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THE 1970 ERUPTION OF ULAWUN VOLCANO

by

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Errata - 1972/13

P.6, line 35, should read: "added to by the products of strong explosive" etc.

P.17, line 5 and 6, for period read frequency.

Plate 2, inset, delete the words "Vent A" and substitute the words "northwest Vent"; delete the words "Vent B" substitute the words "northeast Vent".

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THE 1970 ERUPTION OF ULAWUN VOLCANO

S U M M A R Y

In January 1970 a resurgence of activity occurred at Ulawun Volcano which is situated on the north coast of New Britain. The eruption lasted approximately one month and, with the possible exception of the 1915 eruption is the most severe on record.

Incessant explosive activity, from as many as four summit vents, characterized the eruption, with jetting and fountaining of incandescent lava to a height of 500 metres. Following stronger eruptive pulses, several nuées ardentes were emplaced, one of which devastated a sizeable area of rain forest.

The explosive activity was succeeded by the quiet pouring of lava, and one of the flows reached a point 5 km. west of the crater. Close to the onset of this effusive activity, a section of the crater floor was uplifted to form a 'block' 60 metres high.

Ulawun's seismic activity was characterized by a continuous volcanic tremor of high, but varying amplitude. No precursory earthquakes were felt or recorded. Tiltmeter readings indicated substantial deflation of the volcano prior to the cessation of the activity.

The products of the eruption, including the essential and accessory ejectamenta deposited by the nuées ardentes, are basaltic with tholeiitic affinities.

INTRODUCTION

On 9th January, 1970, after lying dormant for two years, Ulawun Volcano quietly entered into a period of activity which lasted approximately one month. This report presents the observations of the eruption made by the writer and others, together with instrumental data and notes on the petrology and chemistry of the eruptive rocks. Observations throughout the eruption were made from Ulamona Catholic Mission, situated 10.5 km. from the crater.

Information is included from other staff of the Central Volcanological Observatory: W.D. Palfreyman (A/Senior Resident Geologist) and M.G. Mancini (Seismologist) who witnessed part of the eruption and from G.A. Taylor (B.M.R. Canberra), who was with the writer throughout most of the eruption, and whose experience helped clarify some features of the activity. During the latter stage of the eruption, W.G. Melson and R. Citron (Smithsonian Institution) visited Ulawun Volcano to make observations and to produce a cinematograph film. An introductory account of the eruption and its products was published by the Smithsonian Center for Short Lived Phenomena (Davies, 1970). The structure and eruptive history of Ulawun has been described by Fisher (1957) and, more fully, by Johnson (1970), who includes a detailed account of the igneous petrology.

LOCATION AND POPULATION DISTRIBUTION

Ulawun (The Father, Uluwun) is situated on the north coast of New Britain (Lat. 5° 02'S Long. 151° 22'E) approximately 120 km. southwest of Rabaul. Geologically it forms one of a series of active, dormant and extinct volcanoes, which lie on the concave side of the New Britain Island arc system. The history of the arc, and the whole of the complex, tectonically active margin of the Australian continent can now be related to large scale global tectonics. In this respect, Denham (1969) has suggested that the arc is associated with the development of the Solomon Sea rather than with an extension of the Pacific Ocean.

The location of population centres within 16 km. of Ulawun Volcano is shown in plate 1. The population figures were obtained from the District Office at Kimbe and are the result of a census carried out by District Office staff in 1965. During the eruption it was considered necessary to evacuate the Ubili villagers to Matisibu and the Nuau villagers to Nantambu. This decision was reached after the initial outbreak of activity occurred in the northwest sector of the crater, near the head of the prominent northwestern avalanche valley. Fear that the valley might act as a natural guiding path for possible nuées ardentes proved warranted.

FORM AND STRUCTURE OF THE VOLCANO

Ulawun constitutes a nearly perfect cone made up of scoriaceous ejecta and interbedded lava flows of basaltic composition. Dense rain forest extends up to within 1000 metres of the summit, which was formerly estimated (Fisher, 1957) as being 2300 metres a.s.l. Observations during the present investigations suggest that the immediate pre-eruption height was of the order of 2250 metres and that the post-eruption height is over 2340 metres.

The volcano probably built up from sea level, and the surrounding coastal flats are, in the main, composed of debris washed down from the flanks of the mountain. Intercanyon lava flows are exposed in deeply dissected river courses on the northern slopes and evidence of the composition of the upper part of the cone is frequently afforded by great volumes of black and red oxidised fragments, swept down the valleys after torrential rainstorms. Before the eruption the summit was occupied by a fairly symmetrical central crater (Fig. 1) approximately 400 metres in diameter and over 100 metres deep. The form of the crater appears to have altered little since the severe eruption of 1915. Air photographs taken in 1943, 1948 and 1965 reveal, however, that subsidence along concentric fractures has at times led to partial infilling of the crater.

Remnants of an old caldera scarp (Fisher, 1957) form a prominent ridge on the southern and southwestern side of the volcano (Plate 2). The northwest slopes of the mountain are dissected by an imposing avalanche valley which extends from an embayment in the crater lip to the foot of the volcano.

ERUPTIVE HISTORY OF THE VOLCANO

All available information suggests that explosive activity has characterized former eruptions. The composition of the volcanic pile lends strong support to such a mode. The earliest eruption on record was a severe outburst in 1915, and minor eruptions were reported in the 1930's (1937 confirmed) and in 1941. A resurgence in 1960 was followed by minor eruptions in 1961 and 1963; and then a more marked outburst in 1967 during which Vulcanian clouds, borne westwards and northwestwards, deposited up to 1.5 cm. of black ash along the coastal region. Minor damage to local gardens resulted, while the upper flanks of the volcano were draped in tongues of coarse ejecta produced by explosive outbursts from two vents. Despite reports of lava flows from untrained observers no flows have been observed and, as suggested at the time (see Johnson, 1970) these were almost certainly based on erroneous conclusions, drawn from night observations of incandescent ejecta cascading down the flanks of the volcano.

THE 1970 ERUPTION OF THE VOLCANO

The first report confirming resurgence at Ulawun volcano reached the Rabaul Observatory late in the afternoon of 14th January. A pilot of Crowley Airways had observed "intermittent puffs of dark smoke", quite distinct in character from the rising wisps of white vapour common to the summit region. Prior to this report, Sister Eugenis, a part-time observer at Ulamona Mission, had made several unsuccessful attempts to notify the Observatory of the event but poor radio communications had prevented her from doing so.

The writer, together with M.G. Mancini (Seismologist) and Technical Assistant P. Daimbari, arrived at Bialla (41 km. southwest of Ulamona) on the 16th January, carrying out an aerial inspection en route. The remainder of the journey was undertaken by power boat. It was not until the 20th that permission to use Sule airstrip (Plate 1) was granted. A Willmore vertical seismograph was installed at Ulamona and was operational by 1600 hrs. LT on the 16th. Radial and horizontal components were added on the 27th. Monitoring was carried out in a small observation shed which had been erected after the 1967 eruption. The seismometers were placed on the specially constructed concrete block, alongside the two bubble tiltmeters which had been in use throughout 1969. Unfortunately, errors in the reading procedure of the two tiltmeters had made any pre-eruption tilt records invalid. Changes of level and tilting, caused by magmatic pressure variations in and beneath Ulawun, are therefore only known from the 16th January onwards.

The 1970 eruption can be divided broadly into: (a) a vapour emission phase; followed by, (b) an explosive phase; which overlapped with, (c) a quiet effusive phase. Phases (b) and (c) were in turn followed by a decline in vapour emission which represented the return to conditions of volcanic quiet.

One of the outstanding features of the eruption was the prolonged period of explosive activity which had established itself by the 15th and which did not cease until 9th February. During this period, incandescent spearheaded projections of lava, playing semi-continuously, were a spectacular feature of the night-time observations. This activity, frequently accompanied by loud explosions, and subsequently joined by quiet lava streaming, was interrupted by the expulsion of nuées ardentes, the first of which devastated a sizeable area of rain forest.

The visual observations recorded during the eruption, incorporating details of aerial inspections, are given below.

EVENTS CHRONOLOGY

Summary

A resurgence of activity occurred on 9th January, with the emission of grey vapour, which, in the days following, was accompanied by brief periods of ash and cinder ejection, as vents became re-established. The main explosive phase was initiated on the 15th and increased in intensity during the following days, with the opening of new vents. A nuée ardente was erupted on the 22nd, after which intermittent periods of lava pouring occurred. The main effusive phase commenced on the 26-27th with the eruption of three small nuées ardentes and with the upthrusting of a section of the crater floor. The expulsion of lava ceased on 10th February and the declining explosive activity ended on the 11th. The emission of grey to white vapour followed and by the 20th the activity was confined to the gentle emission of thin, white, vapour trails from the three vents.

Detailed Events Chronology

9-14/1/70

Mission staff at Ulamona confirmed that activity began on 9th January with the emission of grey vapour from within the northern part of the crater. No felt shocks were reported in the weeks before this eruption. From the 9th to the 15th, emission of grey vapour tended to be intermittent and was accompanied at times by aerial ejection of ash. (It was not until later in the eruption that the main vents described in this account could be seen from Ulamona. Their relative positions were marked by ash and lava ascending above the level of the crater lip.)

On the 15th the main explosive phase was clearly established and audible explosions, at short intervals, occurred throughout the day. During the night incandescent ejecta occasionally cleared the crater lip, to be deposited at the head of the northwest valley.

16/1/70

An aerial inspection at 0645 hrs (LT) by the writer revealed explosive activity from three small vents, situated within the crater. Two vents (northwest vents), 15-20 metres apart, were contained in a small cinder-spatter cone near the head of the northwest valley (Fig. 1). The third vent (southwest vent) was not so well defined and occupied a depression in the deeper, more central part of the crater. Rhythmic ejection of lava and ash to over 40 metres occurred from all three vents. There was little ash-laden vapour emission, but white vapour was being emitted from numerous points within the crater (Fig. 1); in particular from concentric subsidence-fractures marginal to the crater rim.

Observed from Ulamona Mission, the activity steadily increased through the day. Explosions occurred at 6-15 second intervals with rhythmic ejection which, as seen during the night, propelled incandescent blocks and scoria 50 metres above the crater lip. The northwest vents were clearly the most active. There were no felt shocks.

The sight of 'fire' had a disturbing effect on the Ubili villagers and many congregated nervously at the Mission. The Observatory Staff reassured the elders that the village was in no immediate danger, but this did not prevent several large parties from departing for Matisibu.

17/1/70

The activity continued, and rhythmic ejections produced small sheet (avalanche) flows on the northern flanks of the volcano and in the northwest valley. The evacuation of Ubili and Nuau villages was recommended and commenced at 1100 hrs (LT) under the direction of the Acting District Commissioner and an Assistant. The villagers needed little encouragement to leave, as the increase in activity was obvious to all. After the writer and Mr. Mancini had made an aerial inspection of the region to the south and southeast of Ulawun, it was concluded that the Manu area (Plate 1) was at a reasonably safe distance from the activity and was afforded adequate protection by the old caldera scarp.

By late evening the two northwest vents had coalesced and the growing cone could be seen above the crater rim. Ejection of lava to over 200 metres from the northwest vent was common, and the southwest vent was periodically active. The intensity of explosions increased and the reverberating air-waves frequently shook the Mission buildings during the night.

18/1/70

During the early morning activity from the northwest vent increased, with more voluminous, grey, ash-laden vapour emission. The southwest vent activity declined with periods of up to 2 hours without ejections. Throughout the morning explosions at 8-20 second intervals were typical, becoming less regular throughout the day. Night-time revealed spectacular spearheaded projections from the northwest vent, often reaching to over 300 metres; the incandescent blocks forming extensive sheet flows on the summit region.

The continual impact of semi-consolidated fragments on the outer slopes of the crater imitated distant rifle-fire. Large fragments, on striking the ground, were usually destroyed by the force of impact, producing dancing waves of smaller, flowing scoria. The colour of the lava gave, by comparison with smelting charts, an estimated emission temperature of 1000 - 1100°C.

19/1/70

At first light, dark ash-laden vapour emission was observed at a new locality on the northeast rim of the crater, indicating that a new vent had broken through (northeast vent). The northwest vent ejections were semi-continuous, with the emission of more voluminous ash-laden vapour which rose to over 4,800 metres a.s.l.

The Vulcanian ash clouds, borne by southeasterly winds of moderate strength, deposited films of fine black ash at Ulamona. During the night the northwest vent was very active and the northeast and southwest vents showed periodic activity. Audible explosions fluctuated in intensity and frequency.

20/1/70

Throughout the morning activity from the northeast vent increased with semi-continuous explosive ejections of lava and ash. By midday a well defined cone had formed, the northeast vent having asserted itself as the main summit vent. Ash-laden vapour, rising from the northeast and northwest vents, was borne west-southwestwards, depositing fine ash up to a distance of 90 km. Explosions were loud, but less frequent than on 19th, giving way to longer rumbling during the night. At 1900 hrs (LT) activity from the southwest vent increased, the spearheaded projections from this vent being more voluminous than at any other stage of the eruption. All three vents played continuously between 2000-2330 hrs (LT), the northeast vent being the most active.

Great volumes of incandescent ejecta rained down upon the northern summit slopes. Frequently, scoria, accumulated at the base of the northwest cone, would surge forward and then avalanche 400-800 metres down into the northwest valley, attaining speeds of up to 80 km/hr. These avalanches were commonly reported as lava flows by untrained observers.

In a summary of the activity of the previous days the writer concluded that a strong build-up was still in progress, with a very noticeable increase in the emission of dark, heavily charged ash-laden vapour. The amplitude of the volcanic tremors recorded at Ulamona had increased steadily (Plate 3), and ground motion on the 20th was sufficient to cause a noticeable oscillation of the tiltmeter bubble.

21/1/70

During early morning, activity from the northwest and southwest vents underwent a slight decline. Clear visibility showed that the northeast cone was the highest feature in the summit region and was continually being added to by strong explosive action. Voluminous ash-laden vapour was continually emitted (Fig. 2).

Activity from the northwest and southwest vents increased throughout the afternoon, audible explosions being intermittent. Dense ash-laden vapour formed cauliflower-shaped clouds which expanded slowly. During the night, the northwest, northeast and southwest vents played in a rhythmic fashion with explosions at 1-2 minute intervals. Incandescent blocks of plastic lava were propelled to heights of over 450 metres. A new vent became active between 2000 hrs and 0200 hrs (LT) on the 22nd. Situated in the southern part of the crater, this fourth vent produced explosive ejections at 30 seconds to 1 minute intervals, and its activity was comparable with that of the southwest vent, never attaining the power of the northwest or northeast vents.

22/1/70

At 0405 hrs (LT) a series of strong eruptive pulses discharged a nuée ardente down the northwest valley. The discharge of the mass of gas and scoriaceous ejecta was not preceded by any abnormal activity, and fountaining of lava was observed prior to the event. An eye witness described how dense ash-laden vapour clouds accumulated above the summit, successive emissions gradually enveloping the northwest vent. Some 80 seconds later abundant spots of light could be seen on the lower northwestern slopes, approximately 1000 metres a.s.l. Thinking that a new vent had broken out the eye witness roused the Volcanologists. His observations can probably be ascribed to the avalanche (ash flow) component of the nuée ardente emerging from the incised section of the northwest valley.

Incandescent blocks and igniting vegetation marked the path of the nuée down through the rain forest, and within 6 to 8 minutes the dark ash cloud component, which had blanketed the northwestern slopes, had expanded and risen to over 4000 metres a.s.l. Between 0412 and 0420 hrs an electric storm raged within the ash cloud which appeared to have generated a shower of light rain of 10 minutes duration. At approximately 0430 hrs, as the rain eased, a shower of lapilli fell on the Mission. Many of the residents were greatly disturbed by this new development, thinking that larger ejecta might follow. The writer on examining the ejecta found them to be accretionery lapilli (mud pellets) formed by the agglutination of fine ash during fallout from the nuée cloud. The lapilli, 0.5 to 1.0 cm. diameter, were easily disrupted on contact with the ground.

By 0445 hrs the summit had cleared sufficiently to show that "normal" explosive ejections from all four vents continued.

An aerial inspection at 0700 hrs (LT) revealed an area of almost total devastation approximately 1.1 km wide and 2.6 km long (Plate 2) extending down through the forested region on the lower northwestern flanks of Ulawun. A thick smoke haze hung over the area, and at crater level visibility was at a minimum. The nuée had flattened downslope, and set fire to, most of the rain forest along its path. Many local fires, particularly at the margin of the area, were still blazing, and thin columns of grey vapour rose from several secondary vents developed in the ash deposits.

The northwest and northeast vents were continually active throughout the day, with little response from the southwest vent. Ash-laden vapour emission was again voluminous, dense clouds rising to over 5000 metres. Cumulus cloud, together with the smoke haze rendered observation difficult. At 1650 hrs (LT) a lava flow, formed by the merging of streams from the northeast and northwest vents, was seen descending the northwest valley. This flow was probably initiated during the morning, and by 1800 hrs it had reached a point 1000 metres a.s.l.

During the night all four vents were again active; the lava temperature on emission was estimated at 1000-1100^{o}C. Occasionally, explosive ejections from two or more vents were synchronised, the more rhythmic ejections from the northeast and northwest vents littering the upper slopes with great volumes of incandescent blocks. Bursts of lava were frequently expelled from the north and northwest vents, the incandescent fronts surging down into the northwest valley (Fig. 3). Audible explosions, which had persisted at irregular intervals throughout the day, increased in intensity during the night.

After the unexpected events of early morning, a full 24 hour watch was proposed. To relieve the Volcanologists, the Mission Brothers kindly offered their assistance. Discussions were held with Assistant District Commissioner Burge, and it was decided to retain an administration boat at Ulamona in case of emergency.

23/1/70

Cumulus cloud obscured the summit throughout the daylight hours. Explosive activity continued with emission of voluminous ash-laden vapour (Fig. 4). At a height of 3000-5000 metres the ash clouds were borne southwestwards by moderate to strong winds, fine ash falling along the north coast of New Britain up to 110 km distance from Ulawun. Evening observations confirmed explosive activity from the northeast, northwest and southwest vents; the fourth vent appeared to be inactive. Lava fronts descended the northwest valley at 1-1½ hour intervals and extensive sheet flows avalanched down the northern slopes. Loud explosions occurred at 3-8 minute intervals.

24/1/70

The same pattern of activity continued and the northeast cone became progressively enlarged. Explosions were infrequent and less audible than on previous days.

25/1/70

An aerial inspection was carried out at 0715 hrs (LT). The strong, continuous activity from the northeast and northwest vents had resulted in the growth of two large cones and the subsequent infilling of the northern sector of the crater (Fig. 5). Mounds of ejecta partly isolated these vents from the southern part of the old crater, in which sat the less active southwest and fourth vents. The fourth (or south) vent was situated back from the crater lip, in line with an elongated saddle shaped depression which is shown in Fig. 1 and Fig. 5. This depression probably marked a fissure or line of weakness and is clearly visible on the 1943, 1948 and 1965 aerial photographs.

The summit was obscured by cloud throughout most of the day. Audible explosions increased in intensity towards evening, typically lacking a well defined frequency and showing no apparent correlation with the more forceful ejections. Throughout the night the northeast and northwest vents alone were active.

26 - 27/1/70

The summit of Ulawun was obscured for most of the daylight hours. Muffled explosions occurred at irregular intervals and a steady column of grey to black ash-laden vapour rose out of the cumulus cloud which encircled the volcano.

Clear weather conditions at 2100 hrs revealed a marked change in summit activity. The northeast vent alone was producing the typical, rhythmic spearheaded projections, and at this stage appeared to be the result of coalescence of the original northeast and northwest vents. Later observations disproved this, though it seemed likely that a westerly migration of the northeast vent had occurred. Dark ash-laden vapour was being emitted from the southern vents, over which a continuous glow was noticeable. This glow, less obvious but also present over the southern flanks, indicated the emission of lava. As the southwest vent and the south vent could not be directly observed from Ulamona Mission (their positions were indicated by the aerial ejections) extrusion of lava was only observed during subsequent daytime aerial inspections.

Three small nuée eruptions punctuated the effusive activity; at 2311 hrs on the 26th, 0130 hrs and 0436 hrs on the 27th respectively. These appear to have originated from the southwest vent, travelling down the southern flanks into the caldera valley. All three eruptions were characterized by the accumulation of dense ash-laden vapour above the summit, followed by the envelopment of the summit as successive emissions of ash-laden vapour were unable to rise, and culminated in the downslope movement of the ash cloud under the influence of gravity. Very few incandescent blocks were observed in the basal components of the moving nuées and the ash cloud expanded and diffused rapidly. A vivid electric storm of 4 minutes duration played within the expanding ash cloud of the 0436 hrs eruption.

An aerial inspection at 0630 hrs (LT) on the 27th revealed that a small area of vegetation within the caldera valley had been destroyed, probably by the more voluminous third nuée. The absence on the ground of a substantial ash flow component, compared with that deposited by the nuée of the 22nd, was in agreement with the observed lack of large ejecta produced prior to the formation of the nuées. Two lava flows, 15-20 metres wide descended the southern flanks, from points of emission on either side of a spectacular upraised block. The block is shown in Fig. 7. The two flows were incandescent in daylight; descending over 1000 metres and then merging into one flow in the caldera valley (Fig. 6). By 0700 hrs on the 27th the front of the resultant flow had travelled over 2.8 km from the summit and was moving steadily westwards down and out of the caldera valley. A flow rate of 20-25 metres/hour was estimated.

The upraised block, standing over 60 metres high in a shallow depression, had probably been formed prior to, or contemporaneously with the onset of effusive activity. Its rugged, yet friable appearance and the presence of coarse sub-horizontal banding suggested that it represented an upraised section of the old crater floor, rather than an endogenous lava spine. The two lava sources (approximately 100 metres apart) corresponded closely to the positions of the former southwest vent and the south vent; the southwest cone having been destroyed during the uplift. No pooling of lava at the surface was observed.

Strong explosive ejections from the northeast and northwest vents continued throughout the 27th, producing turbulent sheet flows, but no lava flows, on the northern flanks. Thin, diffuse columns of ash-laden vapour rose from the lava-producing southern vents. Faint rumbling was heard frequently throughout the day.

28/1/70 - 1/2/70

Visual observation from Ulamona Mission throughout this period was greatly hampered by extensive cloud cover. The forceful ejection of lava fragments and ash with accompanying dense ash-laden vapour emission continued from the northeast and usually from the northwest vent. The close proximity of the two vents often rendered visual separation difficult. A glow during the dark hours, often intense enough to illuminate the whole of the southern flank of the volcano, provided evidence of the continuous expulsion of lava from the southern vents.

An aerial inspection was undertaken on the 29th, in order to assess conditions on the southern side of Ulawun. The rain forest on the caldera scarp and to the west was mantled with ash which was falling continually from the dense ash clouds: thinner deposits covered a large area extending northwestwards to the coast and Ulamona and westwards to the Ibana River. To the east and northeast of Ulawun, slight discolouration of rain forest suggested some ash fall. The upraised section of the crater floor was not as prominent as when observed on the 26th and had crumbled at the margins. Its height was estimated as 60 metres. Lava continued to descent into the caldera valley and the front of the flow was moving slowly forward along an old river course, some 5 km from the summit.

A further inspection on the 31st revealed little change, except that the two flows descending from the summit had actively eroded channels in the unconsolidated ejectamenta (Fig. 7). Owing to poor visibility this feature probably went unnoticed on the 29th.

Audible effects throughout the period consisted of faint rumbling at 1-30 minute intervals and these rumblings increased in intensity and duration, such that by 1st February, 20-30 second periods of very loud roaring explosions were common. Reverberation effects were experienced at the Mission.

Throughout the night of the 1st February long periods of observation showed a decline in the volume of ejecta issuing from the northeast and northwest vents.

2 - 3/2/70

Brief periods of observation confirmed a gradual decline in the intensity of ejection from the northeast and northwest vents. The ash-laden vapour emission was noticeably less voluminous and the loud roaring gave way to faint rumbles at 1-2 hour intervals. Heavy rain on the 3rd gave rise to strong vapour emission from the aa lava flows and the ash flow deposits in the devastated area.

4/2/70

At 0340 hrs the intensity of ejection from the northeast vent increased dramatically with spearheaded incandescent projections rising to over 300 metres. This reversion to its former splendour was short-lived and by 0700 hrs (LT) a return to conditions of declining activity became evident. Moderate ejections at 5-15 seconds intervals, accompanied by faint rumbling, persisted into the night and a strong glow over the southern flanks of the volcano confirmed the continuing quiet effusion of lava from the southern vents.

5 - 9/2/70

Poor weather conditions reduced the period of observation to little more than a few minutes a day. On the 5th the audible activity ceased, and by the 9th ejections from the northeast vent were small in volume and weak in intensity. The northwest vent occasionally erupted, but there again a distinct lack of energy was apparent. Expulsion of lava from both the southern vents continued.

10 - 11/2/70

Throughout the 10th and the morning of the 11th, the summit was obscured by cloud. Brief observations during the afternoon and evening of the 11th confirmed that aerial ejection from the northern vents had ceased, though thin ash-laden vapour columns continued to rise.

The absence of a night-time glow over the southern slopes from the 11th onwards testified that the expulsion of lava had stopped, probably on the 10th. A ground examination of the 11th showed that the front of the flow had not moved since the 8th and now stood 5.6 km from the vents.

After the 11th activity was confined to the quiet emission of grey to white vapour from the northeast and southern vents; the thin columns rarely rising more than 50 metres above the crater.

By 20th February, very small amounts of white vapour were given off and it was concluded that the eruption had ended. This emission continued up until the time of writing, both visual and instrumental observations being maintained at Ulamona.

VOLCANIC PRODUCTS

The products of the eruption which have been examined can be best divided into: nuées ardentes deposits, blocky lava flows; and airfall deposits.

A great volume of the material ejected now constitutes the strongly modified summit region, and mantles the upper 1000 metres of the volcano. This fragmentary material, consisting dominantly of scoriaceous lapilli and blocks, has not been examined on the ground. It is reasonable to assume that many fragments have rounded profiles, or breadcrusted surfaces or both, which are typical of aerially ejected bombs.

No estimate has been made of the total volume of material ejected, for even if an approximate figure is given for the volume of ejecta added to the summit region, no reasonable estimate can be offered for the airfall material distributed over the kilometers of inaccessible rain forest.

Nuées Ardentes Deposits

(including notes on the features of the devastated area)

The products described are those of the more voluminous nuée ardente of the 22nd; the area on the southern flanks of Ulawun entered by the three nuées of the 26th-27th has not been examined on foot. Aerial inspections indicated that these later nuée deposits are not extensive and that only a small proportion of the material deposited consists of ejectamenta larger than lapilli size.

The nuée ardente of the 22nd swept down the northwestern side of Ulawun into the rain forest, causing almost complete destruction along its path. The area devastated by this swiftly moving mass of gas and fragmental material is illustrated in Plate 2. The deposits of the nuée can be divided into an ash-flow component, and an ash-hurricane component. The former represents the coarse fragmental material carried along in the basal part of the moving mass; and the latter, mainly the finer ash and cinder suspended in the gas cloud.

(a) Ash-flow Component

It appears that the ash-flow component of the nuée was largely restricted to the northwest avalanche valley during its descent. Before entering the rain forest, however, part of the mass spilled out of its confining channel and moved northwestwards ([redacted] Plate 2). Lower down its course, where the nuée encountered a sharp bend in the river valley, much of the dense fragmentary material overrode the steep bank and spread northwards ([redacted] Plate 2).

Whereas the zone of devastation covered by the ash-hurricane component is littered with fallen and partly destroyed trees, the ash-flow zone is characterized by a paucity of exposed trees. While much of the vegetation is probably buried beneath the coarse fragmental material, some may have been swept away by the advancing front. This would account for the observed local accumulation of trees at the margins of the ash-flow deposit.

The thickness of the ash-flow deposit is incompletely known, since few good sections have been exposed by erosion. In the lower part of the valley, near the front of the area devastated, the deposit was found to be little more than 1.0 metre thick, and near the western margin of the ash-flow considerably less.

Higher up in the valley (approx: 700 metres a.s.l.), over 4 metres of fragmental material is exposed in deep rain gullies (Fig. 8), eroded within two weeks of the eruption.

The ash-flow deposits consist of a totally unconsolidated mixture of ash, lapilli and blocks in which sorting was rarely observed. Over 80% of the material is thought to be essential ejecta of primary origin, and of this 60% is grey to black in colour; the remainder is a red or brown colour. Apart from the colour differences all the essential material is very similar, being strongly scoriaceous and often vesicular. Most fragments are subrounded in shape, and an average size of 5-15 cms diameter is common at many localities. The larger blocks are approximately 2 metres in diameter and over 100 blocks with a diameter greater than 0.5 metre were counted on the surface.

Of particular interest are long, narrow ridges of quite well sorted ejectamenta which trend subparallel to the main river valley (Fig. 9). The ridges probably originated when some kind of lateral sorting mechanism was set up in the river valley, perhaps owing to a slight deflection of the moving mass off a more prominent shoulder or bank. During this course adjustment, material of a certain mass was directed laterally and shoaled up on the valley sides.

Close examination of the essential lapilli and blocks revealed that most have a puffed up interior with a denser margin. Some show an increase in porosity from the margin inwards, while the interior of large blocks is composed of fairly compact porphyritic basalt, traversed by scoriaceous fissures. Some of the blocks appeared to have fractured and broken up in situ, indicating that volatiles were released continually after emplacement. No impact craters were observed.

Scattered throughout the ash-flow and ash-hurricane deposits are accessory blocks and lapilli of a light-grey coloured, compact porphyritic basalt. Compared with the essential ejectamenta, the accessory fragments are angular, rarely vesicular and without a scoriaceous margin. Locally, they litter the surface of the ash-flow (Fig. 10) and the largest block examined was over 1.5 metres in diameter. As no blocks of this type were observed lying in the avalanche valley during the early stages of Ulawun's activity, it is probable that they were derived from the walls of the conduit during the stronger eruptive pulses.

(b) Ash-hurricane Component

The greater part of the devastated area was found to be covered by a layer of black ash with scattered lapilli and blocks throughout. The thickness of the ash layer varies considerably; where the nuée had swept over gently undulating shoulders the thickness is as little as 3 cms, while shallow depressions and stream courses are filled to a depth of 1 metre. At the margin of the devastated area the deposits are rarely over 5 cms thick. Outside the area the rain forest is covered with a thin film of ash, which may well have been deposited from the normal, ash-laden vapour clouds. The blocks scattered over the ash deposit are of both essential and accessory types, and many are partially buried in such a way as to suggest movement of the finer components after the emplacement of the blocks.

Within the ash-hurricane zone, the effect of the moving nuée on the vegetation has been quite spectacular, and features similar to those described by Taylor (1958) at Mt. Lamington are everywhere apparent. Most of the rain forest was flattened downslope, and away from the margin of the area the stripping of trees was so complete that no green foliage remains. Many of the trees were completely uprooted and those which had not been felled from the base were severed higher up (Fig. 11). Eucalypts, over 40 metres high were split open and twisted and only their largest limbs remain attached.

Certain irregularities in the orientation of the fallen forest are apparent and show that the nuée had undergone local changes in direction. In the lee of a broad, curved bank, the trees are lying almost at right angles to the general downslope direction of movement; elsewhere some irregular patterns cannot easily be related to topography and suggest that great turbulant and vortex-like movements had been set up in the ash cloud. In one area, the trees are straddled across each other in all directions.

The abrasive power of the nuée was greatest in the steep sided confine of the northwest river valley. Here, the valley walls have been cleaned of all vegetation, exposing good sections of poorly bedded chaotic ejectamenta, much of which were probably emplaced by earlier nuées. Pitting and abrasion of tree trunks is widespread, and the bark of many trees has been removed on their upslope side. Occasionally, lapilli are found embedded in the trunks. Trees are severely charred on one side (Fig. 12) and many had been fired and subsequently burnt out.

The margin of the devastated area is characterized by a seared zone 20-50 metres wide, in which the vegetation was scorched but not charred. At the outer limit, the foliage is brown, but most of the leaves still remain on the trees. Inwards, the trees become gradually barer and the overall degree of physical damage increases. In this zone, at the base of the devastated area, it was discovered that a number of trees were flattened upslope, i.e. opposed to the direction of movement of the nuée. This feature is thought to be due to the infolding of cold air beneath the arrested, but still hot, nuée cloud.

It is probable that much of the lighter, more buoyant foliage was carried up from the devastated area in the expanding ash cloud. Evidence to support this explanation was found in the Matisibu district, 12 km from the area. Here, many scorched and charred eucalyptus leaves were found several hours after the nuée eruption and indigenous residents said that the leaves floated down amongst the ash during the early morning fallout.

Temperatures within the nuée ardente were obviously high enough to cause charring and to ignite vegetation. Five days after the eruption, temperatures of over 80°C were recorded on thermometers driven into the vapour-emitting ash-flow deposits. During periods of heavy rain the surface of the ash flow deposits emitted dense steam (Fig. 13), even twenty days after emplacement. Pockets of lighter coloured hot ash were exposed by rain gulling in the avalanche valley (Fig. 14). Several active secondary craterlets were observed immediately after the eruption, but when examined on 3rd February these were found to be inactive (Fig. 15). Crater-like depressions marked the site of burntout trees and these were actively emitting vapour and smoke twenty days after the eruption. Large blocks of scoriaceous ejecta were warm to the touch on all the writer's visits to the area up until 14th February.

In the ash-hurricane deposits cooling was more rapid, and within 7 days of the eruption temperatures were not above normal ground temperatures.

A bright orange fungus was found on tree trunks just two days after the eruption. This was tentatively identified as a species of Neurospora by G.A.M. Taylor, and it is known to germinate only when subjected to high temperatures. Seven days later the fungus was re-examined and was found to be a yellow colour.

Blocky Lava Flows

The aerial extent of the aa flows is illustrated in Plate 2. Only the front portions of the flows were examined. Typically, the flows consist of dark coloured porphyritic lava whose surface is broken up into strongly scoriaceous blocks and rubbly clinker (Fig. 16). The interior of larger, more compact blocks of lava exhibit traces of flow banding and poorly developed cooling joints.

During the first ground inspection (on 4th February) of the flow moving westwards from Ulawun, temperatures of over 850°C were recorded in blocks of cooling lava detached from the main body. The intense heat prevented a closer approach being made to the semi-molten lava, and was sufficient to render the measuring procedure unpleasant. The flow moved along at less than 10 metres an hour. A build-up in internal pressure would cause incandescent blocks to tumble down the face of the flow, often breaking up on contact with the ground. The overall motion of the front was not unlike that of a slow conveyor belt.

Inspection on 8th February showed that the lava surface had cooled off considerably and no forward movement was observed. The temperature of the interior of the flow was still high and during heavy rain showers dense steam was emitted. The flow front was over 60 metres wide and 8-10 metres high (F_g. 17).

The blocky flow in the northwest valley (Plate 2) was examined on 12th February and found to be warm under foot. The flow rested on the coarse, fragmental, nuée deposits and its front was 20 metres wide and 5 metres high. No movement of the flow was observed and it is doubtful if any had occurred since its outpouring on 22nd - 23rd January.

Airfall Deposits

Airfall ash was deposited in immeasurable quantities over the rain forest of the coastal regions. Moderate northeasterly and easterly winds, (peculiar for the time of year) carried the ash clouds as far as Kimbe, 130 km distant, where traces of fine ash were recorded. Nearer the source, Bialla and Matisibu received over 1.0 cm of ash and fine cinder, and Ulamona Mission slightly more.

The area immediately to the west of the crater received extremely heavy falls of ash throughout the eruption. On 8th February a survey was made of the airfall deposits lying in and around the old river course along which the western lava flow was moving. It was found that the overall thickness of the ash was fairly constant and varied from 7-13 cm. The location of four samples collected for analysis is shown in Plate 2. Intercalated bands of coarser-grained ash were sometimes observed, which contained occasional pumiceous fragments of lapilli size. As the explosive power of the activity appeared insufficient to propel the lapilli over 6 km they were obviously transported by stronger than usual, easterly winds. The samples (2,3,4 and 5), together with a sample (1), collected at Matisibu (12.8 km from the crater), were analysed for grainsize distribution using normal laboratory sieves. The results are shown in Table 1.

TABLE 1

SIZE* range of particles (mm's) in weight percent								
Sample No.	10 mm	10-5.0	5.0-2.0	2.0-1.0	1.0-0.6	0.6-0.25	2.5-0.1	0.1
1	-	-	-	0.008	0.087	20.201	58.919	20.763
2	1.495	0.231	1.337	10.701	27.846	38.064	11.561	8.782
3	-	0.120	1.139	8.819	28.742	32.732	14.360	14.077
4	-	0.164	1.966	11.320	28.538	32.657	14.620	10.724
5	-	0.075	0.930	5.113	20.555	46.192	17.232	9.902

* The size is described in terms of the minimum diameter of the particles. Objectively, sieves classify the particles on the basis of their least cross-sectional area.

Heavy showers of rain, had by 8th February caused some redistribution of the ash, though the undisturbed appearance of the deposits sampled suggested that the data obtained is fairly representative. It can be seen (Table 1) that the Matisibu, sample (No. 1), collected only 6.8 km further from the crater than the others, is very much finer and no fraction over 2 mm minimum diameter is represented. This indicates the very sharp fall-off in the transporting power of the wind borne ash clouds with increase in size (mass) of the constituents. Samples 2, 3, 4 and 5 all show approximately the same size distribution, although a coarser fraction appears to be significantly higher in Sample 2.

North and east of Ulawun, the airfall deposits are thin and only cause a slight discolouration of the rain forest. On the coast, directly north of the crater (9.6 km distance), less than 0.5 cm was recorded.

SEISMIC ACTIVITY

Over the last decade, much has been learnt about the seismic activity that accompanies volcanic eruptions and how early monitoring of this activity can help predict the time and place of a volcanic outburst. Unfortunately, owing to heavy commitments the Observatory was unable to retain a suitable measuring instrument at Ulamona after the 1967 eruption. During the present eruption, twenty-four hour recording commenced on 16th January, soon after the establishment of the explosive phase.

The seismic activity recorded at Ulamona Mission was characterized by a continuous volcanic tremor, the amplitude variation of which is shown in Plate 3. No impulsive shocks were recorded and no felt shocks were reported in the region, either immediately before or during the 1970 eruption.

The dominant period of the volcanic tremor is 0.8-0.9 cycles per second, and the period range varies from 0.7 cycles per second to 1.0 cycles per second. The magnitude of the ground motion at Ulamona was considerable, and from 20th January to 3rd February caused the tiltmeter bubbles to oscillate continuously. External attenuators were connected to the Willmore seismograph so as to reduce the amplitude of the trace to a readable size. Details of the instrumentation and analytical procedure are given in Appendix I.

The relative ground motion had a double amplitude of 5 microns when recording commenced on 16th January, and a steady increase occurred after the 18th, reaching a peak of 25-28 microns before the eruption of the nuée ardente on 22nd January at 0405 hrs. The ground motion amplitude fluctuated through some 13 microns during the strong explosive activity of the following days, peaking noticeably on the night of 26th January, when the onset of the effusive phase was punctuated by the expulsion of the nuée ardente. The amplitude continued to fluctuate with peaks around 30 microns until 3rd February, when an overall reduction to 15 microns accurred. A further decline in amplitude set in on the 4th (10 microns average) and the 5th, when ground motion was reduced to approximately 7 microns. By 8th-10th February the ground motion was approximately 5 microns, and after the 10th rapid decline reduced the ground motion to a level at which it was indecipherable from the normal background noise, on the seismograph records.

The overall trend of the ground motion amplitude graph is remarkably similar to that of the tilt variation graph for the radial component tiltmeter (Plate 3). Of even greater importance is the way this trend is in accord with the pattern and intensity of the observed summit activity which is described in pages 4 - 11. This agreement is best exemplified by the events of 3rd-8th February, when waning activity was matched by declining ground motion.

Successful attempts were made by Omori (in Minakami, 1960), Minakami (1960 and 1969) and the Philippine Commission on Volcanology, (1967) to classify the types of volcanic earthquakes recorded prior to and during volcanic eruptions. Minakami (1960) showed that continuous volcanic tremor originates in the vicinity of the craters of the erupting volcanoes, usually by explosive earthquakes becoming continuous vibrations.

On comparing Ulawun's seismic activity with that of other Circum-Pacific volcanoes investigated by these authors, the complete lack of discrete earthquakes appears anomalous. While it is reasonable to assume that the deeper, A-type volcanic earthquakes (Minakami, 1960) would have occurred before the eruption and hence before monitoring commenced, B-type and impulsive, explosive earthquakes could have been expected during the gradual build-up in intensity. It thus appears that the magma had ascended the conduit at an early stage and hence the only volcano-seismic activity recorded was a continuous tremor which originated in or beneath the crater.

TILT PHENOMENA

Due to incorrect daily adjustments, the radial and tangential component tiltmeters gave no indication of the rising volcanic potential during the weeks preceding the eruption. The changes in level and tilt recorded from 16th January onwards, however, agree well with the observed summit activity. Plots of the readings are shown in Plate 3. Three readings a day were normally taken; at daybreak, mid-afternoon and at night. It is apparent that a strong diurnal variation, which was independent of the activity, is super-imposed on the main trends.

Tumescence of the volcano accompanied the early stage of the eruption and a maximum was recorded before the expulsion of the nuée ardente on 22nd January. The readings remained fairly steady until 5th February, when rapid deflation of the crater through 25 seconds of arc occurred; stability being regained about 11th February (Plate 3). This change probably reflected the withdrawal of a magma from within and beneath the volcanic pile, a conclusion which is supported by a marked decrease in summit activity during the period. Except for minor fluctuations, the readings remained fairly constant up to the time of writing, at the end of March.

The main changes of slope and direction shown on the tangential component graph also coincide with the general pattern of summit activity. During the period of waning activity from 5th to 9th February a change through approximately 32 seconds of arc was recorded. Prior to this, on 3rd February, an unexplainable change of over 12 seconds of arc in the opposite sense had occurred (Plate 3). It would be presumptuous to correlate this peculiar movement with a sudden shift of the magma before its final withdrawal.

DISCUSSION

The 1970 eruption of Ulawun Volcano ranks, with the possible exception of the 1915 outburst, as the most severe on record. Furthermore, with five eruptions in the last decade, Ulawun stands alongside Manam and Bagana as one of the recently most active volcanoes in the Territory of Papua and New Guinea.

It must be emphasized that the outstanding feature of the eruption was the long period of explosive activity which was maintained without cessation for twenty-six days. This phase was characterized by jetting and fountaining of lava from a total of four vents, all situated within the old crater area. During the early stages, very little ash-laden vapour was emitted from the two initial vents, but as the build-up in intensity continued and new vents were established, great volumes of ash-laden vapour formed impressive eruption clouds above Ulawun. If this explosive activity needs to be classified, a change from the Strombolian to the typical Vulcanian type of activity was recognized. Many workers, however, including Perret (1935), realized that these terms were often inadequate and misleading. It is probably better to consider Ulawun, simply, as an open-conduit type of volcano, characterized by an explosive mode of activity.

The nuée ardente of 22nd January was erupted at a time when the explosive phase was fully established and dense eruption clouds were continually produced. From the recorded observations it is apparent that the nuée was formed by the vertical discharge of scoriaceous lava and ash, and that a laterally directed explosion played no part in its production. This type of nuée ardente has been described as the "d'explosion vulcanienne" type by Lacroix (1904), who distinguished it from nuées ardentes produced by obliquely directed explosions and avalanching of material from lava domes and flows. Vertically discharged nuées are described from Manam Volcano (Taylor, 1963) and Mayon Volcano (Moore and Melson, 1969), and it is apparent that in most cases observed, a build-up in the emission of heavily-charged, ash-laden vapour precedes their formation.

The descent of the nuée ardente on 22nd January was gravity controlled, and it is probable that much material, which had been deposited around the northwest cone prior to the event, was picked up and carried along in the basal layers of the ash cloud. Taylor (1963) emphasized the role of large valleys in channelling the nuées erupted at Manam; and in a similar manner the northwest valley controlled the descent of the nuée of the 22nd at Ulawun. This accounted for the relatively narrow zone of devastation on the lower, northern flanks of Ulawun.

From the observations recorded on pages 7-8, some estimate can be made of the velocity of the nuée ardente. It appears that a minimum average velocity of 110 km an hour must be deduced for the nuée's passage down the upper slopes of Ulawun. Considering the steep slope involved, this figure does not seem unreasonable, as Lacroix (1904) estimated velocities approaching 110 miles an hour for nuées ardentes at Mt. Pelée. More recently, Moore and Melson (1969) calculated a velocity range of 9-63 metres per second for a nuée ardente expelled during the Mayon eruption. On encountering the gentler, forested slopes at the foot of the northwest avalanche valley the nuée's momentum must certainly have been dissipated rapidly, for the fast-moving mass only travelled another 2.3 km before coming to rest.

The heating effects and destruction imposed on the vegetation, together with the temperatures and other features observed in the devastated area many days after the eruption, indicates that the nuée ardente consisted of an admixture of hot fragmental material and gas. Much dissolved gas was probably released from the hot, semi-plastic fragments during the emplacement process, a conclusion supported by the puffed-up, scoriaceous nature of the material examined. Also, many of the large blocks examined had obviously cracked and split open after deposition. Entrapped gases in the massive deposits gave rise to secondary vents.

The ash-flow deposits of the nuée are for the most part unsorted and poorly stratified. In this respect they are similar to the dominantly acid volcanic rocks normally grouped under the term ash-flow tuffs (Ross and Smith, 1961). The unconsolidated nature of the nuée deposits, together with the complete absence of any welded, fused or collapsed fragments, strongly suggests, however, that fundamental differences must exist in the depositional mechanism and also in the physico-chemical conditions that prevailed.

Within hours of the eruption of the nuée on 22nd January lava flows descended the northwest valley. This sequence was also observed at Manam (Taylor, 1963) and Mayon Volcano (Moore and Melson, 1969) and suggests that some degassing of the magma, to a considerable depth in the conduit, accompanies the strong, nuée-producing, eruptive pulses.

The onset of the main effusive phase was probably preceded by pooling of magma beneath the southern sector of the crater, which caused uplift of the crater floor. The true nature of the upraised block is not fully known, but it is hoped that an examination of the summit area will be made in the near future. The pouring of lava from two vents was continuous for fifteen days, and this phase existed alongside the explosive activity from the northeast and northwest vents.

The eruption produced marked changes in the summit topography. The strong explosive activity from the northern vents caused cone growth and the infilling of the northern part of the crater. The continuation of this activity led to growth of the summit, which now stands at approximately 2340 metres a.s.l. The symmetry of the summit region was further destroyed by the upraising of the southern part of the crater floor. The changes imposed on the old crater can be best appreciated by comparing Figs. 1, 5 and 7.

The observations and results of the seismic and tilt investigation carried out at Ulamona Mission have been discussed earlier in the text. It is only necessary to emphasize that both phenomena are in agreement with the observed summit activity. The retention of the recording equipment at Ulamona during the months following the cessation of activity meant that data could be accumulated during the inactive period. Japanese Volcanologists have often stressed the locally recognised importance of monitoring the 'normal' conditions at volcanoes. While no impulsive shocks of volcanic origin were recorded at Ulamona after the 1970 eruption, an event resembling continuous volcanic tremor was sometimes found on the seismograph record. Careful observations showed that this was produced during periods of strong winds. It is only by the elimination of such background noise that the whole concept of volcanic prediction, utilizing seismic data, can be soundly based.

Much has been written during the last decade on the possible relationship between volcanic activity and the disposition of the sun and moon. Certain luni-solar influences were inferred at Langila Volcano during an eruption (Taylor, Best and Reynolds, 1957); and at Manam, Taylor (1960 and 1963) found that important eruptive events were concentrated close to the solstice and equinox. The only possible relationship between such forces and the activity observed at Ulawun during the recent eruption is that full moon occurred on 23rd January, one day after the eruption of a nuée ardente and approximately at the height of the eruption.

The petrography and chemistry of the volcanic rocks is outlined in Appendixes II and III respectively. All the material ejected appears to be of basaltic composition, with tholeiitic affinities, and the lavas are very similar to older flows of basalt exposed on the flanks of Ulawun and which are described by Johnson (1970). It can be concluded, therefore, that no differentiation of the magma has occurred with time.

The eruption of nuées ardentes of basaltic composition has seldom been acknowledged as feasible by the majority of workers, though it must be borne in mind that Taylor (1963) adequately describes similar phenomena at Manam Volcano.

There can be little doubt that future eruptions at Ulawun are to be expected and that the quiescent period now established will be of comparatively short duration. The time interval between the last five eruptions has varied from one to four years and so it is not unreasonable to assume that resurgence of activity will occur before 1974. With the large northeast and northwest cones capping the summit of Ulawun, future eruptions, which are capable of producing nuées ardentes, could again endanger the Ubili and Nuau villagers, together with Ulamona Mission Station.

If the present volcano-seismic conditions are maintained at Ulawun, the recording instruments will probably be removed in June or July, 1970, and until they can be replaced by permanent seismic instrumentation, only the tiltmeters will remain at Ulamona Mission. A routine inspection of these tiltmeters is therefore essential.

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APPENDIX I

Notes on the seismic equipment used at Ulawun

by M.G. MANCINI

The three component Willmore seismograph at Ulamona consisted of a Mark I vertical seismometer (To = 0.7) and two Mark I horizontal seismometers (To = 1.0) coupled to 0.25 second period galvanometers. Light beam length was 10 cm., trace speed 60 mm per minute. The instrument was underdamped. The frequency response curve has a peak of X30,000 at 0.33 sec. period.

The period of the recorded tremors ranged between 0.7 and 0.9 secs. on the vertical component and between 0.7 and 1.0 sec. on the horizontal components. Record analysis was done at two hour intervals. The maximum amplitude, peak to trough, in each interval was chosen and read. Maximum readings were seldom obtained at the same instance on all three components.

The effect of resonance, underdamping and inaccurate calibration made absolute ground motion computation somewhat doubtful. The relative values quoted in the text do, however, describe the seismic story of the eruption. The relative ground motion amplitude plotted against time follows a similar trend on all three components. The vertical component best described the seismic activity, since it incorporated a longer recording time and developed fewer technical faults.

APPENDIX II

Notes on the petrography of the eruptive rocks.

The products of the 1970 eruption which have been examined are all basaltic, and both in mineral content and texture are similar to a suite of specimens from Ulawun, described by Johnson (1970).

The essential (new magma) lava and ejectamenta vary little from the accessory ejectamenta in mineral content, and all the specimens from which thin-sections were obtained are porphyritic. Plagioclase feldspar is the most abundant phenocryst component, far in excess of olivine and pyroxene. A seriate texture is usually partly developed.

All the specimens of essential blocky lava were found to be vesicular, but no amygdaloidal infillings had formed. Plagioclase phenocrysts constitute 20-40% of the rock, are up to 3 mm long and generally have a length to breadth ratio of 2:1-3:1. Twinning on the albite or carlsbad-albite laws is common to all the phenocrysts and some interpenetrating crystals are present. Cores are sometimes weakly zoned and some crystals have a thin, marginal rim of clear feldspar. Where determined, the composition ranges from An_{70} to An_{80}. The plagioclases are clouded with granules and wisps of brownish glass and also granules of pyroxene. The margins of the crystals tend to be partly corroded, suggesting some reaction with the residual magmatic liquid. Several crystals in any one thin-section appear to have been mechanically fractured and broken, probably during the emplacement of the lava flow.

Small subhedral phenocrysts of olivine, often with rims of iron-titanium oxide, occur in all the samples examined. Some have very thin reaction rims of a pyroxene mineral (not determined). Good euhedral phenocrysts of augite (diopsidic?), up to 2 mm long, are the most abundant phenocryst after plagioclase, and hypersthene appears occasionally as subhedral crystals up to 1.5 mm in length. Some slides show a marked deficiency of any pyroxene phenocrysts, and no iron-titanium phenocrysts were observed.

The groundmass has an intergranular texture consisting of laths of plagioclase, granules of olivine and pyroxene together with dusty iron ore, set in a variable glassy mesostasis. The pyroxenes appear to be mainly augite, with minor amounts of hypersthene and pigeonite?. Small wisps of chlorite and thin needles of apatite are sometimes interstitial.

The essential ejectamenta emplaced by the nuée ardente is mineralogically similar to the lava of the flows, and is always scoriaceous and vesicular. The margins of the plagioclase phenocrysts are, however, better defined, which indicates that more rapid chilling of the ejctamenta greatly hindered the reaction process. Also, the phenocrysts are surprisingly far less fractured and disrupted than one would expect considering the unfavourable stress conditions created during the frothing and puffing-up of gas-rich ejecta. Several large, subhedral phenocrysts of hypersthene were observed. The glass content of the groundmass is most variable; within the limits of one thin-section changes from a strong microvesicular texture to dense, nearly opaque iron-charged glass is apparent. One sample has good glomeroporphyritic texture developed, in which both plagioclase and pyroxene crystals participate.

The accessory lava ejectamenta emplaced by the nuée is distinctly different in hand specimen from the essential material, lacking a scoriaceous texture and being medium-grey in colour. It is probable that this lava was completely solidified prior to its emplacement and was derived from the walls of the conduit. It is interesting to note that Johnson(pers: comm) found similar rocks exposed in the northwest valley in 1969. The feldspar phenocryst content varies from 20% to 40% and the crystals are up to 3 mm in length. The plagioclases are better zoned than those of the essential lava, and some oscillatory zoning is present. Some crystals have shallow, bottle-shaped embayments infilled with iron-charged glass, but generally the glassy inclusions are not as abundant as in the essential lava. The composition of the crystals ranges from An_{65} - An_{85}. Olivines are present in all the thin-sections examined; the crystals are small ($<$ 0.4 mm across) and usually rimmed with iron-titanium oxide. Augite phenocrysts are the most common pyroxene mineral and several twinned and zoned crystals were observed. All except one thin-section were found to contain good hypersthene phenocrysts, in far greater abundance (up to 10%) than in the essential lava. Many of the hypersthene crystals have marginal rims of granular clinopyroxene and aggregates of phenocrysts are not uncommon. Subhedral microphenocrysts of pigeonite were found in one thin-section. Small grains of ilmenite occur throughout the groundmass and also as inclusions in plagioclase phenocrysts, in all but one of the specimens. A sample of fine grained, moderately porphyritic basalt displays trachytic texture in the groundmass, which is composed almost entirely of aligned feldspar laths. This specimen was found to be low in pyroxene and olivine phenocrysts.

Following the work of Kennedy (1933) most authors now agree that the type of mineral association encountered in the eruptive rocks of Ulawun shows tholeiitic affinities. Hess (1941) and Poldervaart and Hess (1951) strengthened the distinction between the tholeiitic and other magma types; listing little or no olivine (magnesian and unzoned, if present), two pyroxenes (augite with pigeonite or with hypersthene) and often iron enrichment of the pyroxenes as typical of the tholeiitic suite. It is the presence of pigeonite which is the essential feature of a mineralogical distinction. The Ulawun rocks are similar to those of the volcanic islands north of New Guinea, some of which Morgan (1966) suggests have tholeiitic tendencies.

R E F E R E N C E S

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Kennedy, W.Q.,	1933	Trends of differentiation in basaltic magmas. Am. Jour. Sci., 25, 1933.
Morgan, W.R.,	1966	A note on the petrology of some lava types from East New Guinea. Journal Geol. Soc. Aust., 13, 1966.
Poldervaart, A. and Hess, H.H.,	1951	Pyroxenes in the crystallisation of basaltic magma. J. Geol., 59, 1951.

APPENDIX III

Notes on chemistry of the eruptive rocks.

Analyses of eight samples of lava and ejectamenta erupted during the 1970 activity are presented in Table II, together with some of their norms. Analyses 1, 4 and 8 were carried out at the Smithsonian Institution Washington by E. Jaroswich, the remainder at A.M.D.L. by A. Jorgenson.

The percentage oxides show little variation, and uniformity of composition throughout the whole group is obvious. Typically, SiO_2 is higher, and Na_2O, K_2O and MgO lower, in tholeiitic than in alkaline olivine basalts, and by comparing the analyses with those set out by Turner and Verhoogen (1966, p.208) the similarities with the tholeiitic types can be appreciated. The presence of normative quartz and high normative hypersthene in the Ulawun volcanics is also characteristic of tholeiites. The SiO_2 range of 51.51 - 52.90% is slightly higher than that of typical tholeiitic basalts. The Al_2O_3 content is also above average, but is similar to that of some basalts from Manam Island, where a considerable range in the Al_2O_3 content of the lavas is apparent (Morgan, 1966).

The Ulawun rocks, like those of the north coast volcanic islands (Blup Blup, Kadovar, Manam, Karkar, Bagabag and Long Island - Morgan, 1966) are rich in iron oxides. Lowder and Carmichael (1970) describe basalts from tne Talasea Peninsula which are chemically similar to the Ulawun rocks and which also contain modal pigeonite. As these authors point out, while such characteristics strongly suggest tholeiitic affinities, on the basis of Kuno's index the Talasea rocks could be considered as calc-alkaline. It is thus obvious that the distinctions between the two magma groups is not everywhere clearly defined.

Jakes and White (1969) compared the K_2O/Na_2O ratio of volcanic rocks from Papua and New Guinea with that of rocks from Japan, showing that the ratio increases from tholeiites through calc-alkaline to alkaline rocks. The K_2O/Na_2O ratio for the Ulawun basalts varies from 0.14 to 0.19 and is similar to that of Japanese tholeiites, both being lower than the figure quoted by Jakes and White for rocks from the north coast volcanic islands cited above. It would seem, therefore, that the volcanics of the New Guinea [redacted] arc complex, through from Blup Blup to the Gazelle Peninsula, form a somewhat varied suite.

Chemical Analyses and some C.I.P.W. norms of the eruptive rocks from Ulawun

Composition	Sp. No. 1	2	3	4	5	6	7	8
SiO_2	52.62	52.90	52.80	52.77	52.90	52.50	52.90	51.51
TiO_2	0.96	1.03	0.65	0.96	0.95	0.97	0.79	0.79
Al_2O_3	18.31	17.90	17.90	18.00	18.20	18.20	18.60	18.96
Fe_2O_3	3.23	2.85	2.75	2.99	4.15	2.55	3.55	2.72
FeO	6.81	7.00	7.30	7.14	5.95	7.50	6.70	7.50
MgO	4.94	4.90	5.15	4.98	4.90	5.15	4.50	4.92
CaO	10.45	10.00	9.90	10.48	9.85	9.85	10.10	11.14
MnO	0.14	0.09	0.09	0.14	0.09	0.09	0.09	0.16
Na_2O	2.40	2.25	2.30	2.29	2.20	2.35	2.20	2.24
K_2O	0.40	0.38	0.35	0.37	0.41	0.37	0.40	0.32
P_2O_5	0.08	0.10	0.09	0.08	0.09	0.09	0.08	0.07
H_2O	0.01	0.23	0.44	0.01	0.22	0.51	0.23	0.03
	100.35	99.63	99.72	100.21	99.91	100.13	99.94	100.36
Q	6.60			7.10				4.50
Or	2.36			2.19				1.89
Ab	20.31			19.38				18.96
An	38.01			37.74				40.74
Di	10.88			11.25				11.59
Hy	15.49			16.20				17.06
Mt	4.68			4.34				3.94
Il	1.82			1.82				1.50
Ap	0.19			0.19				0.16
	100.34			100.21				100.34

Specimens Analysed

1. Basalt lava - Flow nose, west of Ulawun.

2. Vesicular basalt lava - Flow nose, west of Ulawun.

3. Basalt lava - Flow nose, in the northwest valley.

4. Scoriaceous lava bomb - Nuée ardente deposits on western flanks.

5. Scoriaceous lava block - Nuée ardente deposits on western flanks.

6. Scoriaceous lava block - Nuée ardente deposits on western flanks.

7. Lava block (accessory) - Nuée ardente deposits on western flanks.

8. Lava block (accessory) - Nuée ardente deposits on western flanks.

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Jakes, P. and White, A.J.R.,	1969	Structure of the Melanesian arcs and correlations with distribution of magma types. Tectonophysics, 8, No. 3, 1969.
Lowder, G.G. and Carmichael, I.S.E.,	1970	The volcanoes and caldera of Talasea, New Britain: Geology and petrology. Geol. Soc. Am. Bull., 81, 1970.
Morgan, W.R.,	1966	A note on the petrology of some lava types from East New Guinea. J. Geol. Soc. Aust., 13, pt.2, 1966.
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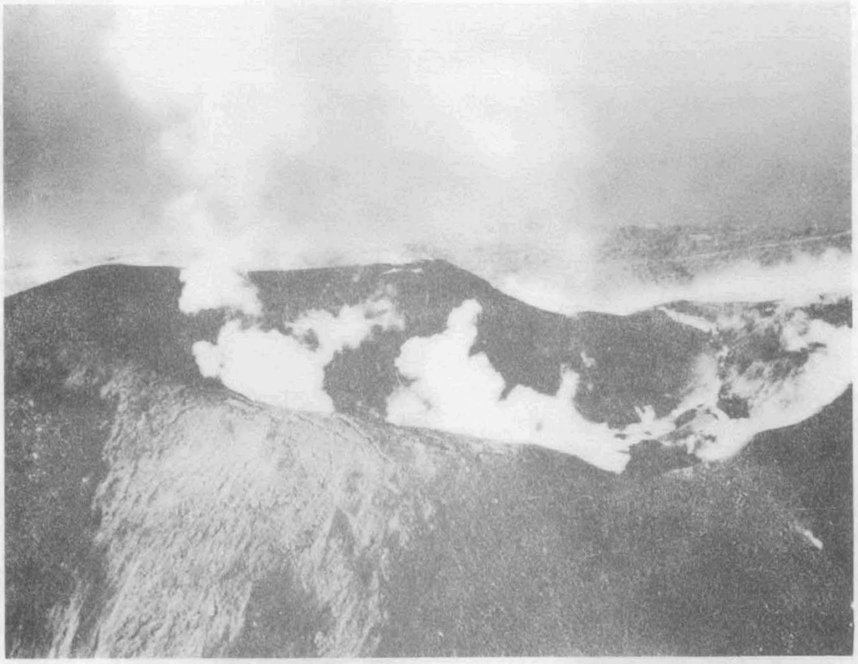
Port Moresby: V. P. Bloink, Government Printer.—B3547/12.70.

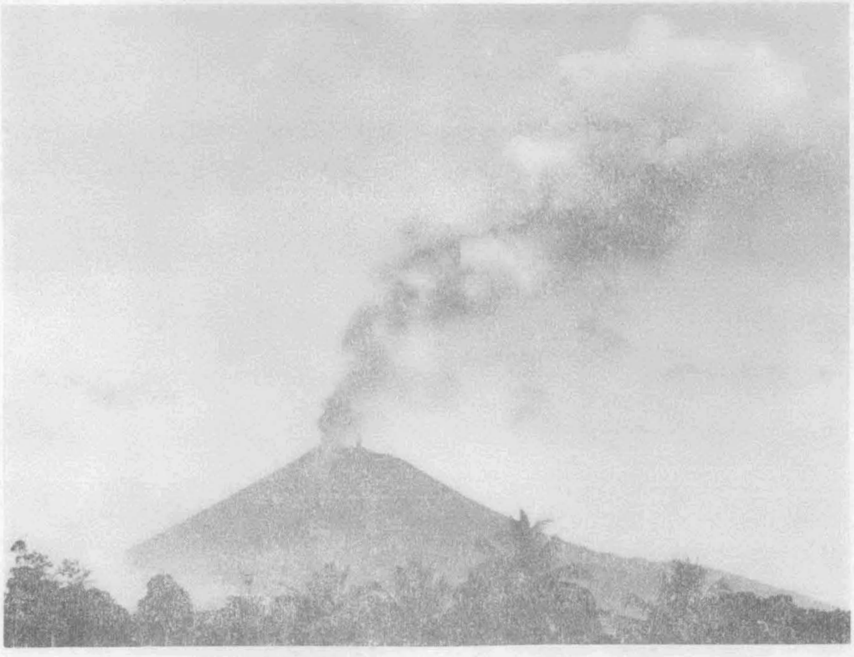
Fig. 1



View looking north.

The northeast WEST vents (close together) can be seen near the far rim of the broad crater. They sit above the northwest avalanche valley. Note the elongated depression cutting the near rim of the crater.

Fig. 2



View from Ulamona Mission.

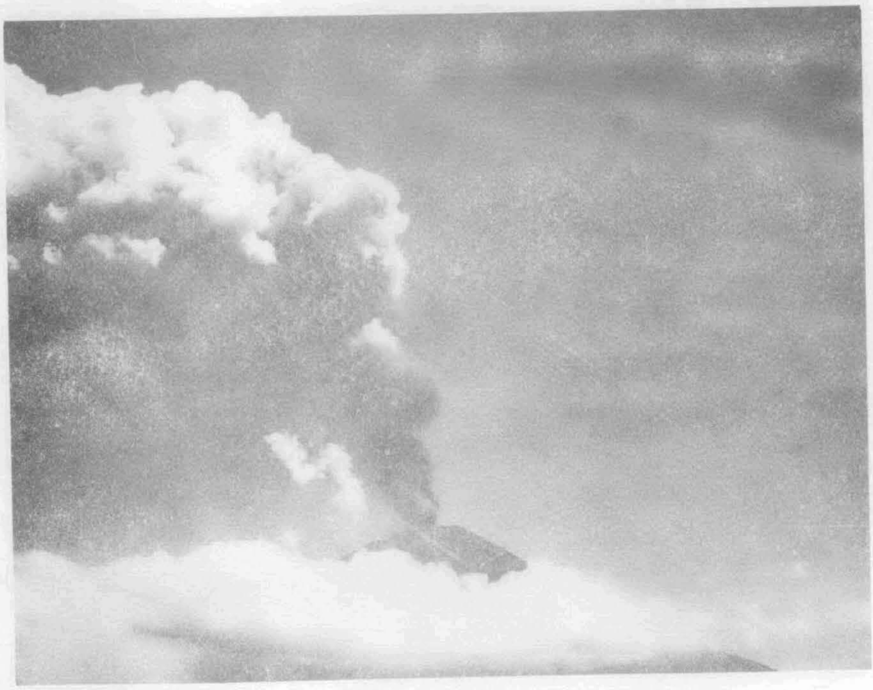
Strong activity from the northeast vent, producing much ash laden vapour. A small, dark, ash cloud to the right of the main column marks the site of the southwest vent.

Fig. 3

View from Ulamona Mission.

Lava descending the northwest valley from the northern vents. Vapour clouds obscure the spearheaded projections of lava from four vents.

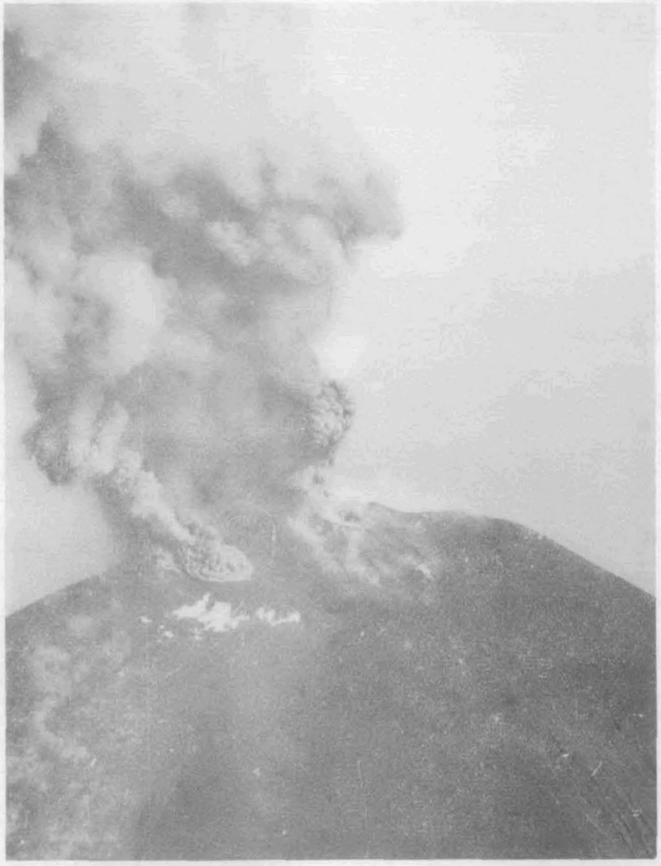
Fig. 4



View looking south.

Voluminous ash-laden vapour emission on 23rd January, observed during a period when the summit was clear of cloud.

Fig. 5



View looking northeast.

Strong activity from the northeast (on the right) and northwest vents, which by 25th January had formed large cones and infilled the northern sector of the crater. The small southwest vent is inactive, the fourth vent cannot be seen.

Fig. 6

View looking east into the caldera valley.

The two lava flows join in the foreground. The flow on the right has bifurcated on meeting a slight tographic 'high'.

Fig. 7

View looking northwest.

Strong activity from the northeast vent. To the left of the northeast cone is the upraised section of the crater floor and an incised channel marks one of the two lava flow descending the southern flanks of the volcano.

Fig. 8

A deep gully exposes four metres of ash flow deposit emplaced during the 1970 eruption (on the right). The ejecta on the left side of the gully forms part of the old valley wall.

Fig. 9

Ridge of well sorted ejecta on the ash flow deposit, emplaced by the nuee ardente.

Fig. 10

Accessory blocks of light coloured lava scattered over the surface of the ash-flow in the foreground. The dark coloured block which supports the onlooker is composed of essential lava.

Fig. 11

View of the ash-hurricane zone showing large numbers of uprooted trees. Several, broken trunks remain standing.

Fig. 12

Tree charred on one side only (facing the crater).

Fig. 13

Steam emission from the ash-flow deposit during a shower of rain.

Fig. 14

Dissected ash-flow deposit in the avalanche valley. The lighter coloured ejecta exposed was found to be at a temperature of 40°C sixteen days after emplacement.

Fig. 15

Inactive, secondary vent in the ash-flow deposit.

Fig. 16

Front of the aa flow west of Ulawun, illustrating the blocky and scoriaceous nature of the lava.

Fig. 17

Front of the aa flow west of Ulawun after movement had ceased. Steam still rises from the top surface of the flow.

PLATE 1

Location Of Population Centres Around Ulawun

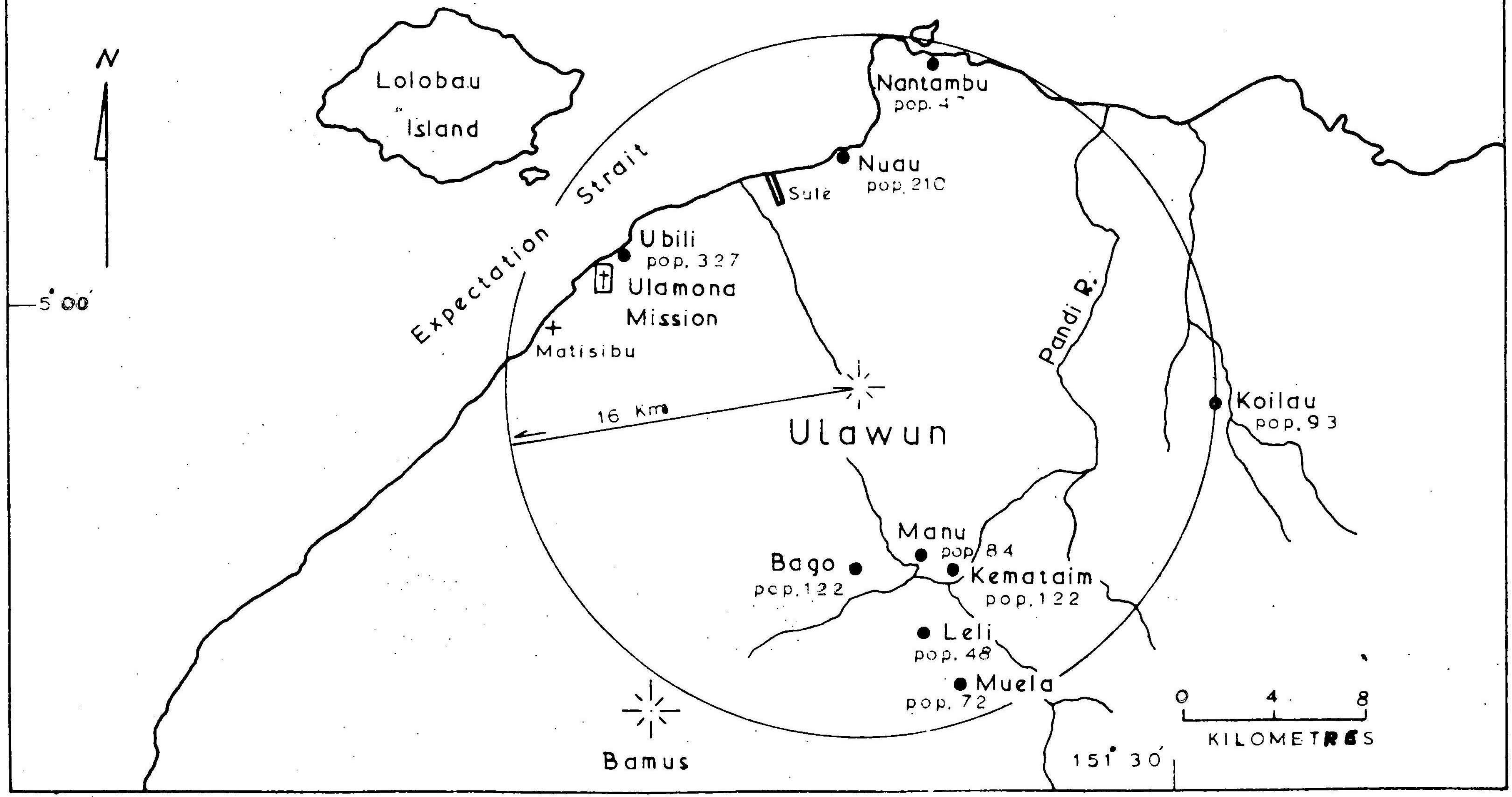
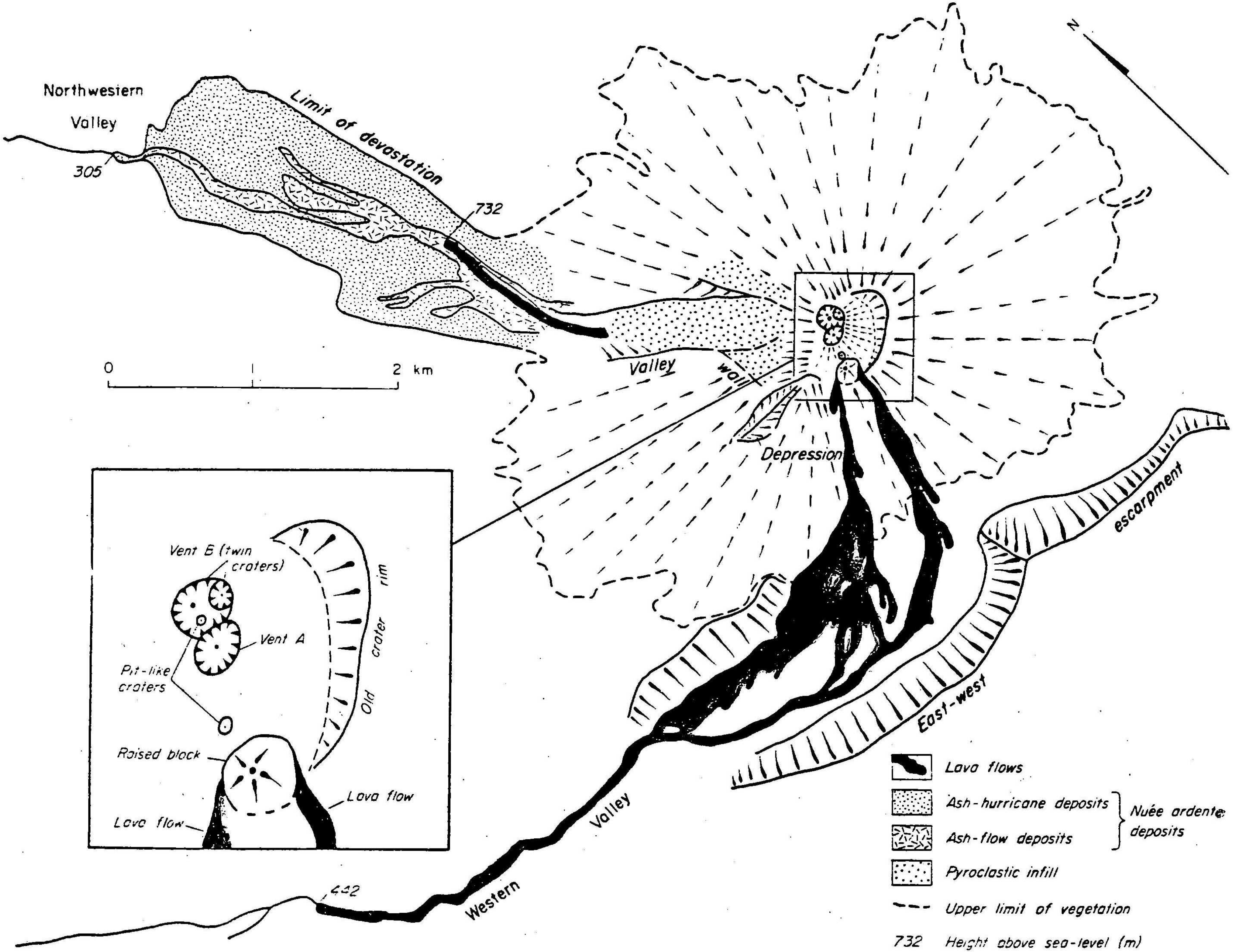
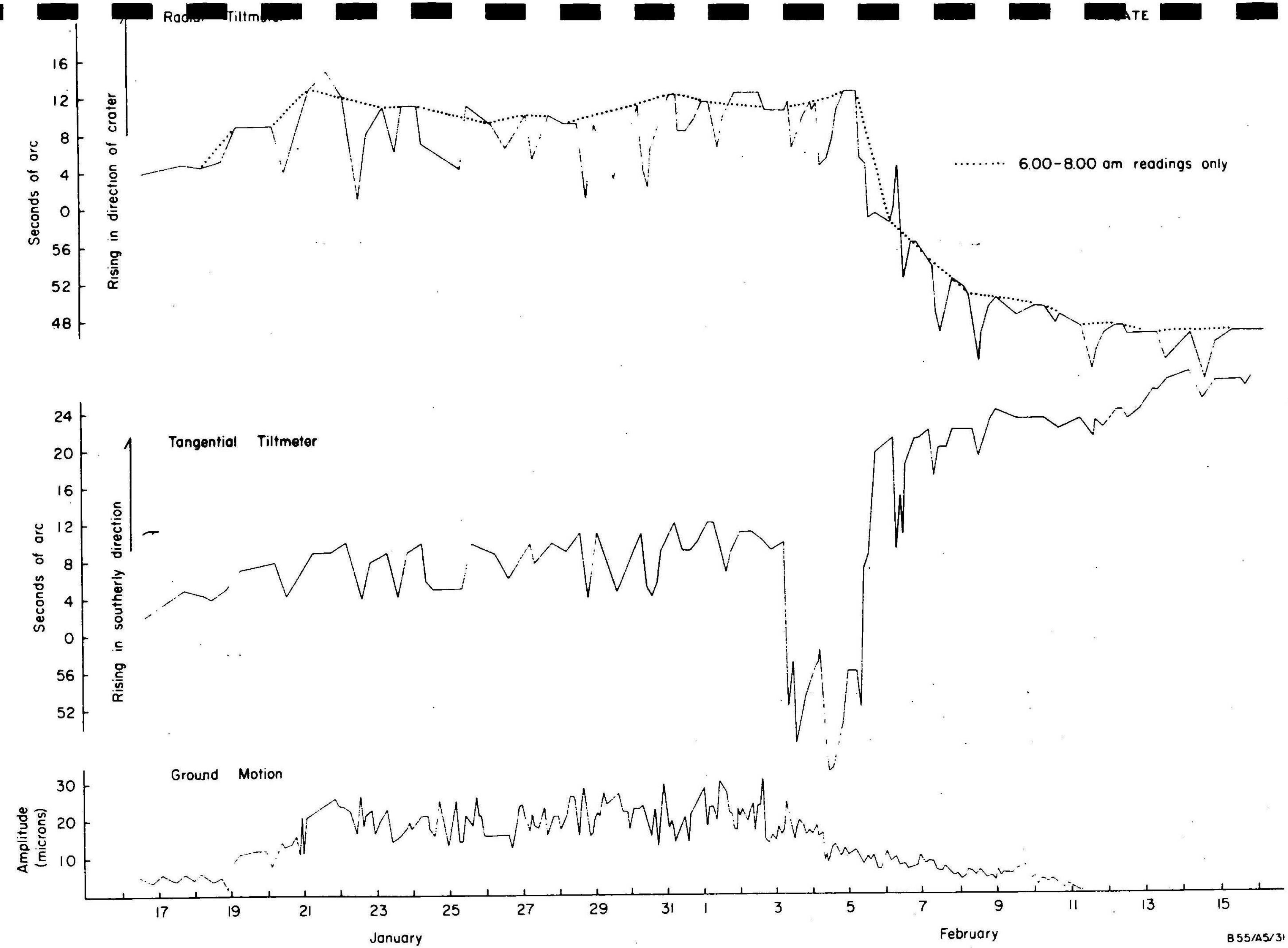


PLATE 2


Northwestern
Valley
305
Limit of devastation
732
N
0
1
2 km
Valley
wall
Depression
escarpment
East-west
Western
Valley
442
Vent B (twin
craters)
Vent A
Pit-like
craters
Old
crater
rim
Raised block
Lava flow
Lava flow
Lava flows
Ash-hurricane deposits
Ash-flow deposits
Nuée ardente
deposits
Pyroclastic infill
Upper limit of vegetation
732 Height above sea-level (m)


Seconds of arc
Rising in direction of crater
6.00-8.00 am readings only
Tangential Tiltmeter
Seconds of arc
Rising in southerly direction
Ground Motion
Amplitude (microns)
January
February
B55/A5/31