DEPARTMENT OF MINERALS AND ENERGY

GEOLOGICAL SURVEY OF PAPUA NEW GUINEA

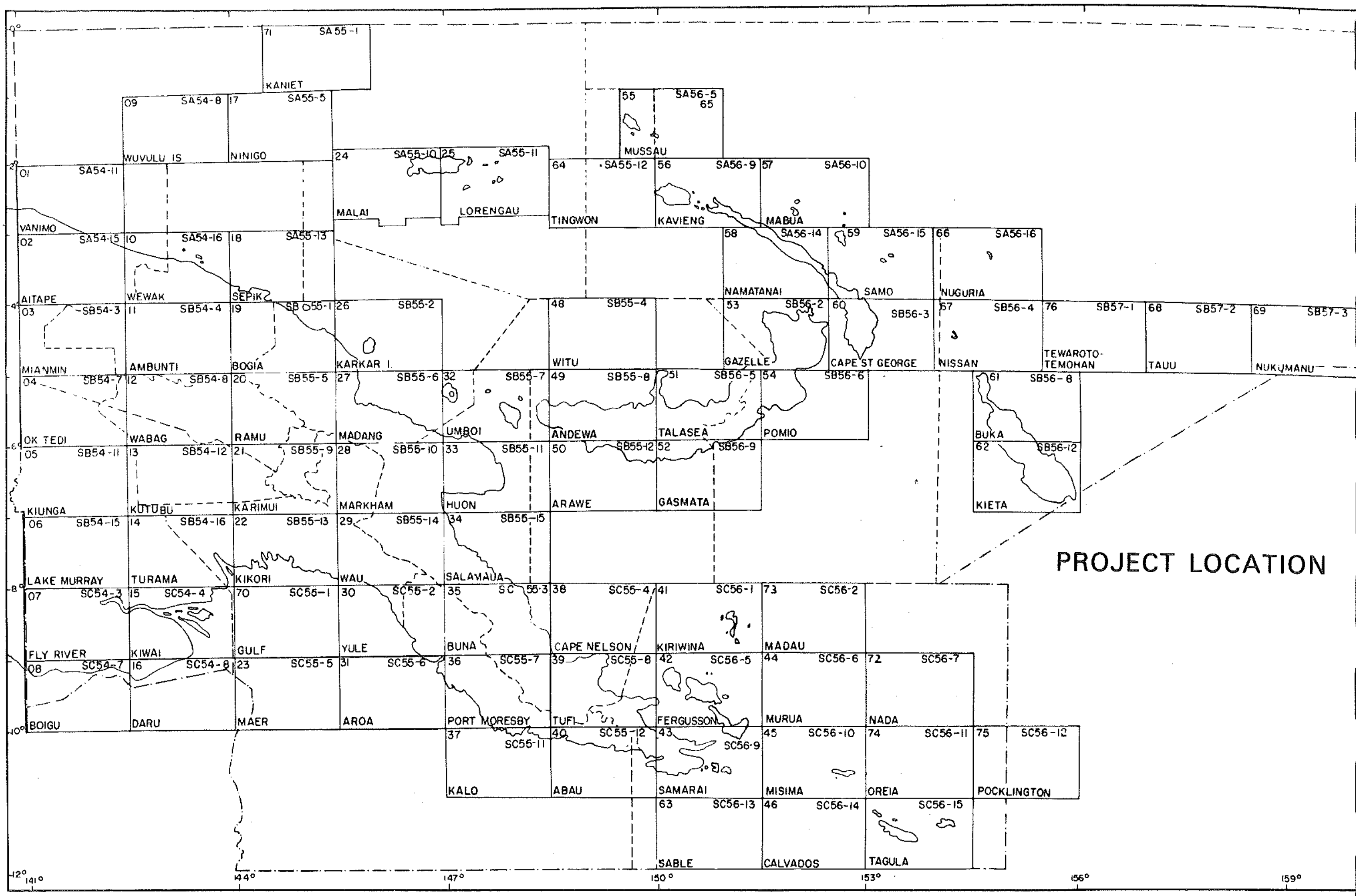
REPORT 83/13

VOLCANIC HAZARDS AT ULAWUN VOLCANO

by

C.O. McKee

August - 1983



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DISTRIBUTION OF GSPNG REPORT 83/13 'VOLCANIC HAZARDS AT ULAWUN VOLCANO'

Please find enclosed a copy of the above.

This report has been prepared to assist all those likely to be involved in pre-disaster preparedness planning for Mt Ulawun Volcano.

It presents an assessment of the volcanic hazards at Mt Ulawun and makes recommendations that will be of use in the event of future eruptions at Mt Ulawun.

Additional copies of this report are available and may be purchased from the Librarian, Geological Survey of Papua New Guinea Headquarters, P.O.Box 778, Port Moresby. Price K5-00 (Private) K4-00 (Government Departments and Statutory Authorities).

P. Lowenstein

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SUMMARY

Ulawun is one of the most active volcanoes in Papua New Guinea. It is also a very dangerous volcano, having produced pyroclastic flows, one of the most destructive kinds of eruptive activity, in each of its last four eruptions, in 1970, 1973, 1978 and 1980. Its eruptive history indicates that, on average, it erupts every 5-6 years, although eruptions since 1960 have occurred at about 3 year intervals.

The volcanic hazards which are most likely to be experienced at Ulawun include pyroclastic flows, lava flows, airfall tephra and mudflows. Other possible hazards are volcanic gases, flank eruptions and catastrophic structural collapse. Hazard maps showing areas likely to be affected by these hazards have been prepared. Areas subject to airfall tephra hazards are determined by prevailing winds, resulting in fan-shaped zones appropriate to this hazard on the eastern and western flanks of Ulawun. Flowage hazards (pyroclastic flows, lava flows and mudflows) will usually be confined to the main valley systems, but in very large eruptions other parts of the flanks of Ulawun may be affected out to a distance of 10-12 km. Areas likely to be affected by flank eruptions are confined to sectors of Ulawun's eastern and western flanks.

Various measures are suggested for the protection of lives and property during serious eruptions. Perhaps most important is the need for public awareness of the relevant volcanic hazards and the areas likely to be affected by them. From this knowledge proper pre-planning can be achieved to meet the needs of all volcanic emergencies.

VOLCANIC HAZARDS AT ULAWUN VOLCANO

1. INTRODUCTION

Ulawun, also known as the Father, is an imposing stratovolcano rising to abour 2300m a.s.l. (Fig. 1). It is the highest of all of the approximately 50 major volcanoes in the 1000 km-long Bismarck Volcanic Arc, which stretches from Rabaul to Wewak. Seen in profile from the north or south it has a regular conical shape, but viewed from the east or west a prominent escarpment on the southern flank of the volcano mars the symmetry.

Judging from the record of activity in the short period in which literate observers have made frequent sightings of Ulawun (since 1878), it appears to be one of the most active volcanoes in Papua New Guinea. Many of the early observations indicate mild explosive activity, but eruptions in 1898 and 1915 were much stronger, and strong eruptions in the 1970's and 1980 included important phases of pyroclastic flows (of hot fragmental material) and lava flows.

The recognition of Ulawun as a very active volcano capable of producing one of the most destructive kinds of volcanic activity (i.e. pyroclastic flows), has led to it being assigned a high danger score (Lowenstein, 1982). Fortunately, there is a relatively small population living near the volcano, a factor which tends to limit the hazard rating.

This report describes the individual volanic hazards relevant to Ulawun and includes maps defining areas subject to these hazards. These hazard maps should be considered preliminary and may require modification as more information on Ulawun becomes available. A simplified hazard map has been prepared for quick reference (Fig. 2). Recommendations for protection of the communities near from the effects of volcanic eruptions are also made.

2. TOPOGRAPHY, GEOLOGY AND STRUCTURE

The following account of the topography, geology and structure of Ulawun is based on the work of Johnson et al., (1972). An accurate topographic map of Ulawun is available from Department of Lands, Surveys & Environment (Papua New Guinea 1:100,000 Topographic Survey, Sheet 9188 (Edition 1), Series T601).

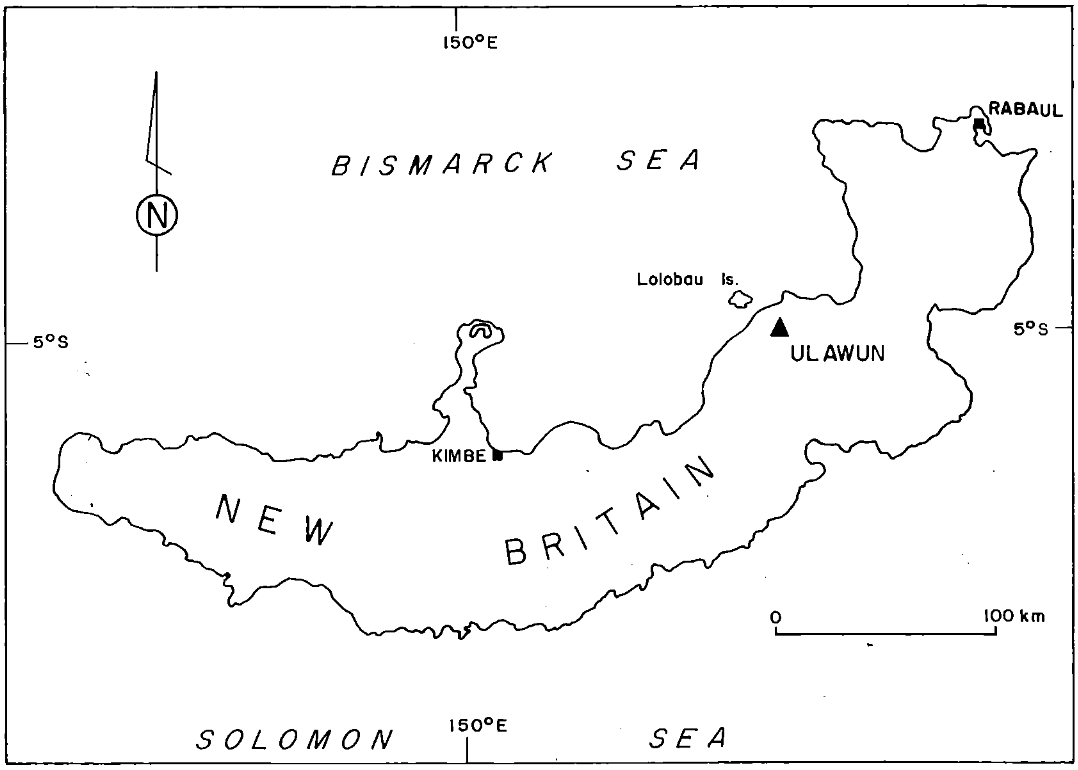

Fig. 1 Locality map of Ulawun Volcano in east - central New Britain Island.

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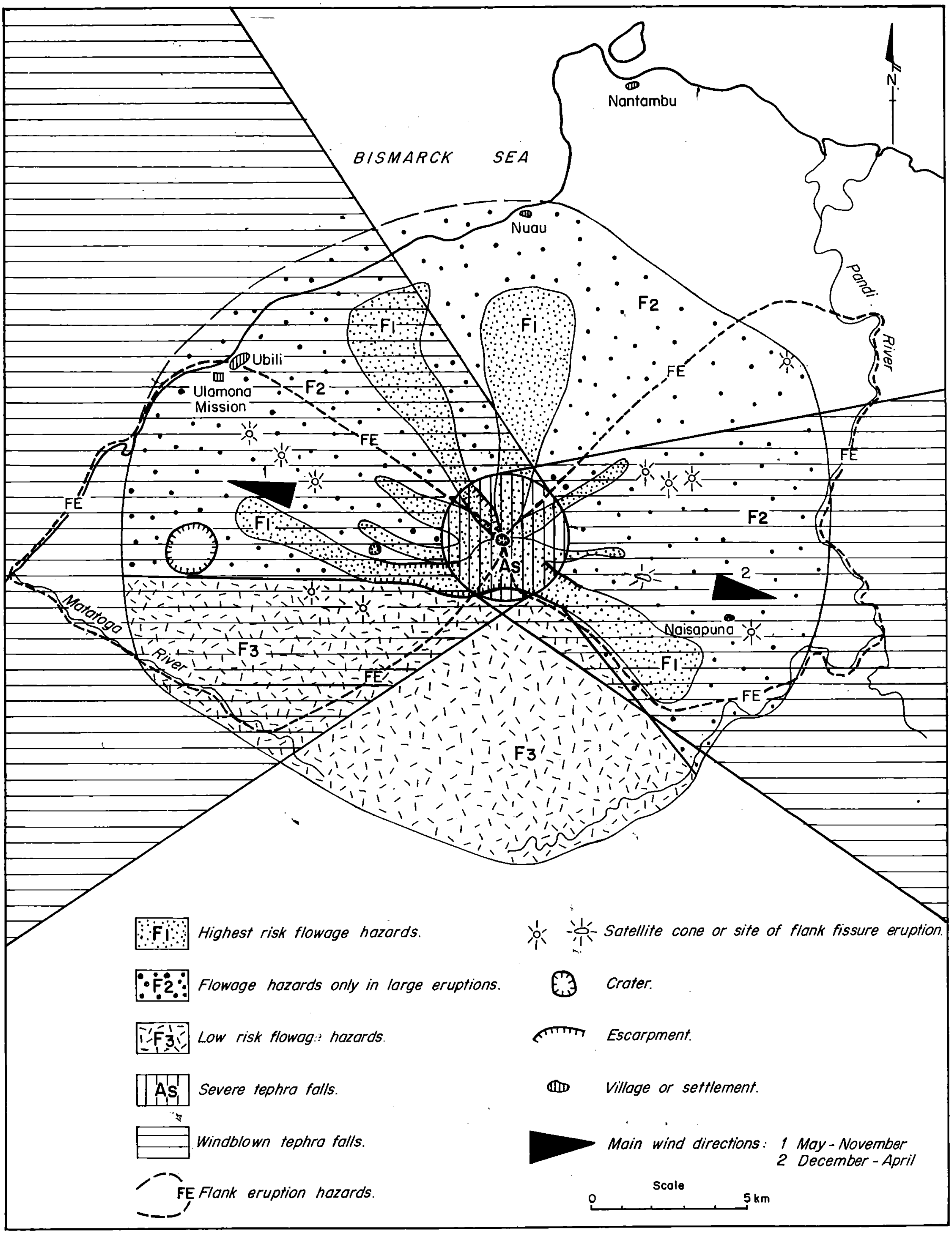

Fig. 2. Simplified volcanic hazards map of Ulawun Volcano. The areas shown here as subject to falls of windblown tephra are defined by the combined directions of lower-and upper-atmosphere winds. No allowance has been made here for the effects of wind shear.

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At the 200m contour line, the area of Ulawun is about 200 km^2. It is slightly elliptical in plan, measuring 18 km from northeast to southwest and 15 km from northwest to southeast. The height of the summit is given as 2334m above sea level on Topo. Survey Sheet 9188, but two eruptions since the production of this map have probably altered the volcano's height. A prominent north-facing escarpment is present on the southern flank of the volcano. This cliff reaches a maximum height of about 160m above the volcano's slopes immediately to the north, and its highest point is about 1715m above sea level. It is completely forested, although products from the 1980 eruption destroyed some vegetation on the cliff-face and at the apex of the ridge. Elsewhere on Ulawun, forest covers the lower slopes up to 1000-1450m a.s.l. Above this level the slopes are covered with tephra (fragmental lava), and are more or less free of vegetation. In general, there is relatively little erosive dissection of Ulawun, which is an expression of its high level of activity, the edifice frequently experiencing the addition of new veneers of eruptive products. However, prominent valleys exist on the northwestern and western flanks.

Exposures in the main valleys show that Ulawun is a strato-volcano composed of numerous thin lava flows and interbedded tephra of basaltic and low-silica andesitic composition (see Section 4). Massive, unsorted clastic layers are probably products of pyroclastic flows. A prominent fan of lava flows on the southern side of the northwestern valley indicates that this flank of the volcano has received much of the effusive products of eruptions in probably the last few hundred years. Eruptions at Ulawun have originated from a central vent whose position has changed little throughout Ulawun's history. The escarpment on the southern flank indicates collapse of the summit, but later eruptions continued from a central vent producing a younger cone whose products are conformable with those of the older parts of the volcano on its western, northern and eastern sides.

Satellite cones and craters are present on the eastern and western flanks. The volume of products erupted from these vents is insignificant compared with that from the central vent, probably less than 1% of the volume of the edifice. Several lineations of satellite vents indicate that radial fractures of Ulawun have been exploited. The group of three centres immediately south of Ulamona Catholic Mission define a radial fissure from which lava flowed to the coast forming the headland immediately southwest of Ulamona. The 1978 eruption included flank fissure activity on the eastern side of Ulawun which resulted in the emplacement of a 6 km-long lava flow.

Ulawun's summit has undergone marked changes as a result of successive eruptions. After the 1980 eruption a single terminal crater was present having a diameter of about 150m. At present the rim has a fairly uniform height, although a slight depression exists at the head of the northwest valley. A gully is present on the upper southeastern flank but its head is slightly below the crater rim. Continued erosion or renewed eruptions may cause the removal of this headwall. The identification of low points in a crater rim is often critical in determining the pathways of future pyroclastic flows.

3. ERUPTIVE HISTORY

Ulawun's known recorded history is presented in Table 1. The earliest recorded eruption of Ulawun was one in 1700, when explosions at the summit were observed (Dampier, 1906). Ulawun was apparently not seen again by literate observers for another 178 years. From 1878 onwards, there were at least 15 and possibly up to 18 eruptions (Cooke, 1981; Johnson et al., 1972). Most of these eruptions were apparently mild explosive events. However, an eruption in 1898 generated pyroclastic flows which devastated the northern slope of the volcano, and the eruption in 1915 produced large quantities of airfall ash which caused the collapse of houses around the foot of Ulawun and deposited 5-10cm of ash at Toriu, about 50 km northeast of Ulawun's summit. Between 1915 and 1967, eruptions at Ulawun were unremarkable explosive events.

The 1970 eruption was the first of four consecutive eruptions of increased violence in a ten year period up to 1980. The 1970, 1973 and 1978 eruptions (Cooke et al., 1976; McKee et al., 1981) included powerful summit explosive activity, an important component of which was phases of pyroclastic flow generation. In addition, lava flows were emplaced, from summit vents in 1970 and 1973, and from a flank fissure in 1978. The 1980 eruption was particularly strong projecting eruptive products to an altitude of about 20km and forming pyroclastic flows which swept down all flanks of the volcano and destroyed an

TABLE 1

Date	Explosions	Pyroclastic flows	Lava flows	Remarks
1700	*			
1878	*			
1898	*	*		Pyroclastic flows advanced to N base of Ulawun.
1912	?			
1915 (April)	*			Very strong eruption. 5-10cm ash at Toriu (50km NE of Ulawun). Houses at base of Ulawun collapsed under weight of ash.
1918 (July)	*			
1919 (May)	*			
1927 (July, Sept.)	*			
1937	?			
1941 (Jan.)	*			
1951	?			
1957-58 (Dec.-Mar.)	*			
1960-62 (Aug.-Nov.)	*			Intermittent explosions.
1963 (Mar.-May)	*			Intermittent explosions. Ashfall at Ulamona.
1967 (Jan.-Dec.)	*			Intermittent explosions, peak in Jan. 10-12mm ash at Ulamona. Ashfall at Lolobau.

Table 1 - continued

Date	Explosions	Pyroclastic Flows	Lava flows	Remarks
1970 (Jan.-Feb.)	*	*	*	Pyroclastic flows 5km long on NW flank, 2km long on S flank-area affected 5km^2. 8 million m^3 of lava flows in NW and W valleys.
1973 (Oct.)	*	*	*	Pyroclastic flows 3km long in W valley-are affected 2km^2. 10 million m^3 of lava flows in W and E valleys.
1978 (May)	*	*	*	Pyroclastic flow 7km long on SE flank-area affected 7km^2. 9 million m^3 of lava flow on E flank from fissure source.
1980 (Oct.)	*	*	*	Extremely powerful explosions sent ash to 20km altitude. Pyroclastic flows up to 8km long down all flank-area affected 20km^2.

area of about 20 km^2. A disturbing feature of the last three eruptions is that the size of the pyroclastic flows and areas devastated has increased with each successive eruption.

On the 15 definite eruptions since 1878, 5 have definitely produced pyroclastic flows. The indicates that there is a 33% chance of a pyroclastic flow being produced in an Ulawun eruption. However 4 of the 5 eruptions producing pyroclastic flows, have occurred recently (since 1970), and this may indicate that the chance of the next eruption producing pyroclastic flows may be significantly higher than 33%.

4. VOLCANIC HAZARDS AT ULAWUN

The nature of future eruptions of Ulawun and the attendant volcanic hazards will depend to a large extent on the type of molten rock (lava) involved. The most abundant constituent of volcanic rocks is silica (SiO_2) and the proportion of silica in lava determines certain physical characteristics. Volcanic rocks of low silica content ($<$53%) are termed basic, and are usually relatively fluid when hot, and the gases dissolved in these lavas tend to be released with lower explosive power than silica-rich rocks. One of the most common rocks of this type, and in fact the most common of all volcanic rocks, is basalt. A large proportion of basalt is erupted in the form of lava flows.

As silica content increases in lavas they become less fluid and gas pressures can reach higher levels. Lavas of intermediate composition have silica contents ranging between 53% and about 73%; the most common intermediate volcanic rock types produced are andesite and dacite. Lavas with silica contents greater than 73% can be referred to as acidic; rhyolite is the name given to the most common acidic volcanic rock.

Lavas of intermediate and acidic composition generally pose a greater threat because of the possibility of strong explosiions of trapped gases. The lavas can be erupted as coherent flows or domes of massive lava, but they are commonly erupted as pyroclastic flows which originate from the shattering by explosions of a body of lava. However, the generation of relatively small pyroclastic flows at the largely basaltic Papua New Guinean volcanoes Ulawun and Manam, clearly demonstrates that the formation of pyroclastic flows is an activity not restricted to volcanoes producing intermediate and acidic lavas.

The volcanic hazards which apply at Ulawun include pyroclastic flows, lava flows and mudflows (collectively referred to as "flowage" hazards), airfall tephra and volcanic gases. Also, the potential for flank eruptions, which involve the hazards of lava flows, airfall tephra and volcanic gases, must be considered. A somewhat unlikely hazard, that of catastrophic structural collapse, is mentioned in order to illustrate the full potential of the volcano.

(i) Pyroclastic flows

Pyroclastic flows are mobile masses of hot, dry lava fragments mixed with hot gases. They may be produced by direct outflow from a vent onto a volcano's flanks, by collapse of a Plinian eruption column or other dense eruption cloud over a vent, by explosions at a lava dome, and by avalanching of unstable parts of lava domes and lava flows. Pyroclastic flows usually have two components; a basal flow of hot coarse tephra which travels over the ground and is cushioned by hot gases, and an overriding cloud of gases and fine tephra at high temperatures (several hundred ^{o}C). The speed and distance of travel of pyroclastic flows is determined largely by the steepness of the slopes on which they are travelling and the actual volume of material in the flow. Under favourable conditions they can travel at speeds of 50 to more than 150 km/hour, and may reach distances greater than 10 km from their sources.

Topography around volcanoes influences the path of pyroclastic flows. The coarse basal component tends to be guided by topographic lows such as river valleys, but the accompanying cloud of gases and fine tephra may spread laterally to some extent.

The main dangers from pyroclastic flows are that the basal rocky component can bury and incinerate people and objects in its path, and that the cloud of hot gases and fine tephra can cause asphyxiation, burning of the lungs by hot dust or gases, and burning of the skin. Additionally, tephra carried in the clouds may cause injury, and both impact and heat can damage property.

(ii) Lava Flows

The eruption of hot, relatively fluid lava forms lava flows; lava flows move downslope away from their source vents until the lava cools and solidifies. Lava flows are usually slow-moving, flow fronts advancing at rates ranging from barely perceptible to about as fast as a person can walk, so there is little danger of being overtaken by one. However, their high temperatue and great mass renders then a threat to buildings and vegetation in their path by burial, smashing and burning, and they can block and obliterate roads.

(iii) Mudflows

Mudflows are generated when a mass of water-saturated rock debris or tephra is mobilized and moves downslope under the influence of gravity. They behave like fluids and follow valleys and other topographical low features. Their distance of travel is governed by the steepness of slope, the degree of fluidity, and the volume of material, and their speed is determined by the first two factors. They are capable of high speeds (reportedly up to 85 km/h) on steep slopes. Their destructive powers are similar to those of lava flows in that they obliterate pre-existing land surfaces, and bury, smash and remove buildings. The dangers to humans and animals are burial, impact of large boulders carried in mudflows, and burning if the rock debris in the mudflows is hot.

(iv) Airfall tephra

Tephra (or volcanic ash) is the name given to fragmental material ranging from fine dust to large blocks which is ejected into the air above a vent, eventually falling back to Earth. Tephra is produced in most eruptions and is probably the most widespread volcanic hazard. Tephra-producing phases of eruptions range from continuous jets of fragment-laden gas that persist for several hours, to explosions that last only a few seconds. Most explosions from craters are directed upwards, but some are oblique. The eruptions that produce tephra grade into and include ones that produce pyroclastic flows.

Eruptions often start with explosions of tephra. Usually the rate of tephra production is low at first, but it may quickly increase (within hours or days).

The distribution of tephra around a volcano depends on the height to which it is ejected, the strength and direction of prevailing winds, and the size and density of the fragements. Large tephra fall close to the source but fine dust may be transported hundreds (even thousands) of kilometres away. However, in many cases, the effects of tephra at distances greater than about

25 km will amount to maintenance and clean-up problems rather than present direct hazards. The following passage, derived from 'Potential Hazards from Future Eruptions of Mount St. Helens Volcano, Washington,' USGS Bulletin 1383-C 1978, by D.R. Crandell and D.R. Mullineaux, comprehensively describes the hazards of tephra:

> "Tephra endangers lives and property by the impact of flying fragments, by forming a blanket covering the ground surface, by producing a suspension of fine particles in air and water, by carrying acids, and, close to the vent, by its heat. People can be injured by falling fragments, by breathing tephra-contaminated air, by collapse of tephra-laden roofs, and by fires started by hot fragments. Tephra eruptions can also result in psychological stresses by blocking roads and causing people to be isolated, by causing darkness during daylight hours, by increasing acidity and turbidity in exposed water supplies, and by interrupting, telephone, radio and electrical services. Exposure to one or more of these stresses may lead to panic even though an individual's health or life is not directly endangered. Damage to property results largely from the weight of tephra, especially if it becomes water-soaked, from its smothering effect, from abrasion, and from corrosion. Machinery is especially susceptible to the last two effects. The health and economic welfare of people in the fallout area can also be radically affected by the destruction of or damage to food crops and domesticated animals".

An indirect hazard associated with tephra eruptions is lightning in electrically-charged eruption clouds. This phenomenon can be a threat to life and property, can damage power lines, and severely interrupts communications.

(v) Volcanic Gases

Volcanic gas emanations are common even when volcanoes are not erupting. Although the main component of volcanic gas emissions is usually water vapour other gas species can endanger life and property. The main dangers to health and life result from the effects of acid and ammonia compounds on eyes and respiratory systems. Dense gases can collect in local basins to suffocate and poison people and animals. Toxic gases can harm plants and can poison animals that eat the plants. Gases can be corrosive to metal and the small amounts of gases which condense on tephra particles can cause the tephra deposits to be corrosive. Gas emissions can be concentrated near a vent, but are quickly dispersed and diluted by winds.

(vi) Flank Eruptions

A total of 13 satellite volcanic centres have been recognized on the eastern and western flanks of Ulawun. While flank eruptions are generally short-lived and considerably smaller in magnitude than eruptions at the central vent, the danger from the attendant hazards is increased because of the closer proximity of the eruptive source to inhabited areas. The hazards associated with flank eruptions are airfall tephra, volcanic gases and lava flows. An important feature of satellite volcanoes is that they are monogenetic i.e. they erupt only once, at the time of their creation. However, the region in which they form remains active, and new satellite centres could develop elsewhere on the same flank of the central volcano.

The only flank eruptions which have been witnessed at Ulawun took place in 1978 (McKee et al., 1981). One source of flank eruption was a 500m - long fissure about 500m above sea level on Ulawun's eastern flank. Residents of a small village, Naisapuna, about 4 km downslope did not report any unusual observations in this location before the outbreak of the flank eruption. Fountaining and non-explosive effusion of lava continued for several days along the fissure, producing a 6 km-long lava flow having a volume of about 9 million m^3. The lava flow passed within a few tens of metres of the village but presented no direct threat to life or property in the village.

A second source of flank eruption in 1978 was a fissure high on the southeastern flank of the volcano. This fissure appeared to be a briefly - active source of flowing lava on the first day of the eruption. The fissure may also have been the source of the 7 km-long pyroclastic flow which swept down the southeastern flank of the volcano. This is a special case of flank eruption because, in contrast to most flank sources, which are located on the lower slopes of volcanoes, this source was located only a few hundred metres downslope from the summit crater. It could be argued that this is a sub-terminal source, rather than a true flank source, owing its formation to a splitting of the crater wall.

Most of the satellite volcanoes on Ulawun were sites of explosive activity which resulted in the erection of tephra cones or in the formation of craters. In the immediate vincinity of volcanoes such as these, the most serious hazard is airfall tephra. Heavy, hot blocks and other hot tephra may be projected to distances of about 2 km, and beyond this, falls of lighter tephra will be experienced in a similar way to airfall tephra from a central vent eruption. In addition, volcanic gases may be emitted in large volumes before and during eruptions from satellite volcanoes. All things considered, a minimum separation distance of 2 km from the site of a satellite volcanic eruption should be maintained to avoid possible falls of tephra and the effects of highly concentrated volcanic gases near the vent. Valleys downslope from satellite volcanoes are potential channels for lava flows.

(vii) Catastrophic Structural Collapse

Catastrophic structural collapse of the summit or of a sector of Ulawun would be a truly major eruption and would result in total devastation within a radius of up to several tens of kilometres by deposition of large quantities of airfall tephra and by massive pyroclastic flows. Two modes of catastrophic structural collapse are envisaged (Johnson et al., 1983), viz. (i) caldera collapse, caused by a shallowing of the magma reservoir ceiling causing a loss of support of the volcano's summit which subsequently subsides, and (ii) gravitational sliding, in which the volcanic edifice becomes overgrown and oversteepened leading to instability culminating in major slumping of the volcano's flanks.

At present, there is no evidence for imminent caldera collapse at Ulawun. However, the formation of calderas has occurred at at least ten of the other volcanoes in the Bismarck Arc, indicating a general possibility of future caldera collapse at Ulawun.

The chances of gravitational sliding appear significantly higher, as indicated by, (i) the present large size of the edifice and the prospect of further growth to approach the threshold of gravitational stability, (ii) a recent trend of increasing violence of eruptions which may be contributing to weakening of the edifice, and (iii) recent eruptions from the volcano's flanks indicating the presence of fractures in the edifice.

At present, Ulawun and its neighbour Bamus are more than 400m higher than all other volcanoes in the Bismarck Arc. The threshold of gravitational stability for stratovolcanoes in the Bismarck Arc is unknown, but a number of them show features signifying catastrophic collapse possibly due to gravitational sliding. Both Ulawun and Bamus appear to have undergone previous episodes of such collapse, shown at Ulawun by the prominent escarpment on its southern flank. Re-construction of these volcanoes is now well advanced, and both could be approaching a condition of overgrowth and oversteepening.

Ulawun's eruptive history indicates that paroxysmal explosive activity (generating pyroclastic flows) is not uncommon. However, the frequency of such eruptions since 1970 is much higher than the average frequency. This may be a short-term fluctuation or part of a longer-term progression towards stronger explosive activity. Each successive, strong explosive eruption imposes new strains on the volcanic edifice.

An indication of weakening of the edifice was given during the 1978 eruption when fissures opened low on the eastern and high on the southeastern flanks of Ulawun. The great internal stresses set up by the pressure of lava within the volcano caused the opening of the fissures. After this eruption it was considered that the volcanic edifice may have been sufficiently weakened for future eruptions to also exploit radial fissures and to possibly culminate in foundering of a sector of the volcano. However, the succeeding (1980) eruption was contained entirely by the central summit vent. The brevity of this eruption and an evidently clear central conduit may have prevented the opening of new flank fissures.

It is not possible to numerically determine the chances of the next eruption involving catastrophic structural collapse because no information is available on dates of previous collapses at Ulawun. While this kind of event is rare in the life-time of a volcano, the possibility of another collapse at Ulawun is not insignificant.

5. HAZARD ZONES

In mapping the volcanic hazards associated with Ulawun it has been found necessary to prepare separate maps to show areas subject to airfall tephra hazards (the fall of airborne tephra) and areas subject to flowage hazards (pyroclastic flows, lava flows and mudflows). A hazards zone appropriate to flank eruptions has been included on the flowage hazards map. A simplified hazards map has been prepared (Fig. 2) for quick reference. The details of the mapping of the hazards are shown on the larger-scale maps (Figs. 5 & 6).

(i) Airfall Tephra Hazard Zones

The distribution of airfall tephra will depend on the location of the source, the height to which the tephra is ejected, the strength and direction of prevailing winds, and the size and density of the tephra fragments. The most important of these factors are probably the strength and direction of prevailing winds and the height to which the tephra is ejected. In New Britain seasonally variable winds are experienced at elevations from surface level to about 4 km altitude, but above 4 km a reasonably steady air-flow from east to west prevails (McAlpine et al., 1975). Wind data considered here are for Rabaul which is the nearest meteorological station.

The low level wind system consists of winds from the southeast during the period May to October/November (southeast trade winds) and winds from the northwest during the monsoon from December to March/April. The low-level wind rose (Fig. 3) shows the percentage of time annually that winds blow to 16 sectors of the compass. The wind speeds for each sector are typically low to moderate having a maximum value of about 11 knots. It is seen that the dominant direction to which winds blow is approximately northwest.

Winds above about 4 km altitude blow predominantly towards the west (Fig. 4). Wind speeds are much higher than those applicable at low altitudes, with a maximum value of about 29 knots.

The determination of airfall tephra hazard boundaries (Fig. 5) is based on the assumption that eruptions will be focused at the summit of Ulawun. The first airfall tephra hazard zone (As) is the area around the summit crater, which is devoid of vegetation. This lack of vegetation and experience of observing some of the historical eruptions indicates that heavy tephra fragments ejected on ballistic trajectories fall around the summit crater at distances up to about 2 km. This area receives tephra falls in every eruption and distribution is affected only slightly by the speed and direction of prevailing winds.

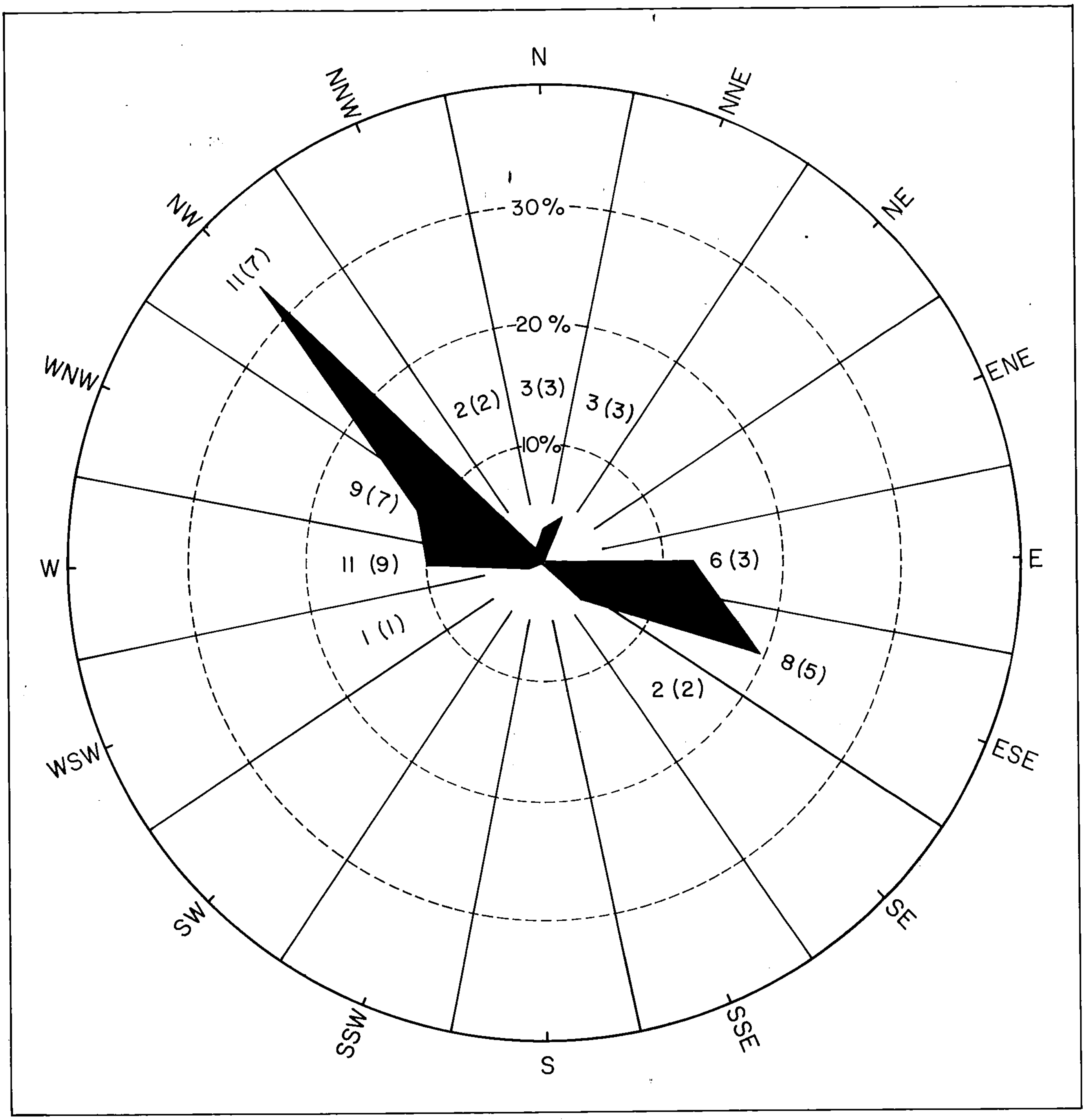

Fig. 3 Low level wind rose showing approximate percentage of time, annually, that winds from surface to 3·1km above sea level blow toward 16 sectors of the compass. Percentages, indicated by length of solid patterns at the axis of each sector, are rounded averages of monthly vector mean winds determined at standard pressure levels from surface to 3·1km above sea level (McAlpine et. al., 1975) Wind observations were recorded at 0900 hours local time (2300 UT). Figures in each sector are maximum wind velocities followed by average wind velocities in brackets, both values expressed in knots.

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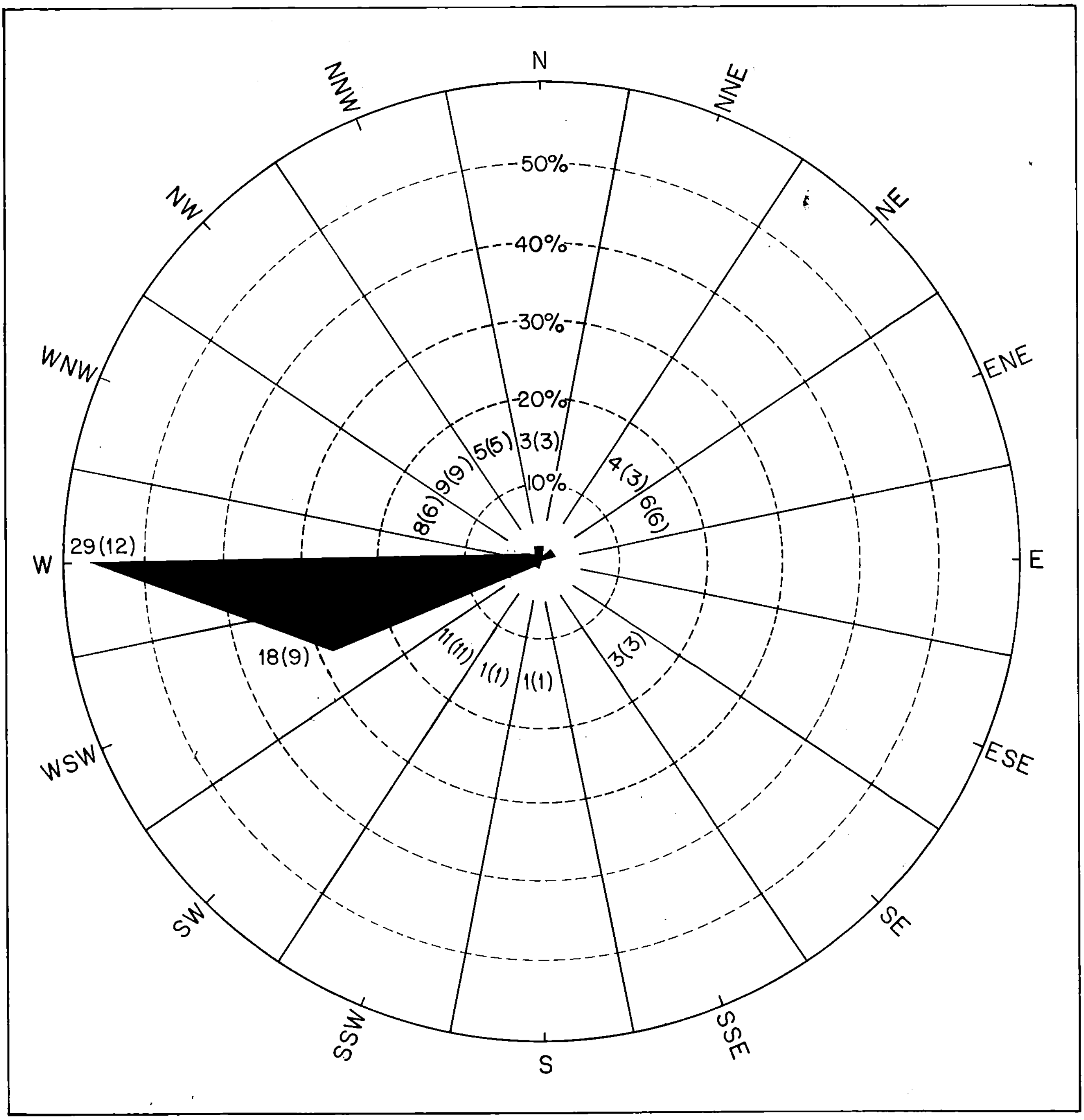

Fig. 4 Upper level wind rose showing approximate percentage of time, annually, that winds from 4·4km to 17·8km above sea level blow toward 16 sectors of the compass. Percentages, indicated by length of solid pattern at the axis of each sector, are rounded averages of monthly vector mean winds determined at standard pressure levels from 4·4km to 17·8km above sea level (McAlpine et. al., 1975). Wind observations were recorded at 0900 hours local time (2300 UT). Figures in each sector are maximum wind velocities followed by average wind velocities in brackets, both values expressed in knots.

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Outside this central hazard area , zones of relative hazard, forming fan-shaped areas, have been constructed on the basis of wind data to an altitude of about 18 km (the highest eruption column produced in historical eruptions of Ulawun was about 20 km in 1980). The severity of hazard decreases progressively with distance downwind from the source i.e. hazard decreases from the inner side to the outer side of each successive concentric zone. The construction of the hazard zones surrounding zone A_S takes into account the dispersing effect of the prevailing seasonal winds. These zones (A , B , C) have two fan-shaped segments whose axes are parallel with the directions of the seasonal winds. The radial boundaries of zone A were determined from the combined effects of the wind roses (Fig. 3, 4). These boundaries are oriented on trends of 258^{o} and 326^{o} for the western part of the zone, and on trends of 79^{o} and 124^{o} for the eastern segment. The sectors enclosed by these lines include 95% of wind directions in the season of the southeast trade winds and 87% of wind directions during the monsoon season. The radial boundaries of zone B diverge by 15^{o} from the radial boundaries of zone A - a feature designed to account for the effects of wind shear. In turn, the radial boundaries of zone C diverge by 15^{o} from the radial boundaries of zone B, thus acting as an additional allowance for the effects of wind shear.

The arcuate boundaries separating zones A, B and C were chosen by considering the tephra distribution in eruptions since 1970. The joint boundary of zones A and B lies at a distance where tephra deposits may be expected to be about 20cm thick, and at the joint boundary of zones B and C, tephra thickness can be expected to be about 5cm. It is felt that tephra thicknesses of greater than 20cm present a serious hazard (zone A) and tephra thicknesses of 20-5cm are considered a high-moderate hazard (zone B). Tephra thickness of less than 5cm constitute a moderate-low hazard (zone C), and the outer limits of this zone would be set at points where tephra thickness fell to 1cm. Insufficient data is available to confidently define the outer boundary of this zone, however.

It should be noted that the determination of the arcuate boundaries between zones A, B and C is approximate and based on very limited data. In addition, during individual eruptions only parts of these zones will be affected. The dispersal patterns of tephra from individual eruptions may vary from narrow sectors to quite broad fans, the determining factors being wind speed and direction and height of the eruption column.

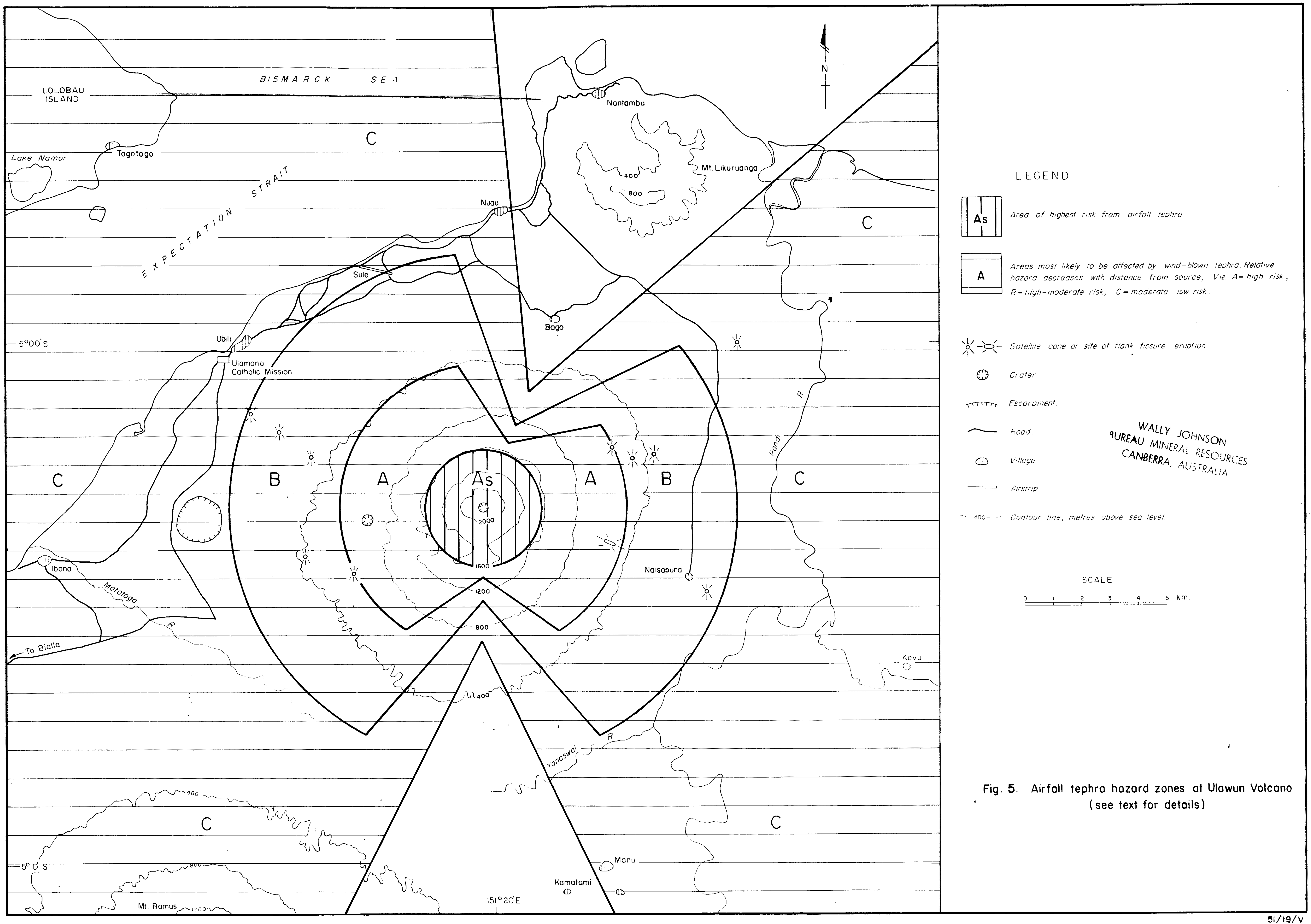

Fig. 5. Airfall tephra hazard zones at Ulawun Volcano (see text for details)

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(ii) Flowage Hazard Zones

Three zones of flowage hazard are shown on Figure 6. Within each individual zone, the severity of the three kinds of flowage hazard could be similar, although the broad zone on the southern flank of the volcano (F3) would not be affected by lava flows from a summit crater eruption but small areas could be affected by lava flows from new satellite centres.

Zone F1 is the area of highest risk from the effects of flowage hazards and includes areas which have either experienced the effects of flowage hazards in historical time or, because of current topography, show a high likelihood that flowing products of a future eruption will affect them. All of these areas contain topographic low features and are directly connected, or almost so, to the summit crater. The principal areas are the northwestern, western and eastern valleys, and a broad fan-shaped zone on the northern flank. The lengths of these main zones have been determined by lengths of historical pyroclastic flows and by areas of devastation from other recent pyroclastic flows identified on aerial photographs. The maximum length of historical pyroclastic flows is 8-9km. Secondary areas of F1 hazard zone intervene between the main zones, and are about half as long as the main zones.

Historical lava flows in zone F1 have entered the northwestern, western and eastern valleys, advancing to a maximum length of about 6-7km.

No mudflows have been produced historically in zone F1, but the potential for their generation in the areas of this hazard zone is recognized. The formation of mudflows is likely to occur at some distance downslope from the summit as the rainfall catchment area near the summit is very small.

Zone F2 is a broad zone extending to 10-12km from the summit and covers that part of the volcano north of the escarpment on Ulawun's southern flank. The outer, arcuate boundary of this zone is partially determined by the limits of lava flows identified on aerial photographs and by known lava flow exposures. In addition, global statistics (Tomblin and Michael, in prep.) indicate that there is an 80% probability that pyroclastic flows will be shorter than 12km.

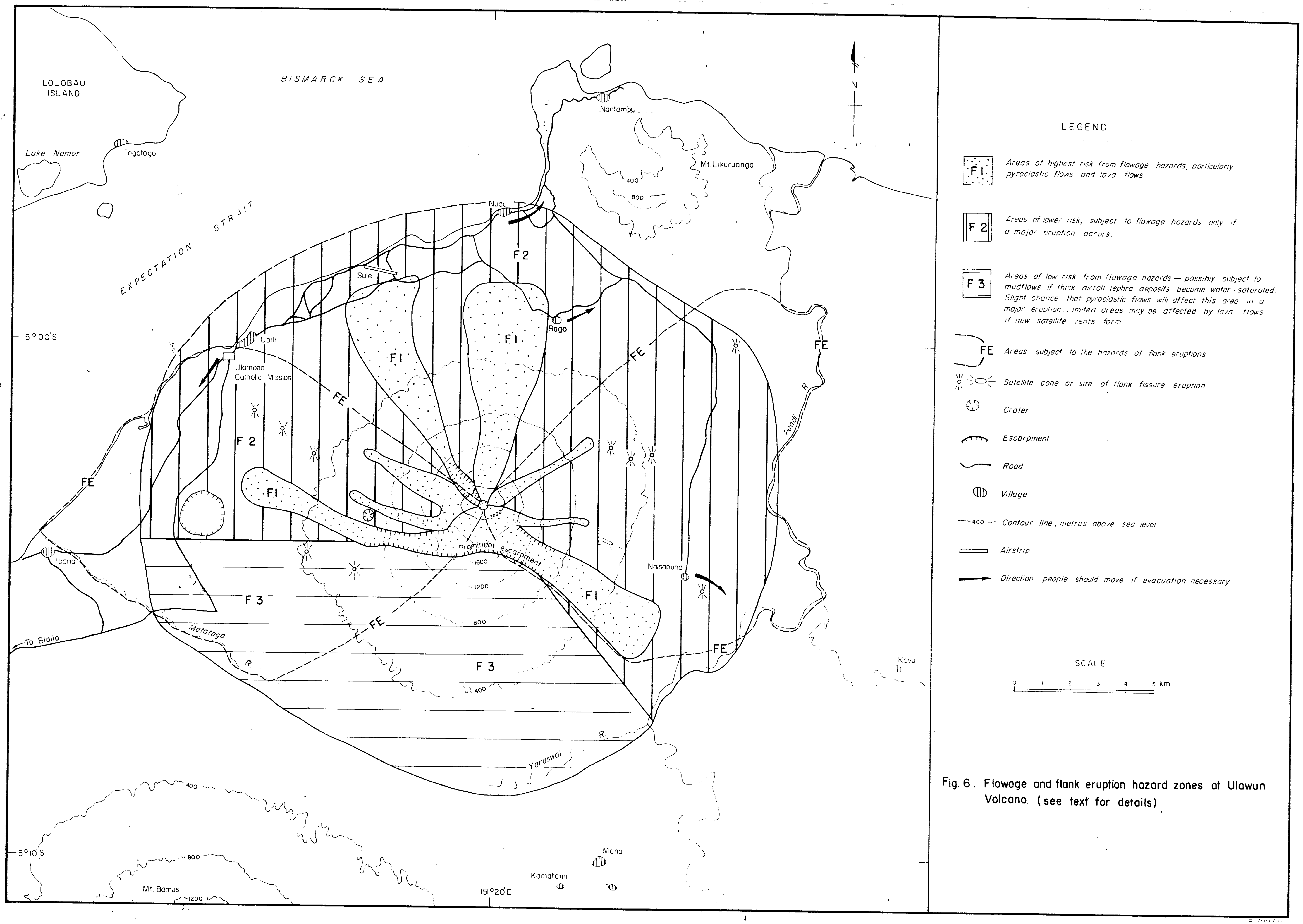

Fig. 6. Flowage and flank eruption hazard zones at Ulawun Volcano. (see text for details).

Parts of this zone may be affected by flowage hazards if a major eruption occurs in which:

(a) prolonged periods of pyroclastic flow or lava flow generation congest main valleys on the upper flanks,

or (b) dramatic changes to summit crater topography take place,

or (c) eruption column collapse results in a massive deluge of pyroclasts on the summit and upper flanks.

The effect of thse various possible events is that established pathways from the summit for pyroclastic flows and lava flows will become less affective and preferred alternative valleys will be exploited.

In addition to the possibility of lava flows from the summit crater advancing into zone F2, lava flows from new satellite volcanic centres may also affect this zone. The mapped satellite centres lie on the eastern and western flanks of Ulawun, mainly within zone F2. Satellite volcanoes may produce extensive fields of lava flows. Previous effusive activity at satellite centres at Ulawun has produced lava flows up to about 6 km long.

Mudflows could be generated in the parts of zone F2 which lie on the middle flanks of Ulawun. These mudflows would then move onto the lower flanks where spreading would take place. Deposits of pyroclastic flows could be re-mobilized and thick deposits of airfall tephra could flow if conditions became favourable. The high areal density of the relatively shallow drainage system indicates that numerous small mudflows could form over a large area of thick tephra deposits.

In most Ulawun eruptions, zone F3 would probably not be affected by flowage hazards. Examination of aerial photographs of this part of the volcano indicates uniform cover of vegetation with none of the signs of devastation typical of areas periodically affected by flowage hazards. However, a potential volcanic hazard in this zone is mudflows which could develop if airfall tephra deposits were sufficiently voluminous. The likehood of thick tephra deposition is higher in the northern, eastern and western parts of this zone.

Zone F3 is protected to a great extent from pyroclastic flows by the prominent north-facing escarpment which forms the zone's northern boundary. Pyroclastic flows can climb over topographic obstacles hundreds of metres high, but the probability of this taking place of Ulawun would be very small and would be significant only in a very large scale eruption involving collapse of a very tall eruption column.

Small areas of this zone could be subject to emplacement of lava flows from new satellite vents. Although Ulawun's satellite volcanoes lie mainly within flowage hazard zone F2, two satellite centres are located within zone F3 near its northern boarder.

(iii) Flank Eruption Hazard Zone

The most distal satellite eruption centres on the flanks of Ulawun are about 11 km from the summit, and the areas containing these volcanoes fan to the east and to the west from Ulawun's summit. On the reasonable assumption that future flank eruptions will be confined to these same areas, a hazard zone (FE) relevant to the effects of these eruptions has been constructed around the existing satellite volcanoes (Fig. 6). Allowance has been made for a margin of 2 km around each centre for the effects of heavy airfall tephra and volcanic gases, and a margin of up to 6 km (depending on topography) has been applied for lava flows.

6. PROTECTIVE MEASURES

Protection of lives and property from the effects of eruptions can be achieved by the following measures.

A. Before an eruption:

(i) Understanding the nature of the various relevant volcanic hazards.

(ii) Taking note of the areas likely to be affected by these hazards.

(iii) Ensuring that areas of highest risk are not occupied by settlements, plantations or gardens.

(iv) Designing eruption contingency plans which recognize not only the need to protect life and property, but which also minimize the disruption to human activities and do not recommend costly over-reaction to volcanic emergencies.

(v) Establishing a warning system by which residents of threatened areas could be advised of the danger.

B. <u>When an eruption has already started</u>:

(vi) Placing a damp cloth over mouth and nose to prevent breathing tephra-contaminated air.

(vii) Isolating water supplies from airfall tephra by measures such as disconnection of feeding pipes to water tanks and sealing of the tanks.

(viii) Sealing of houses and machinery to prevent penetration of tephra.

(ix) Regular removal of tephra from buildings to reduce the possibility of their collapse under the weight of thick tephra deposits.

(x) Frequent inspections of vehicle air filters and additional means of filtering air to prevent fouling of engines by fine tephra.

Eruption warning signs will be detected by volcano surveillance equipment installed on the volcano, and advice on the condition of the volcano will be transmitted by the Rabaul Volcanological Observatory to Provincial and National Government authorities. It should be noted that the prediction of the actual commencement of an eruption is less important than forecasts of the evolution of the eruption. This is a far more difficult task and largely depends on the experience and skills of volcanologists. In most eruptions, a build-up period of, at least, hours to days precedes the peak of activity, so there is usually sufficient time to assess the situation and make reasoned decisions.

Fortunately, the population living near Ulawun is small in number (1020 people within 12 km of the summit). The highest concentrations of population are at the villages Ubili (near Ulamona Mission) and Nuau. In the event that evacuation of areas around the volcano is recommended, the directions in which people should move are indicated on Figure 1. The villages around Ulawun are so located that the prime threat will be from pyroclastic flows in large eruptions. The main threatened areas are the more highly populated coastal villages north and northwest of Ulawun. A less severe threat is from airfall tephra, although only one eruption since 1878 has caused serious damage from airfall tephra in populated areas around the volcano. All areas outside of the flowage hazard zones are considered sufficiently safe for assembly of evacuees in all foreseeable eruptions except the very largest, involving catastrophic structural collapse, for which the chances of occurrence are small.

Evacuations have occurred from villages around Ulawun, during eruptions in 1970, 1978 and 1980. These were spontaneous actions and were not initiated by Government authorities. Evacuations cause great social and pyschological upheavals and can be costly. Without proper co-ordination and direction from Government authorities there is a risk that unnecessary expenditures of resources will be made. Therefore it is recommended that careful pre-planning prior to emergency situations is carried out and that evacuations are ordered only when serious dangers exist.

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