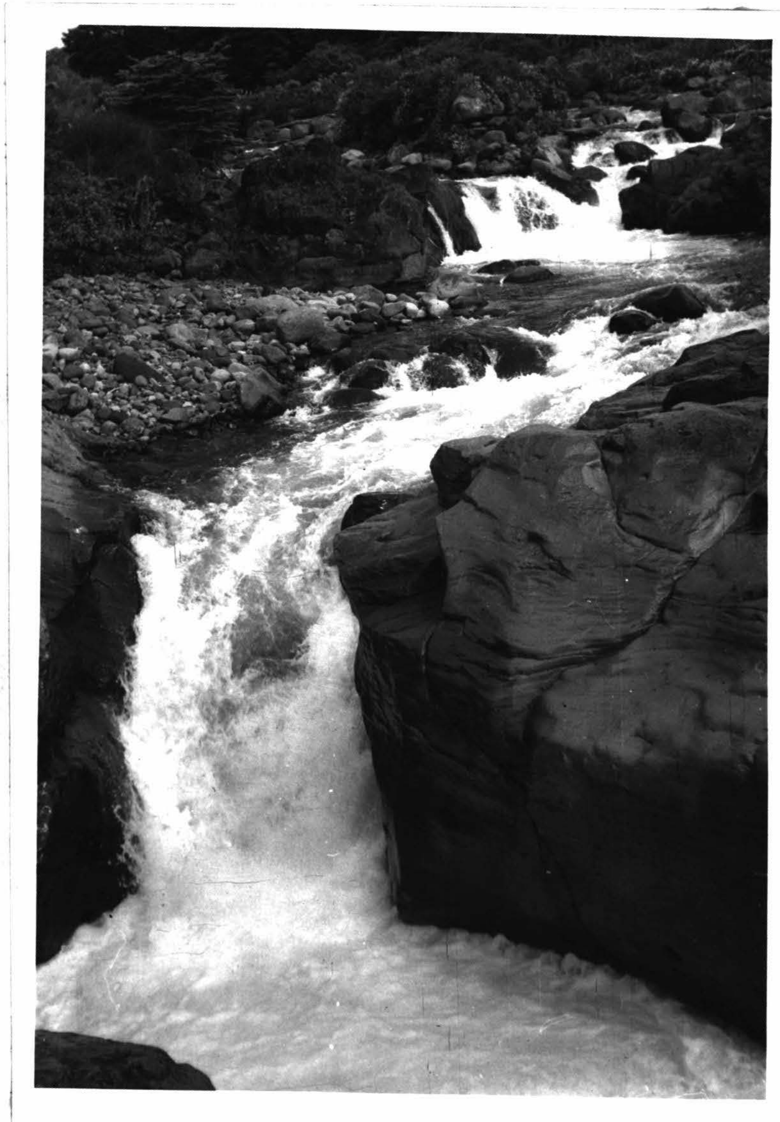
The groundmass predominates; in fact the rock is almost entirely groundmass (Fig. 58). Within the glassy groundmass are scattered lath-shaped second generation felspars, a little larger than typical microlites. A few reach microlite size. In parts, the laths show a pronounced alignment due to flow.

Specimen 42 has more felspar laths and microlites and is thus a little more crystalline. Hence the slightly lighter colour in the hard specimen. In other respects it is exactly the same as specimen 43. Phenocrysts are few and are quite isolated. There are no glass inclusions.

There are very few phenocrysts of augite and only two or three of hypersthene. They are all about the same size (Table VI).

Iron ore occurs as numerous scattered very small crystals in the groundmass.

Only a few measurements of optic axial angles could be made because of the lack of phenocrysts. For augite $2V_Z$ is $51^\circ \pm 1^\circ$ and $Z \wedge c$ 45°. For hypersthene $2V_X$ is $64^\circ \pm 1^\circ$.



Figs. 54 and 55-
Mahuia Rapids.

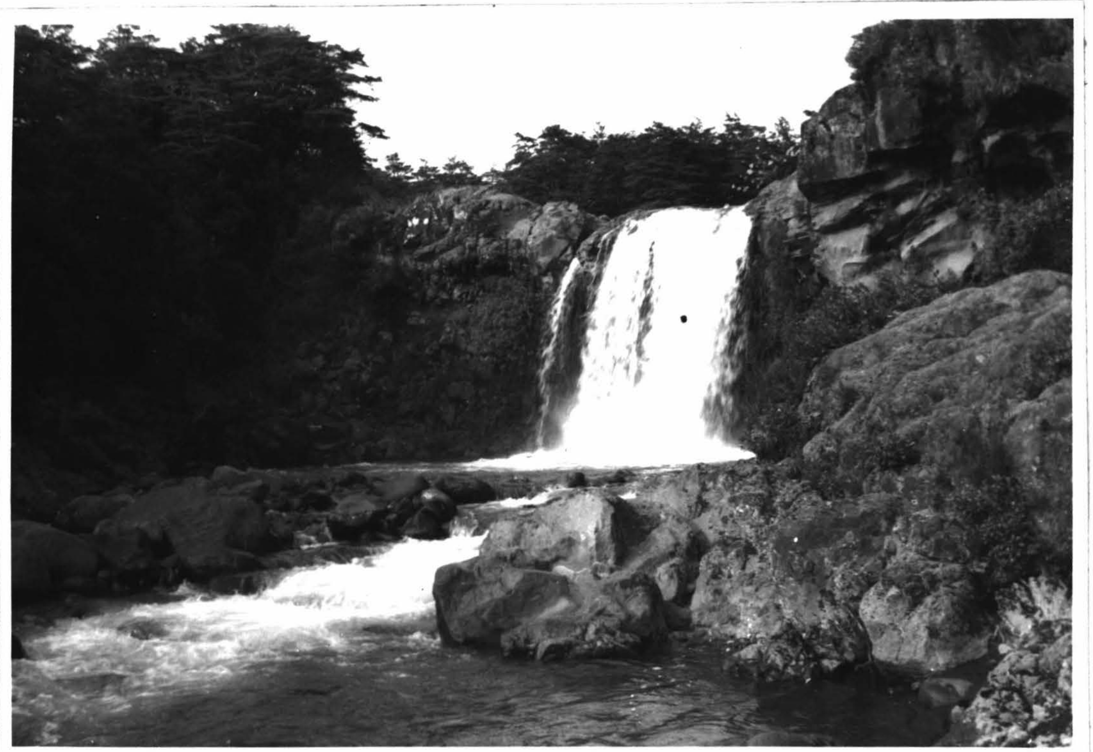


Fig. 56.
Tawhai Falls.

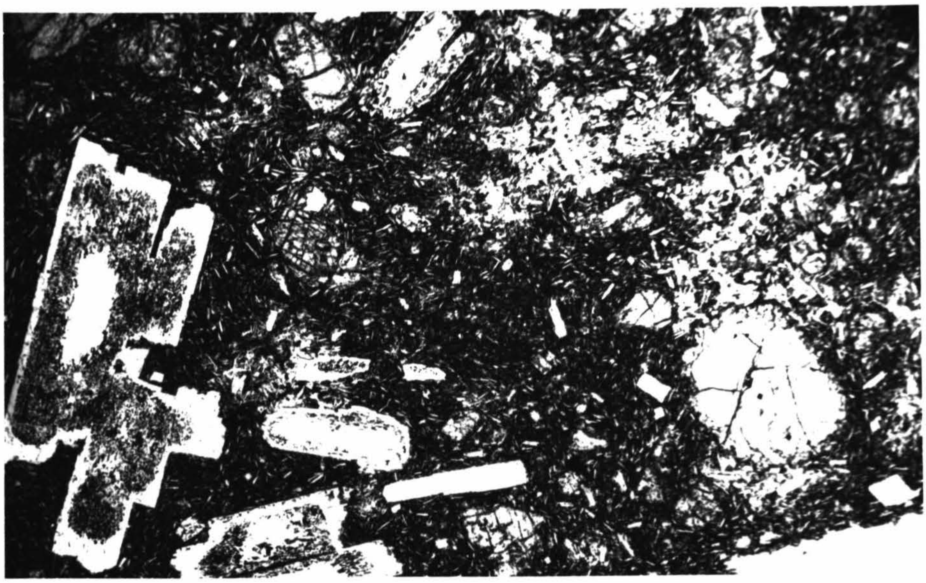


Fig. 57.
Photomicrograph of section 41, Mahuia Rapids, showing almost holocrystalline groundmass and comparatively few phenocrysts.
Plane polarised light.
x 24 (approx).

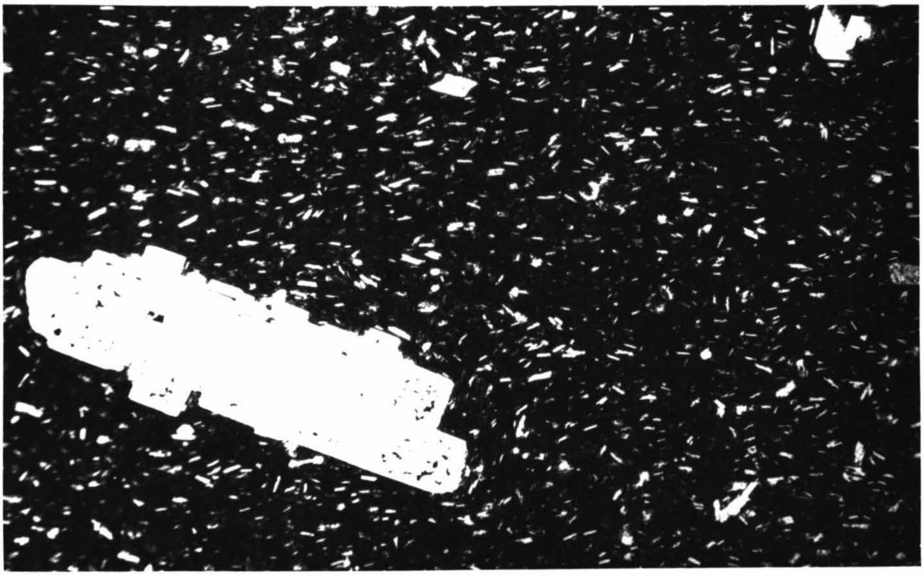


Fig.58.
Photomicrograph of section 42, Tawhai Falls, showing predominant groundmass and isolated phenocrysts of plagioclase.
Plane polarised light.
x 30 (approx).

TABLE V

Modal Analyses of Ruapehu Andesites

Flow	Slide No.	Groundmass	Plagioclase	Augite*	Hypersthene*	total Pyroxene*	Olivine	Iron ore
A.A. Ridge	12	58.06	26.52	4.58	10.59	15.17		0.25
9	9	58.45	28.98	4.06	7.65	11.71	0	0.85
A.A. Ridge	11	70.67	19.47	3.81	5.39	9.20	0	0.66
8	21	61.84	26.04	4.80	6.19	10.99	0	1.14
7	6	71.11	21.21	4.32	2.78	7.10	0	0.58
6	18	63.36	24.83	5.07	5.96	11.03	0	0.79
5 (Staircase)	19	66.4	22.63	3.95	4.94	8.89	0	1.9
5 (Skippers)	23	59.7	27.33	8.0	3.97	11.97	0	0.97
4	38B	63.07	25.16	3.84	7.31	11.15	0	0.62
3	26	66.98	23.68	2.49	5.72	8.21	0	1.10
2	37	70.37	22.39	2.93	3.36	6.29	0	0.95
1	31	62.07	22.39	6.77	7.97	14.74	0	0.79
Paretetaitonga	40	71.55	19.89	1.75	6.60	8.35	0	0.21
Mead's Wall	B	60.56	24.58	4.27	9.86	14.13	0	0.74
Dyke I	16	66.03	21.96	4.22	6.68	10.90	0	1.11
Dyke II	39	85.41	7.29	4.31	2,98	7.29	0	0
Basement (Skippers)	30	46.5	33.5	8.46	7.39	15.85	0	4.23
Pinnacle Ridge	25	48.7	35.7	7.66	5.65	13.31	0	2.28
Mahuia Rapids	41	70.67	8.94	14.8	3.82	18.62	1.79	0
Tawhai Falls	43	88.5	1.49 + 9.25 plagioclase laths in groundmass	.75	0	.75	0	0

*Although the total pyroxene percentage will be fairly accurate, the augite and hypersthene percentages are probably only approximate, owing to the difficulty in many cases of distinguishing between augite and hypersthene while using a Swift Electric Counter. The figures given therefore for augite and hypersthene will be only a rough attempt to separate the pyroxenes.

TABLE VI

Crystal Dimensions

Flow and Slide number	Description	Measurements
Flow 5 (Staircase) Slide 19	Plagioclase phenocrysts	Size varies from about 1.7mm by 0.8mm down to about 0.2mm by 0.05 mm
" "	Felspar microlites	Length about 0.02mm
" "	Hypersthene phenocrysts	Order of size is about 0.5mm by 0.1mm
" "	Glomeroporphyritic aggregate of augite crystals	1.6 mm by 1.02 mm.
" "	Augite phenocrysts	From about 0.25mm in diameter down to about 0.05 mm diameter
" "	Phenocryst of augite with hypersthene mantle	Crystal measures 1.6mm by 0.6mm and mantle is 0.1mm thick
" "	magnetite grains in groundmass	0.03 in diameter
" "	Small magnetites	About 0.17 mm in diameter
Flow 5 (Skippers) Slide 23	Plagioclase phenocrysts	Largest measures about 2.3mm by 0.75 mm.Sizes vary from about 0.9mm by 0.4mm down to 0.1mm by 0.07 mm.
" "	Augite phenocrysts	Range from 1.2mm by 0.7mm to smaller phenocrysts 0.1mm in diameter. Average size about 0.5mm diameter

TABLE VI continued

Flow and Slide Number	Description	Measurements
Flow 5 (Skippers) Slide 29	Plagioclase phenocryst with two inclusions of hypersthene	Plagioclase measures 1.46mm by 0.5mm. Inclusions measure 0.24mm by 0.1mm and 0.14mm by 0.08 mm.
Flow 5 (Skippers) Slide 24 H(B)	Aggregate of felspar laths, felspar granules and quartz.	Felspar laths 0.4mm by 0.1mm or narrower. Felspar granules 0.02mm in diameter. Larg quartz granules 0.17mm in diam.
Flow 9 Slide 7	Plagioclase phenocrysts	Variable size from about 1mm by 0.3mm to Skeletal phenocrysts 0.1mm by 0.05 mm.
Dyke II Slide 39	Plagioclase phenocrysts	Largest observed 3.03mm by 0.85mm. Average size about 1.7mm by 0.9mm.
" "	Felspar microlites	Up to 0.08mm long, but average about 0.06 mm.
" "	oval-shaped vesicles	0.1mm by 0.05mm on the average
" "	Felspar xenolith	Largest observed 3.3mm by 1.85 mm.
Basement - "Skippers" Slide 30	Augite phenocrysts	Largest phenocryst 4.9mm by 1.85mm. Average size about 0.4mm in diameter ranging down to those 0.07mm in diameter
" "	Hypersthene phenocrysts	Average 0.7mm by 0.2mm. One glomerophenocryst measured 1.9mm by 1.2mm
" "	magnetite	Largest phenocryst 0.8mm by 0.3mm. Average size about 0.08 mm.

TABLE VI continued

Flow and Slide Number	Description	Measurements
Pinnacle Ridge Slide 25	Plagioclase phenocrysts.	Largest - 1.2mm by 0.4 mm. Average about 0.4mm by 0.1 mm.
" "	Felspar granules in groundmass	0.02 in diameter.
" "	Augite phenocrysts	Largest 0.8mm by 0.6mm Average 0.2mm diameter or smaller
Mahuia Rapids Slide 41	Olivine phenocrysts	Largest 3.6mm by 1.3mm Average 0.5mm in diameter.
" "	Plagioclase phenocrysts	Range from 1.9mm by 0.4mm down to 0.2mm by 0.1 mm.
" "	Augite phenocrysts	Average diameter 0.6mm or smaller
Tawhai Falls Slides 42 and 43	Plagioclase phenocrysts	Largest 2mm by 0.5mm Average 0.4mm by 0.2mm
" "	Hypersthene and augite phenocrysts	Average diameter 0.2mm

CLASSIFICATION OF RUAPEHU ANDESITES

The andesites studied in this report are all hypersthene and augite bearing. In some, the percentage of augite is almost the same as the percentage of hypersthene. In others, hypersthene is the predominant pyroxene and this seems to be the more general case. The rocks may therefore be classed as hypersthene-augite andesites.

Since there appears to be little change in composition, it may be that further classification of the Ruapehu andesites can be based only upon the nature of the groundmass. Microlites are characteristically present in varying numbers in the groundmass so that at first glance the groundmass may be said to be hyalopolitic.

Even though this may be the case, varying degrees of crystallinity in the groundmass can be detected, slight as they may be in many cases; but from which a method of classification can be adopted.

The system of classification adopted in this report is as follows:

(1) Those with a holohyaline groundmass:

This type is characteristic of Flow 9 and parts of Flow 8 though on the whole it is not particularly common. The groundmass is entirely glass with only incipient crystallisation and no microlites.

(2) Those with a hyalopilitic groundmass:

This type has abundant deep brown glass in the groundmass with numerous felspar microlites. Usually imbedded in the groundmass are many small rectangular-shaped phenocrysts of plagioclase together with less numerous, larger phenocrysts.

This type is probably the most common in the Whakapapanui Series although an older flow at Tawhai Falls is hyalopilitic. The latter however has few phenocrysts and the groundmass felspar is not typically microlitic but more lath-like. The 'Staircase' portion of Flow 5 is perhaps the best example of this type.

(3) Those approaching an intersertal texture:

The groundmass in this type is crowded with microlites similar to but more abundant than those in the hyalopilitic groundmass. They show also a more pronounced fluidal arrangement. Glass is present but is not so conspicuous or abundant as in the above types.

The small rectangular plagioclase phenocrysts so characteristic of the hyalopilitic type, appear to be absent and the felted appearance of the groundmass is rather characteristic. This type is best displayed in the 'Skippers' portion of Flow 5.

Sometimes it is difficult to distinguish between the intersertal and hyalopilitic types for both tend to grade one into the other. Even within the same flow (e.g. Flow 5) and in the same locality, the texture can change.

In hand specimens, the above three types are hardly distinguishable for they all have very dark coloured and fine grained groundmass.

(4) Those with a more crystalline to almost holocrystalline groundmass:

This type can often be distinguished in hard specimens by its slightly lighter colour and coarser grain.

Microlites are much larger and are better classed as felspar laths. These are often closely packed together, show fluidal arrangement and tend to suppress any distinctly microlitic felspar. Glass is not obviously present except in the less holocrystalline rocks.

In the more holocrystalline rocks plagioclase laths, although often abundant, are sometimes associated with small irregularly shaped granules of felspar which may represent a residual product of crystallisation. This type of crystallisation is rather typical of section 25 from Pinnacle Ridge, whereas section 30 from the Whakapapanui Gorge basement and section 41 from the Mahuia Rapids are not quite so crystalline.

The Basalt Andesite Dacite-Rhyolite Association

The pronounced linear distribution of active or recently active volcanoes from New Zealand to Tonga Islands was probably first recorded by Thomas (1926). Since the cones are predominantly andesite, he regarded them as belonging to one great volcanic group. This line of activity is situated on a sub-oceanic ridge extending roughly N.N.E. from New Zealand to the Tonga Islands and bordered on the east by the Kermadec-Tonga trench.

Umbgrove (1947, p.39) suggests that this linear belt of volcanoes " ...... is closely associated with a deep fault plane ....., and constitutes an important line of demarcation of volcanic rocks known as the andesite line."

The "andesite line" is sharp over long distances and marks also the approximate limit of the sial; there being no sial east of the line. The olivine - basalt trachyte association of volcanic rocks is widespread and typical of the oceanic islands to the east of the "andesite line" and within the Pacific basin (intra-Pacific province of Turner, 1951, p. 124). On the continental side of the line, the basalt andesite dacite rhyolite association is predominant in the Tertiary and Quaternary lavas of the circum - Pacific orogenic belt (circum - Pacific province of Turner, 1951, p. 124).

Pyroxene andesites in particular appear to be typical of large composite volcanoes in orogenic belts. As these rocks are closely associated with the folded mountain chains bordering the Pacific, they are often referred to as belonging to the Pacific suite (Harker, 1909, pp. 93 - 100) though the term is now becoming obsolete and is generally replaced by the calcic or calc-alkalic petrographic province.

The later stages of orogeny are usually accompanied by eruption of andesitic lavas (Turner, 1951, p.212) so that it is to be expected that rocks of this association will be present as flows and tuffs in all regions of Tertiary and Quaternary orogeny.

It is not surprising therefore, since New Zealand is part of the circum-Pacific orogenic belt, to find rocks of that association. But Benson (1941) points out that New Zealand Tertiary volcanic rocks " ...... comprise a wide range of characters from those of the andesite-dacite-rhyolite-basalt association in the North Island to those of the basalt-trachybasalt-trachyandesite-trachyte-phonolite association in the southern part of the South Island."

The proximity of these associations (the so-called Pacific and Atlantic suites respectively) is not so unexpected for the line separating these associations ("andesite line") has been envisaged by a number of workers as passing fairly close to the east coast of New Zealand. Harker (1909, p.96) considered the line to pass through the southern part of New Zealand so that it divided the Dunedin district from the basalt-andesite-dacite-rhyolite association of the remainder of the country.

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ix I Photomicrographs of Ruapehu Andesites

Slide	Objective	Ocular	X nicols or P.P.	Voltage	Exposure	Filter
).10. Flow 5 ("Staircase") exture of rock	Low Power	None	P.P.	5	1 sec.	Blue
).19. Flow 5 "Staircase") igite phenocryst with m of hypersthene	medium power	None	X nicols	5	15 secs.	Blue
). 23. Flow 5 "Skippers") exture of rock	low power	None	P.P.	5	1 sec.	Blue
). 24 H(A). Flow 5 "Skippers") ot of plagioclase and persthene phenocrysts	low power	None	P.P.	5	½ sec.	Blue
). 29. Flow 5 "Skippers") persthene inclusions plagioclase	medium power	None	P.P.	5	½ sec.	Blue
). 9. Flow 9 exture showing glassy oundmass	low power	None	P.P.	5	1 sec.	Blue
). 7. Flow 9 iclusions of plagio- ase in hypersthene	medium power	None	P.P.	5	1 sec.	Blue
). 20. Flow 8 oundary between glassy id more crystalline oundmass	low power	None	P.P.	5	1 sec.	Blue
). 39. Dyke II exture of rock	low power	None	P.P.	5	1 sec.	Blue
). 25. Basement rock Pinnacle Type showing exture. (Pinnacle Ridge)	low power	None	P.P.	5	½ sec.	Blue
). 30. Basement rock Pinnacle Type iowing texture	low power	None	P.P.	5	1 sec.	Blue
).41. Mahuia Rapids exture of groundmass	low power	None	P.P.	5	1 sec.	Blue
).43. Tawhai Falls exture of groundmass	low power	None	P.P.	5	2 secs.	Blue

APPENDIX I

All photomicrographs in this report were taken with an Exakta Varex, Model VX camera using Kodak Recordax micro-File film. The film was developed in Ilford microphen fine grain developer for 6 minutes at 20°C. All prints are on Ilford Bromide paper (normal grade). The camera lens was removed and the camera fixed to a Swift microscope by means of a special microscope attachment.