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Cape Gloucester Area, New Britain: Volcanic Geology, Petrology, and Eruptive History of Langila Craters up to 1970

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CAPE GLOUCESTER AREA, NEW BRITAIN: VOLCANIC GEOLOGY, PETROLOGY, AND ERUPTIVE HISTORY OF LANGILA CRATERS UP TO 1970

by

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SUMMARY

The Cape Gloucester area at the western end of New Britain island consists of Quaternary volcanic rocks. Most of this material is the product of two symmetrical stratovolcanoes, Talawe and Tangi, both of which rise more than 1500 m above sea-level. A cluster of volcanic centres, collectively named the Aimaga Volcanic Complex, lies on the saddle between Talawe and Tangi, and these three major volcanic centres form a prominent north-south line more or less perpendicular to the east-west trend of New Britain and the volcanic islands to the west. Langila Craters are an active group of four coalesced volcanic centres on the eastern flank of Talawe. From oldest to youngest, these include Munlulú Crater, and no. 1 and no. 2 craters, which overlap one another progressively northnortheastwards. In 1960, eruptions broke out on the northwestern flank of no. 1 crater, and formed a new cone and crater, here termed no. 3 crater. A Recent lava field north and northeast of Langila Craters was probably formed within the last one or two hundred years by eruption of lavas from the Craters. North and northeast of Talawe volcano there are several satellite cones which are also probably Recent. Many of these satellite cones show a northnortheast - south-southwest alignment similar to that shown by Langila Craters.

The earliest eruptions on record from Langila Craters took place towards the end of the 19th century. These eruptions are believed to have been strongly explosive, and possibly to have produced lava flows. Langila Craters appear to have remained quiescent up to May, 1954, when a major period of explosive activity commenced from no. 2 crater; these explosions continued intermittently until 1956. Reports received from numerous sources indicate that between 1956 and 1970 explosive activity from both no. 2 and no. 3 craters took place during all but three years (1957, 1959, and 1964), and that no. 1 crater had remained inactive. Effusive activity during this period was limited to eruption, from no. 3 crater, of a small lava flow in 1961, and of a larger flow in 1967. Fumarole temperatures, condensate compositions, ground movements, and seismicity are related phenomena which have all been studied since 1952.

The lavas of the Cape Gloucester area are predominantly basalts and "andesites" (sensu lato); probably none of them is dacitic, and rhyolites appear to be absent from the area. The basalts and andesites are highly porphyritic, and the most common type of phenocryst is plagioclase. Other phenocryst minerals include clinopyroxene (augite), pleochroic orthopyroxene, olivine, and iron-titanium oxide. Phases in the groundmass of the lavas are plagioclase, clinopyroxene, orthopyroxene, iron-titanium oxide, glass, and less commonly, olivine, tridymite, and cristobalite.

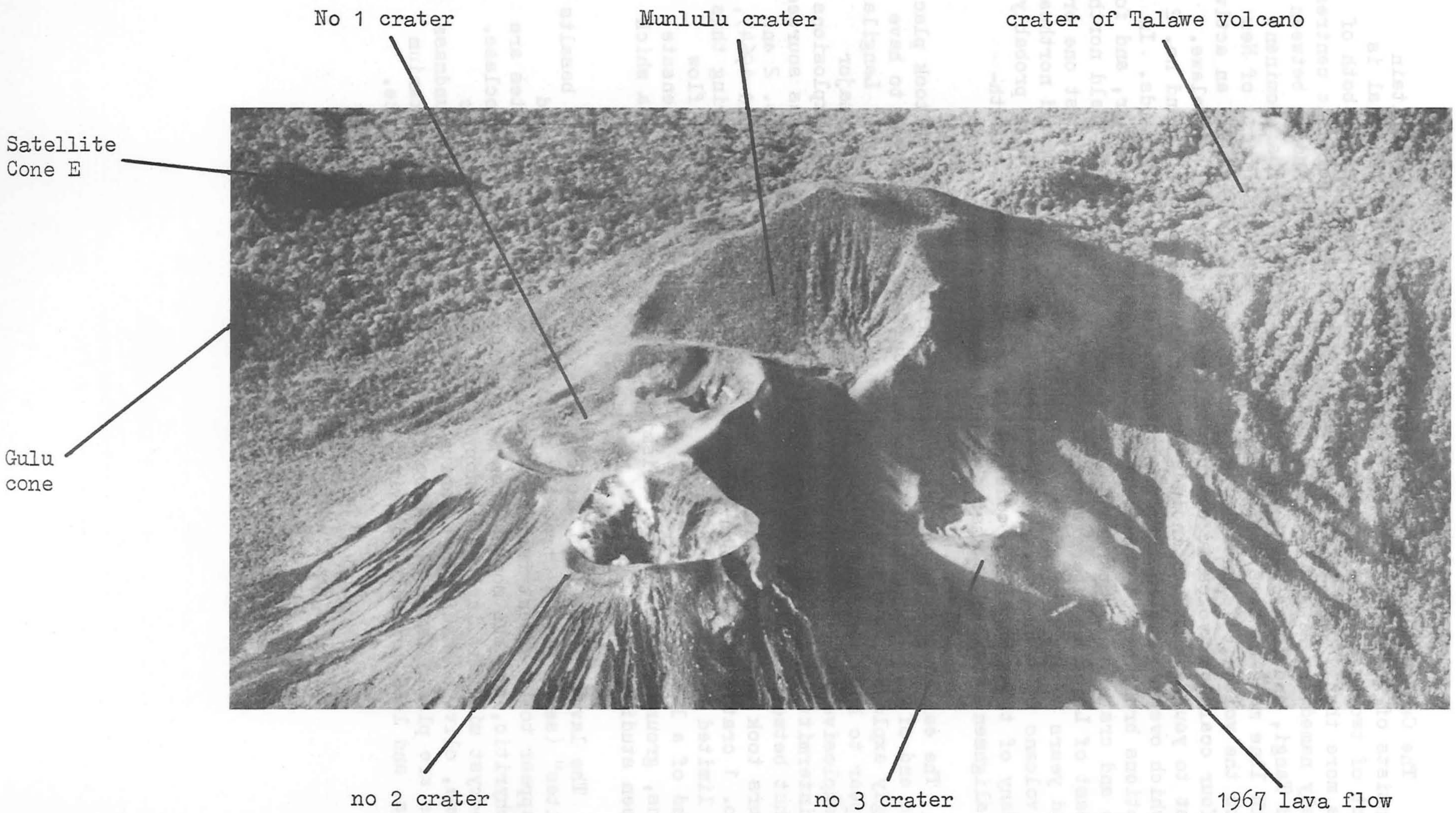

Figure 1 Langila Craters from the north. Photographs taken 30/12/67 by G.W. D'addario. Neg. No G.A/4194.

INTRODUCTION

The western tip of New Britain island consists of Quarternary volcanic rocks that cover an area of about 200 sq km. Much of this volcanic material is the product of two prominent symmetrical strato-volcanoes, Talawe and Tangi (figures 2 and 3).

Talawe, 13 km north of Tangi, is the larger of the two volcanoes, and on its eastern flank is a prominent cluster of active cones with summit craters - the "Langila Craters" (figure 1). During this century, Langila Craters have produced numerous explosive eruptions, and, because of their potential danger to the community, they are under surveillance by local observers who have been instructed to report any increased or anomalous volcanic activity to the Central Volcanological Observatory in Rabaul.

Langila Craters have been described by Fisher (1939) and Best (1956b), and by Taylor, Best, and Reynolds (1957) in B.M.R. Report No. 26. The B.M.R. Report documents observations of volcanic activity at Langila Craters between 1954 and 1956. It also presents a statement on conditions at the vents in 1952, and, in an appendix by J.K. Lovering, gives petrographic descriptions of 10 samples from the vicinity of the Craters.

This Record is concerned with the following topics: 1. the Quaternary volcanic geology of the Cape Gloucester area; 2. the known eruptive history of Langila Craters, as summarised from unpublished data in files of the Central Volcanological Observatory, and from published sources; 3. changes in the morphology of Langila Craters since the investigations of Taylor, Best, and Reynolds; 4. the petrology of one hundred and eleven samples collected throughout the Cape Gloucester area.

The area has been visited by each of the writers. A helicopter reconnaissance was made by Johnson on 2nd November, 1969, and later (7-17th November, 1969) ten days were spent covering the area on foot, collecting material for petrological studies. Palfreyman climbed the northern flank of Talawe on 11th June, 1970, and Davies and Johnson followed the same route on 3rd September, 1970, establishing an overnight camp, and reaching and examining one of Langila Craters on 4th September. In this Record, Johnson is responsible for geological and petrological descriptions and interpretations, and Palfreyman and Davies present the account of eruptive history. The Record is the third in a series of reports dealing with the geology, petrology, and eruptive histories of Quaternary volcanoes in New Britain (see Johnson, 1970 a,b).

TOPOGRAPHY AND GEOGRAPHY

Between Talawe and Tangi, and slightly east of a line joining the summit of the two volcanoes, lies a cluster of low-lying volcanic hills which, collectively, are here named the Aimaga* Volcanic Complex (figure 3). Talawe, Tangi, and the Aimaga Complex form the three most prominent topographic features in the area, and their products make up the bulk of volcanic material in the Cape Gloucester area.

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* Named after Aimaga village which lies immediately west of the hills.

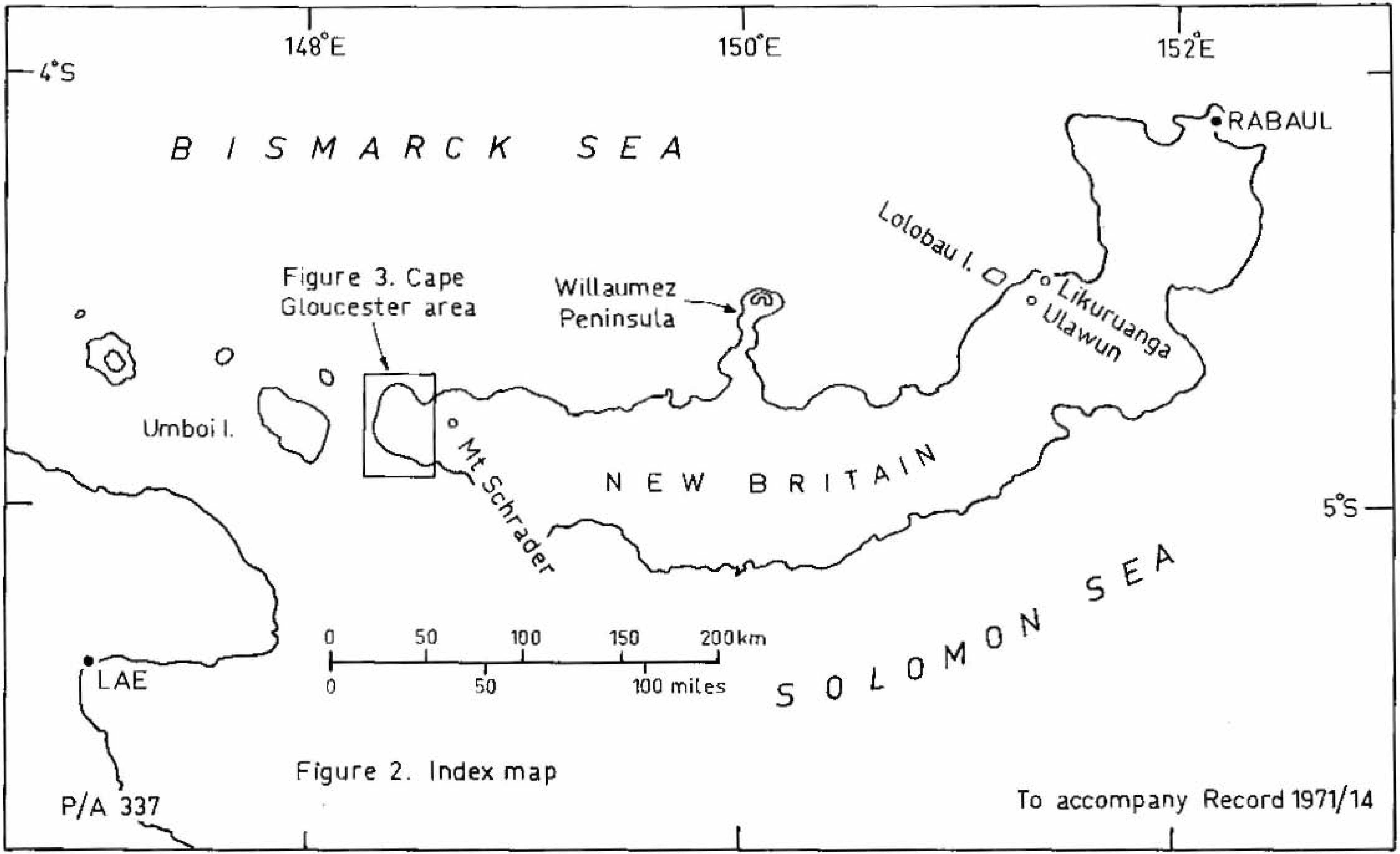

Figure 2. Index map

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The largest watershed in the Cape Gloucester area is that of the Itni River and its tributaries which drain the eastern slopes of Tangi and the Aimaga Complex, and the western slopes of Mount Schrader (figures 2 and 3). The tributaries of the Itni join south of a low-lying saddle (about 150 m above sea-level at its highest point) between the Cape Gloucester volcanoes and Mount Schrader, and the main river flows into the Solomon Sea at Cape Bushing, where outwash detritus has formed a prominent swampy delta (figure 3).

The second largest watershed is that of the Gima River which drains the southwestern flank of Talawe, the western flank of the Aimaga Volcanic Complex, and the northwestern flank of Tangi. Lagoon Point, north of Sag Sag village, probably consists of old deltaic material deposited by the Gima River before it changed its course, and emerged at the coast near Sag Sag. Other smaller streams in the Cape Gloucester area - many of which are ephemeral - drain directly into the sea from the slopes of the volcanoes.

With the exception of Langila Craters and the area to the north, the Cape Gloucester region is covered mainly by rain forest. Restricted patches of kunai grass are found on ridges close to the western and northern coasts, and there are widespread areas of kunai near the Cape Gloucester air-strip, and west of Borgen Bay.

Much of the population of the Cape Gloucester area is restricted to the coast, but there are also several villages in the interior, notably, in the headwaters of the Itni and Gima Rivers. The area is covered by the Kilengi Lollo Census Division (Talasea Subdistrict) which, according to the "Village Directory, 1968 (Department of District Administration), has 33 villages and a population of 3350. The Division is patrolled regularly by officers from the Cape Gloucester Patrol Post on the western shore of Borgen Bay (figure 3).

There is a road from the Patrol Post to the Cape Gloucester airstrip which is used regularly by TAA flights from Rabaul and Lae (Douglas DC3 and de Havilland "Twin Otter" aircraft). The road continues westwards to Kilenge Roman Catholic Mission on the northwestern coast. Twelve kilometres southwest of Kilenge Mission, at Sag Sag, and close to the mouth of the Gima River, is a Church of England Mission. In the past, reports of volcanic activity from Langila Craters have been provided by the staffs of both these missions, and by officers stationed at the Patrol Post.

Much of the shore-line of the Cape Gloucester area is fringed by reef, and there are several submerged and poorly chartered off-shore reefs along the northern and northeastern coastlines. There are a few anchorages used by small vessels, but none of these is sheltered from winds of both the "southeastern" and "northwestern" seasons. Between Cape Gloucester and Umboi Island to the west is the Dampier Strait, a notoriously treacherous and poorly chartered passage for ships (figure 3).

The only large-scale maps of the Cape Gloucester area are a series of 1 inch-to-1 mile maps prepared by the United States Army in 1943*. The small-scale map in figure 3 is based on these military maps, but several amendments have been made, and the approximate positions of villages have been replotted. Three flight lines of good quality vertical air-photographs cover the western part of the area, and a series of oblique photographs showing the western side of the volcanoes has been utilised.**

GEOLOGY

Tangi Volcano

Tangi is a dissected stratovolcano with a breached summit crater. On the U.S. Army maps, its height is given as "approximately 5600'" (1717 m), but on the World Aeronautical Chart 1:1,000,000 map (reference: "Lae (2988)") the value is 4998' (1524 m)*** Below about 600 m above sea-level, the lower flanks of Tangi slope at less than 10°, and they form a "pediment" from which the central area of the volcano rises steeply to the crater rim (figure 4). In plan, this high central area is crudely oval, with an east-west axis about 9 km long, and a north-south axis about 6 km long (figure 3).

On the air-photographs of Tangi, the low-angle pediment and the central area show contrasting degrees of dissection. The central area is incised by deep V-shaped ravines separated by knife-edge ridges, whereas the pediment is cut by shallow gullies separated by "planezes" (Cotton, 1952). The steep-walled ravines of the central area terminate in precipitous cliffs at the crater rim, and impose a subdued serration on the profile of the rim. Despite their steepness, the walls of the ravines are covered by thick vegetation; in places, landslips have taken place exposing rubble and mature soil profiles.

The dissected flanks of Tangi reach a maximum slope of about 35° below the summit crater, and extrapolation of these slopes indicates that the original summit of the cone was about 700 m higher than the present-day crater rim. Before collapse of the summit area, the height of Tangi was therefore comparable with that of Ulawun, the highest volcano in New Britain at the present day.

In plan, the summit crater of Tangi is oval, with an east-west axis about 2 km long, and a north-south axis about 1.6 km long. The crater is more or less concentric with the oval outline of the dissected central area of Tangi, but its centre is displaced slightly southwards (figure 3). Immediately beneath the crater rim, the walls

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* These maps are referred to as follows: "Cape Gloucester, S515-E14815/15"; "Mt Tangi, S530-E14815/15"; "Borgen Bay, S530-E14830/15"; "Annen Point, S545-E14815/15"; "Cape Bushing, S545-E14830/15".

** Air-photograph references: CPE 7275, nos. 1 - 29V; Run 261-X "Rooke Island to Gloucester" (19/9/43), nos. 60 - 74R (photographs unclassified by Central Photographic Establishment, Melbourne).

***On 13th November, 1969, an altitude of 1433 m was read from a pocket altimeter on the northwestern crater rim; this value is uncorrected for diurnal pressure variations.

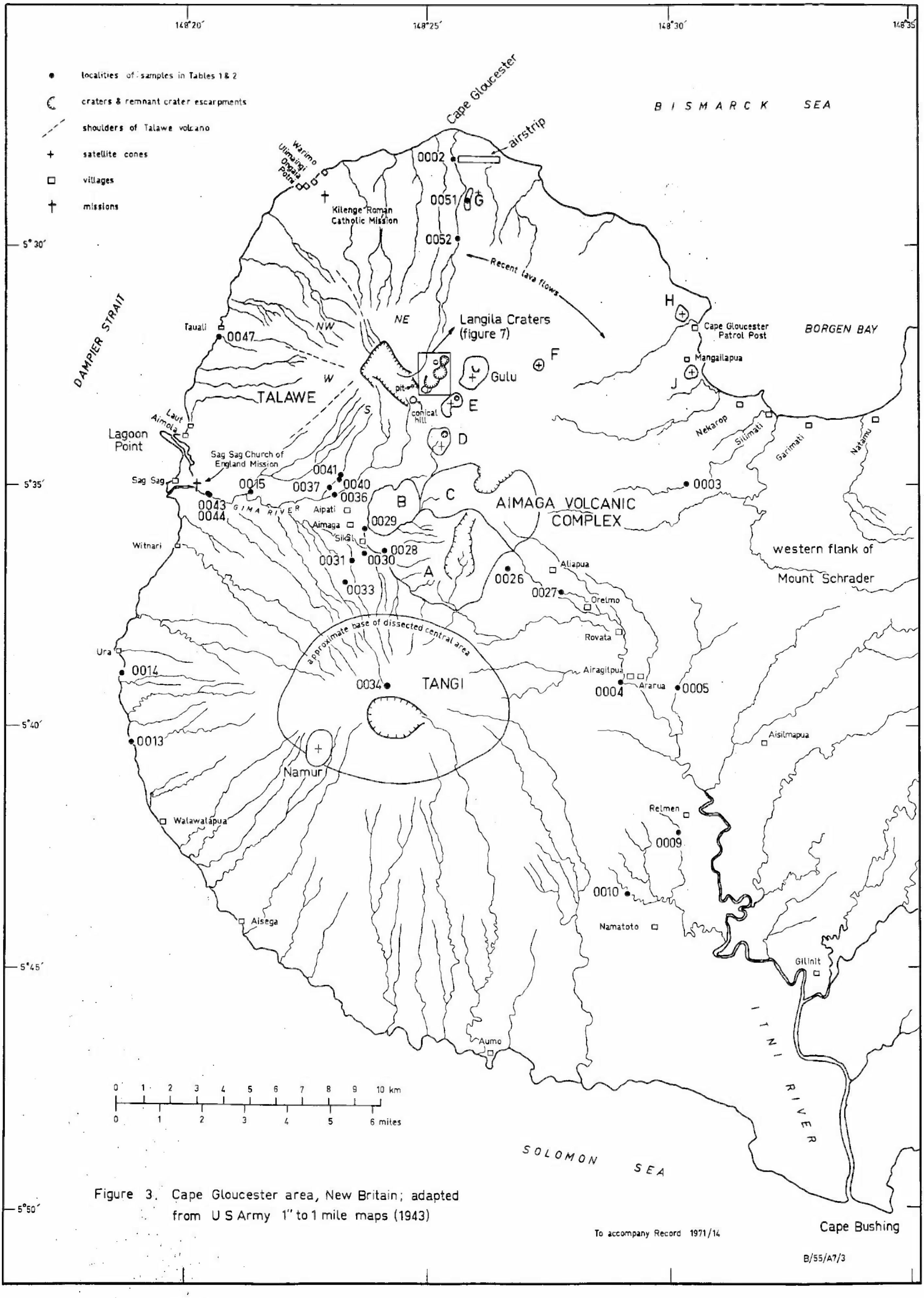

Figure 3. Cape Gloucester area, New Britain; adapted from U S Army 1" to 1 mile maps (1943)

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of the crater are precipitous, and they sweep down to form a bowl-shaped depression. Numerous steep-sided gullies drain the crater; these merge eastwards into a single stream that breaches the eastern crater wall (figure 4), flows down the southeastern flank of Tangi, and emerges at the coast near Aumo village.

There are no remnants of post-crater lava flows that may once have filled the summit crater, and it is assumed that collapse of the summit area was the last volcanic event to take place on Tangi. Most of the dissection of the volcano clearly took place after the crater had formed, as collapse has not preserved truncated, V-shaped cross-sections in the crater rim profile. The size, form, and degree of dissection of the summit crater of Tangi are comparable with that of the summit crater of Likuruanga volcano, eastern New Britain (figure 1; Johnson, 1970 b).

About 2 km southwest of the summit crater rim is a prominent satellite cone, named "Mt Namur" on the U.S. Army 1" to 1 mile maps (figures 3 and 4)*. The cone is steep-sided (slopes up to 40°), dissected, and thickly vegetated. A short ridge runs southsouthwest - northnortheast across the summit of the cone, but no remnants of a summit crater are present. Namur is the only visible point on the flanks of Tangi where magma has been extruded from a satellite vent.

Lava samples for petrographic study and chemical analysis have been collected from streams on the upper northern, and lower southeastern slopes of Tangi. Most coastal exposures of Tangi reveal weathered, ferruginous, semi-indurated volcanic rudites whose clasts, in general, are unsuitable for chemical analysis. The clasts are invariably rounded, and in many cases they are spheroidally weathered, and embedded in a rust-red earthy matrix which, in places, is rich in clay. These outcrops are found mainly on the western coastline south of Sag Sag, especially between Witnari and Aisega villages. In places, well-bedded volcanic arenites and lutites, with iron-enriched bands formed by seepage, are also exposed along the coast. The deep weathering of the volcanic rudites in coastal outcrops and the degree of dissection (described above) indicate that Tangi has been exposed to weathering for a much longer period than most Quaternary volcanoes in New Britain.

Coastal outcrops also suggest that the low-lying pediment surrounding the central area of Tangi probably consists mainly of clastic material, most of which appears to be detritus washed down from higher slopes. Lava flows are also almost certainly a constituent of the pediment, especially nearer the central area, but most of these do not seem to have reached the present-day coastline.

An impressive series of flat-lying lava flows is exposed in the Gima River valley, 1 km east of Sag Sag Mission. These flows are massive, up to 8 m thick, and locally show crude columnar jointing. Scoriaceous layers are present between flows, but there are no intercalated air-fall pyroclastic beds. These lava flows could have originated from any of the

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* On these maps, Mt Namur is shown incorrectly southsoutheast of the summit crater of Tangi. In figure 3, the cone has been replotted employing air-photographs.

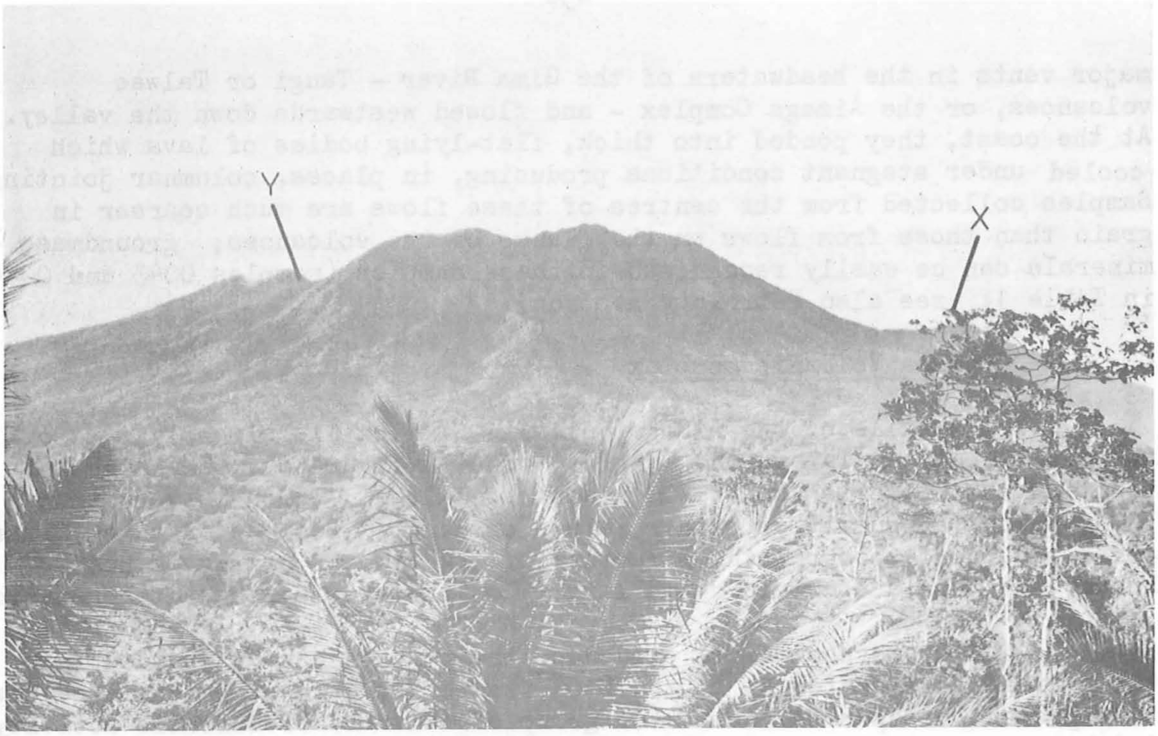

Figure 4. Tangi volcano, south from Aimaga village, showing Namur satellite cone (X), and breach on eastern side of summit crater (Y). Neg. No. M/979.

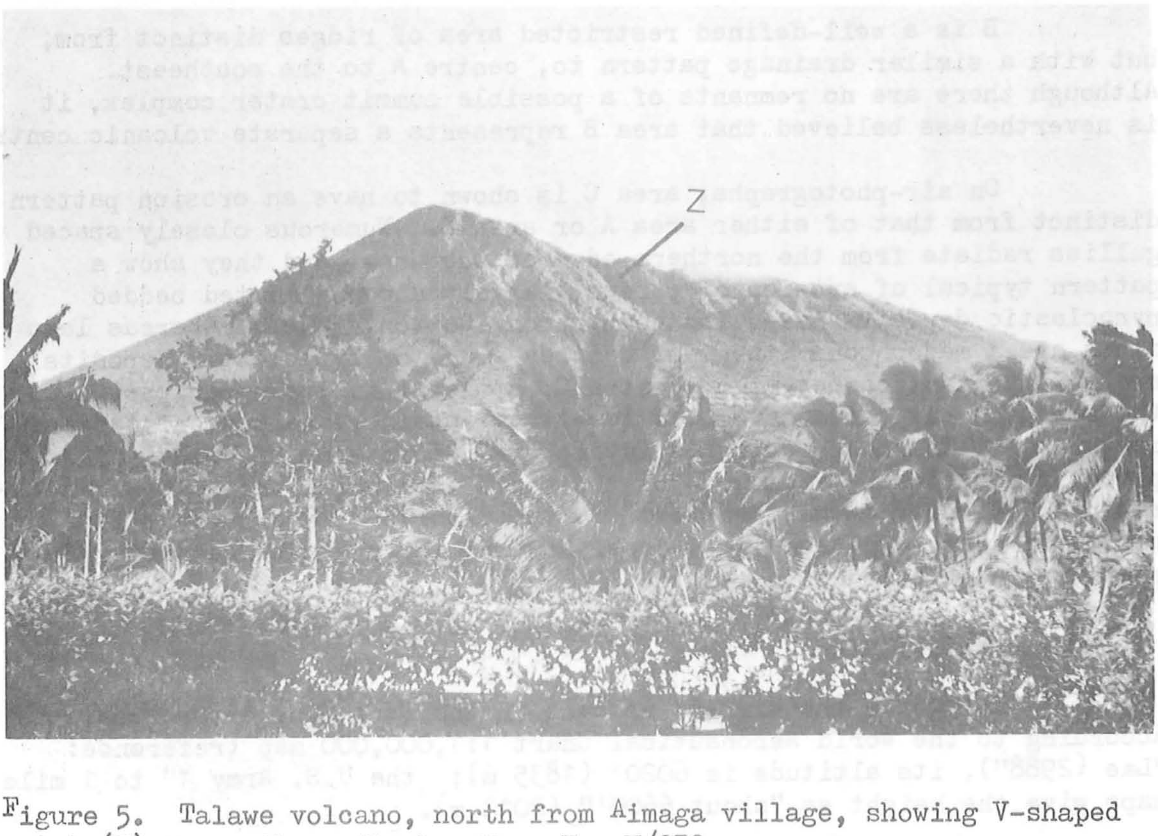

Figure 5. Talawe volcano, north from Aimaga village, showing V-shaped notch (Z) on southern flank. Neg. No. M/979.

major vents in the headwaters of the Gima River - Tangi or Talwae volcanoes, or the Aimaga Complex - and flowed westwards down the valley. At the coast, they ponded into thick, flat-lying bodies of lava which cooled under stagnant conditions producing, in places, columnar jointing. Samples collected from the centres of these flows are much coarser in grain than those from flows on the flanks of the volcanoes; groundmass minerals can be easily recognised in these samples (samples 0043 and 0044 in Table 1; see also Petrology section).

Aimaga Volcanic Complex

The hills of the Aimaga Volcanic Complex lie slightly east of the saddle between Talawe and Tangi volcanoes (figure 3). The highest point on the hills is about 1000 m above sea-level, which is more than 500 m below the summit of either Talawe or Tangi. Because of thick timber cover and poor exposure, the structure of the Aimaga Complex is poorly known, and this account is based largely on photogeological interpretations.

On geomorphological evidence, the Complex can be divided into three areas (designated A, B, and C on figure 3), each of which is believed to represent a separate centre (or group of centres) of volcanic activity. A is the largest of the three centres. Its lower flanks on the eastern, southern, and western sides increase in slope upwards to a steep-sided dissected central area that has an irregular drainage pattern. The summit area is an elongate irregular depression that trends northnortheast, and merges with the central area of centre C. More or less continuous ridges on either side of the elongate depression suggest that the summit area of centre A may have once been a row of coalesced craters, similar to the present-day Langila Craters, but now modified by erosion.

B is a well-defined restricted area of ridges distinct from, but with a similar drainage pattern to, centre A to the southeast. Although there are no remnants of a possible summit crater complex, it is nevertheless believed that area B represents a separate volcanic centre.

On air-photographs, area C is shown to have an erosion pattern distinct from that of either area A or area B. Numerous closely spaced gullies radiate from the northern edge of the area, and they show a pattern typical of erosion of porous, largely unconsolidated bedded pyroclastic deposits (see, for comparison, Cotton, 1952). Whereas lava flows are a major constituent of centres A and B, pyroclastic deposits are an important component of centre C, at least in its upper part. On the northern edge of centre C, a low-lying scalloped embayment faces northwards. This depression is interpreted as an area of collapse - probably modified by erosion - of the vents from which the volcanic material of centre C was erupted. On the floor of the embayment is a series of northward-trending ridges, some of which may be remnants of post-embayment volcanic cones.

Talawe Volcano

Talawe is the highest volcano in the Cape Gloucester area. According to the World Aeronautical Chart 1:1,000,000 map (reference: "Lae (2988"), its altitude is 6020' (1835 m); the U.S. Army 1" to 1 mile maps give the height as "about 6600'" (2012 m).

Compared to Tangi, the form of Talawe is much more irregular: its flanks show various degrees of dissection, and its crater, instead of being oval and well-defined as that on Tangi, is bounded by straight sides, and is poorly defined on its southeastern edge. Moreover, in contrast to Tangi, the central area of Talawe cannot be separated as a distinct topographic unit from the lower slopes of the volcano. Another topographic difference is that, whereas the slopes of Tangi are more or less continuous around the volcano, those of Talawe can be divided into four planar areas - on the northeastern, southern, western, and northwestern sides (labelled NE, S, W, NW respectively in figure 3); these areas intersect in three prominent shoulders radiating from the crater rim. A fifth planar flank may once have existed on the southeastern side of Talawe, but if so it is now concealed by the Langila Craters.

The crater depression of Talawe has a quadrilateral outline, with two long sides, each about 2.5 km in length, on the northeastern and southwestern sides. These are collateral with the planar flanks of the volcano, and they diminish in height to the southeast. The southeastern part of the crater rim is marked only by a conical hill, believed to be an erosional remnant, but which may be a satellite cone. In contrast, the northwestern edge of the summit depression is well-defined, extending from the summit of Talawe northeastwards to the head of a deep and wide V-shaped valley on the northwestern shoulder of the volcano. This prominent valley appears to have grown by avalanching from its sides, and, in form, it closely resembles the deep erosion valley on the northwestern flank of Ulawun volcano (figure 2; Johnson, 1970a).

Except on the southeastern side, the walls of the summit crater are steep; in places, they are scarred by landslide areas. A low ridge, trending northeast-southwest, divides the floor of the depression into a larger northwestern part and a smaller southeastern part, each drained by different streams. The northwestern part is drained by a stream that breaches the crater wall on its northeastern side, and flows northwards to the coast. The stream that drains the southeastern part breaches the southeastern corner of the crater depression, and flows southwestwards down the southern slopes of Talawe, joining the westward-flowing Gima River. The southwestern rim of the depression is breached by a third stream that drains the eastern side of the summit peak, and forms a prominent V-shaped notch in the southern flank of Talawe (figure 5). A circular, crater-like pit, about 200 m in diameter, is present at the eastern end of the summit depression.

Apart from the major stream valley on the northwestern shoulder of Talawe (mentioned above), the northwestern, western, and southern flanks of Talawe are cut by gullies which are narrower, less deep, and more numerous than the valleys on the upper part of Tangi volcano. In addition, the upper northeastern slopes of Talawe are almost undissected, suggesting that a thick layer of porous pyroclastic material, possibly from the active Langila Craters to the east, may cover this flank. These juvenile erosional features indicate that the volcanic activity of Talawe ceased later than that of Tangi.

The absence of a well-defined circular or oval summit crater on Talawe suggests that erosion might have severely modified the original crater. However, it is believed more likely that the quadrilateral outline is a primary feature of the Talawe crater, and that collapse has taken place along linear faults rather than along a continuous ring fracture.

Exposures in two of the three major stream sections that drain Talawe Crater have been examined, and in both cases lava flows are the dominant constituent. In the lower part of the V-shaped notch on the southern flank (west of Aipati village and above about 350 m above sea-level), lava flows, mostly 2-3 m thick, intercalate with scoriaceous layers, and with dark brown slightly weathered beds of ash and vesicular lapilli. At about 580 m above sea-level on the northern flank of Talawe, in the stream breaching the northeastern crater rim, a series of waterfalls (over 15 m high) expose massive outcrops of lava which in places are flow-banded and flow-brecciated.

Coastal exposures between Sag Sag and Kilenge also reveal scoriaceous lava flows from Talawe. In places - for example, above Tauali village - bedded ash and lapillus beds overlie the flows. In contrast to the deeply weathered volcanic rudites of Tangi, these lava flows and pyroclastic deposits from Talawe are fresh. This testifies further to the conclusion reached above that, since its last eruption, Talawe has been exposed to a shorter period of weathering and erosion than has Tangi.

Langila Craters and associated satellite cones and lava fields

Because of the possible deleterious effects of an eruption on villages and the Cape Gloucester airstrip, Langila craters have been kept under surveillance, and have been visited several times during the past thirty years by volcanologists from the Central Volcanological Observatory in Rabaul. Fisher (1939) and Best (1956b), for example, published accounts of visits to the Craters in 1937 and 1952, respectively, and the area was the subject of a detailed report by Taylor, Best, and Reynolds (1957) who were concerned with increased activity from the vents in 1952, and with eruptions between 1954 and 1956. Reference to the geological structure and morphology of the Craters was made by all these authors. To avoid repetition, therefore, the descriptions presented in this report will be brief, and will be concerned primarily with changes in the form of the Craters area since investigations in the 1952-56 period. An account will also be given of other satellite cones in the Cape Gloucester area, and of young lava fields associated with Langila Craters.

The term "Langila Craters" employed in this Record refers to the cluster of four coalesced cones, each with summit craters, on the eastern flank of Talawe volcano. These centres are Munlulu, no. 1 crater, no. 2 crater, and no. 3 crater. Their relative positions are shown on figures 1, 3, 7, and 8.

<u>Munlulu</u> is the oldest and highest of the four cones. Its highest point (probably about 1200 m above sea-level) is a triple point formed by the intersection of two small coalesced craters with the southwestern edge of a much larger crater on the northeastern side of the cone (figure 1). Each of these craters is covered by vegetation, and none of them has produced eruptions within historic times.

The largest crater of Munlulu ("Munlulu Crater"; Fisher, 1939) is about 550 m in diameter from east to west. Its northeastern rim is overlapped by the southwestern rim of no. 1 crater, and its floor is pitted with the impact craters of bombs ejected from the younger craters to the north. In November, 1969, the crater floor was covered by

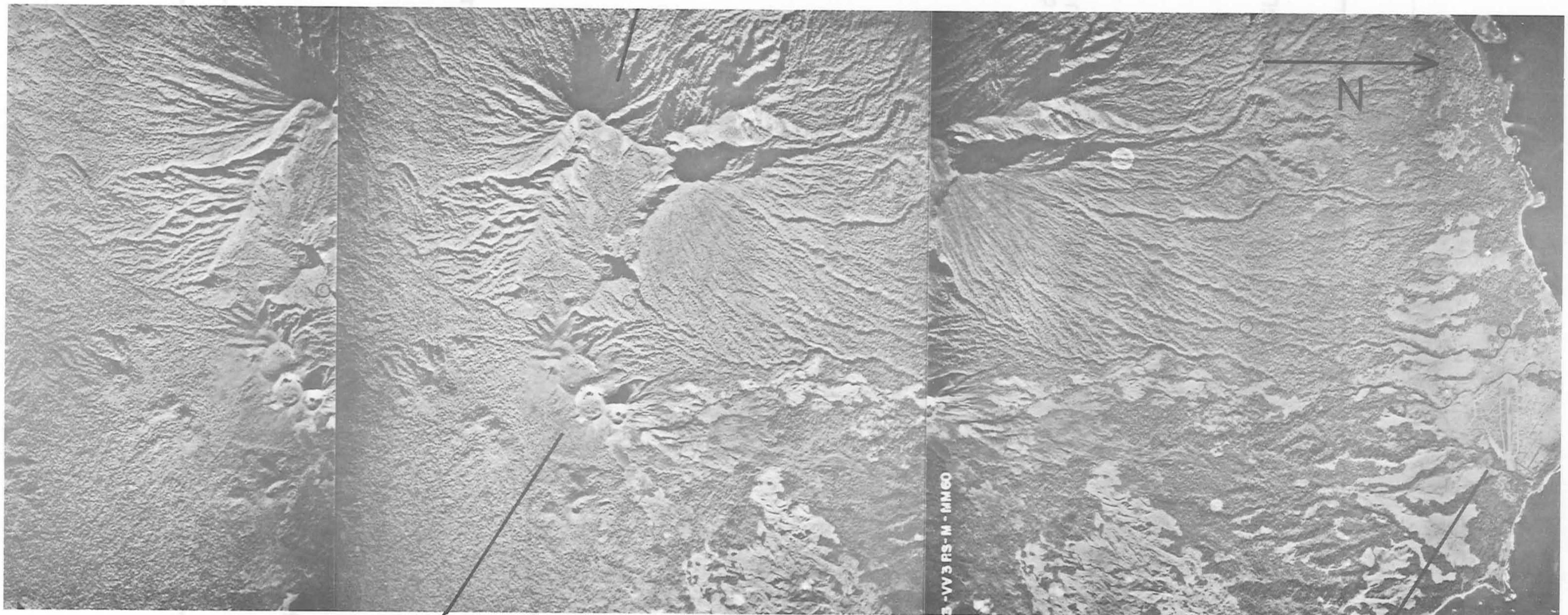

Figure 6. Stereoscopic pairs of air-photographs, showing Talawe volcano, Langila Craters, and the Cape Gloucester airstrip. (Taken 25/3/47).

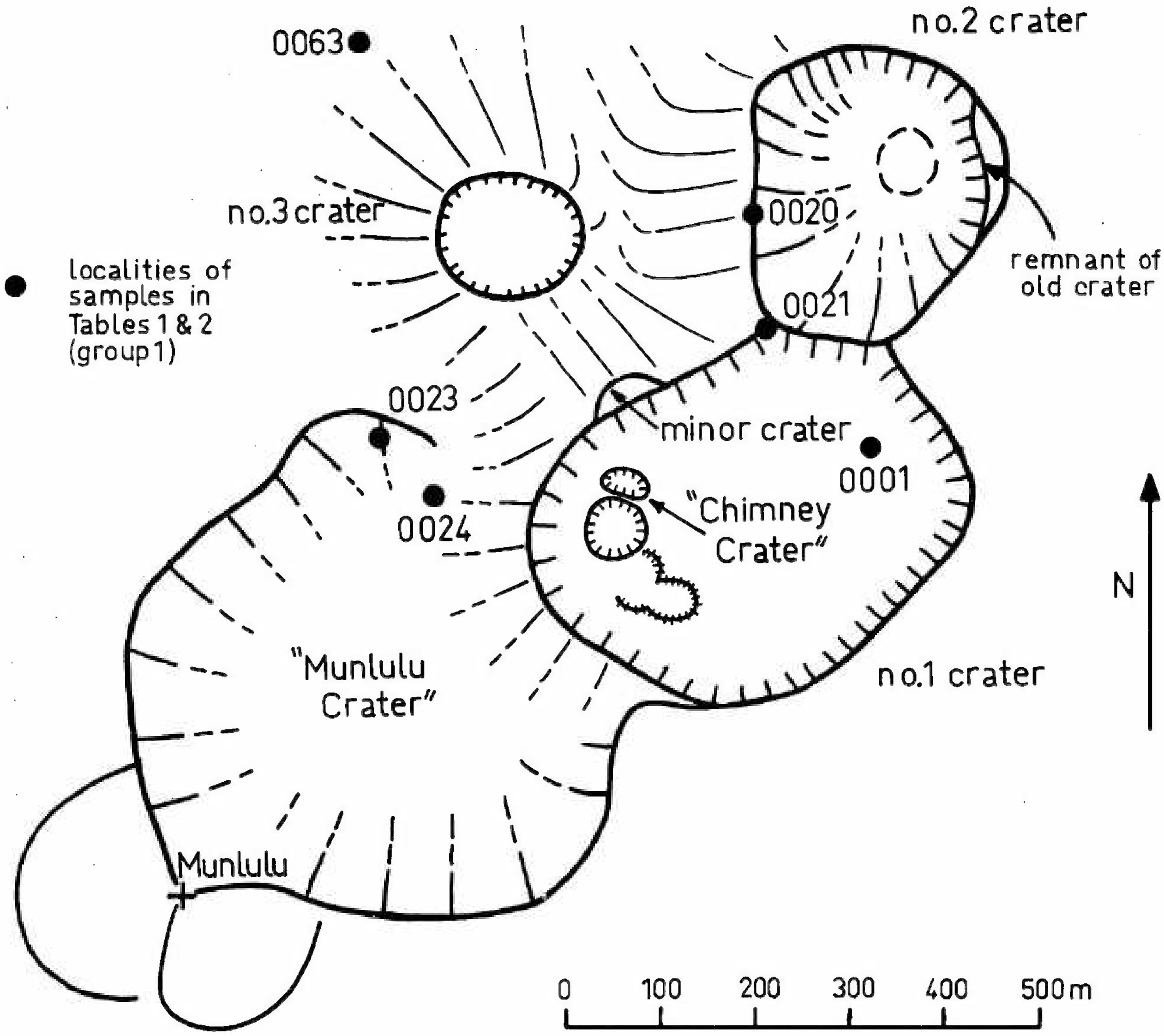

Figure 7. Sketch map of Langila Craters

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bracken-like undergrowth, and trees - mostly 2-4 m high - had been stripped of their foliage; the remaining upright trunks appeared to be dead. On 11th November, 1969, hot soil patches were encountered on the northwestern rim of the crater, but no visible water vapour or sublimate deposits were observed. This hydrothermal area was noted by Best (1956b), and observed by G.A.M. Taylor between 1952 and 1954 (personal communication, 1971).

No. 1 crater occupies the summit of a cone intermediate in size between the larger Munlulu cone to the southwest, and the smaller cone of no. 2 crater to the northeast (figures 1 and 7). Apart from a slight increase in degree of dissection on the flanks of the cone (caused by the killing of vegetation by eruptions), and the addition of bombs and some ash ejected from no. 2 crater, there appears to have been no appreciable change in form of no. 1 crater since the investigations of Taylor, Best, and Reynolds (1957). These authors described no. 1 crater as follows:

> "The shape of this crater is roughly rectangular with rounded corners and it is elongated in a northeasterly direction. Dimensions are 1500 by 1250 feet [460 m] by 380 m]. The south-western and western end abuts into the old and poorly defined Munlulu crater, and the northern corner forms a common ridge with the southern rim of No. 2 crater. The highest portion of the rim is on the south-western side, where the height is estimated at 4,000 feet [1220 m]. Along the northwestern side is a steep-sided ridge which at its north-eastern end joins the southern end of the western edge of No. 2 crater. The easterly portion is about 300 feet [90 m] lower and is more easily accessible. There appears to have been numerous active centres within this crater, and remnants of their activity remain in the form of small undulating ridges... The latest activity that occurred in this crater was confined to the western section of the crater. Recently extinct craterlets and currently active fumarole centres still exist on both sides of the high ridge on the northwestern side."

On the floor of no. 1 crater, just beneath the western rim, three smaller craters are preserved, the most southerly of which is shallow, consisting of two coalesced depressions (figure 7). In contrast, the two craters to the north are steep-sided, and both are deeper than 30 m. The most northerly of the craters was termed "Chimney Crater", and between 1952 and 1956 it produced gas and vapour emissions (Best, 1956b; Taylor, Best, and Reynolds, 1957). It was presumably also from Chimney Crater that fumarolic emissions were observed in 1937 (Fisher, 1939). On two occasions in November, 1969, poor visibility prevented a close examination of the walls of this crater, and the presence of fumarolic activity at this time could not be definitely established. However, the solfataras noted by Fisher (1939), Best (1956b), and Taylor, Best, and Reynolds (1957) on the northwestern rim of no. 1 crater were still present, and small amounts of sulphur were being deposited.

A minor crater on the northwestern rim of no. 1 crater was observed during the investigations between 1952 and 1956 (Best, 1956b; G.A.M. Taylor, personal communication, 1971). This crater is also clearly shown on air-photographs taken by G.W.D.'addario in December, 1967 (C in figure 12), but owing to poor visibility its presence was not confirmed on visits to the area in 1969 and 1970 (figure 7). Two "small explosion craters" were also observed by Taylor, Best, and Reynolds (1957) on the northwestern slopes of no. 1 crater about 120 m below the crater rim. These craters were not observed in 1969 and 1970; neither are they shown on D'addario's photographs.

Erosion gullies on the outer eastern flanks of the cone of no. 1 crater expose bedded lava blocks, scoriae, lapilli, and ashes; similar fragmental deposits are intercalated with a series of lava flows in the walls of Chimney Crater. The erosion gullies are comparatively new features on the flank east of no. 1 crater, as thick scrub protected this area from erosion up to 1954 (G.A.M. Taylor, personal communication, 1971). However, eruptions since that time have greatly extended the area stripped of vegetation around Langila Craters, and the steep eastern side of no. 1 crater is one of several areas that have been exposed to more rapid erosion.

<u>No. 2 crater</u>. Whereas the volcanic cones of Munlulu and no. 1 crater appear to have undergone no significant changes, no. 2 crater has been drastically modified, and none of the features inside the crater described by Taylor, Best, and Reynolds (1957) can now be recognised. However, up to the present time, the shape of the cone, and the general outline of the crater rim have remained unchanged, and the following description by Taylor, Best, and Reynolds (1957) still holds:

> "The No. 2 crater is rounded in outline at the northeastern end, but the western, south-eastern, and southern sides are nearly rectilinear. It is smaller than No. 1 crater, about 1050 feet [320 m] long in a north-north-easterly direction, and 900 feet [275 m] wide. The elevation of the crater rim ranges approximately from 3,600 to 3,900 feet [1100 m to 1190 m], and as in the No. 1 crater, the eastern wall is 200 to 300 feet [60-90 m] lower than the western one."

Within no. 2 crater, Taylor, Best, and Reynolds (1957) identified two craters (see air-photographs taken 25/3/47 in figure 6). The eastern one was described as a "shallow secondary crater about 500 feet [150 m] in diameter". The second crater, termed "Twin Crater", occupied the south-western half of no. 2 crater. This crater was elongate in a north-westerly direction, had dimensions of about 275 m by 120 m, and a crater, referred to as "Fissure Crater", was present on its western side.

In November, 1969, this configuration of craters was absent: instead of two craters, there was a single vent in the northeastern quadrant of no. 2 crater, with precipitous walls defining its northern and eastern sides (figure 7). On the western and southern sides, the crater walls dropped steeply to a platform that shelved inwards at a high angle to the edge of the deepest part of the crater. Emissions of water vapour concealed the bottom of the crater, but its depth was

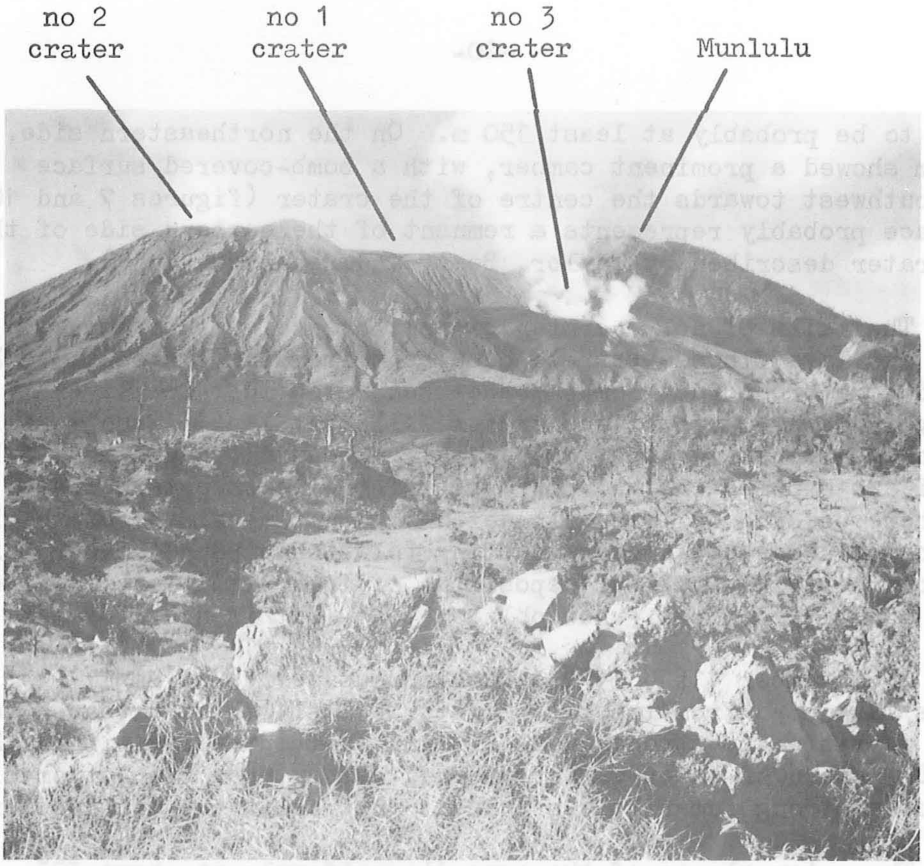

Figure 8. Northwestern side of Langila Craters, showing thick vapour emission from no. 3 crater, and slight vapour emission from no. 2 crater. In the foreground are the blocky tops of lava flows erupted from the Craters. Presumably because of the effect of toxic volcanic gases and vapours, the trees in the foreground have been stripped of their foliage. Taken 4/9/70 (Neg. No. M/1109).

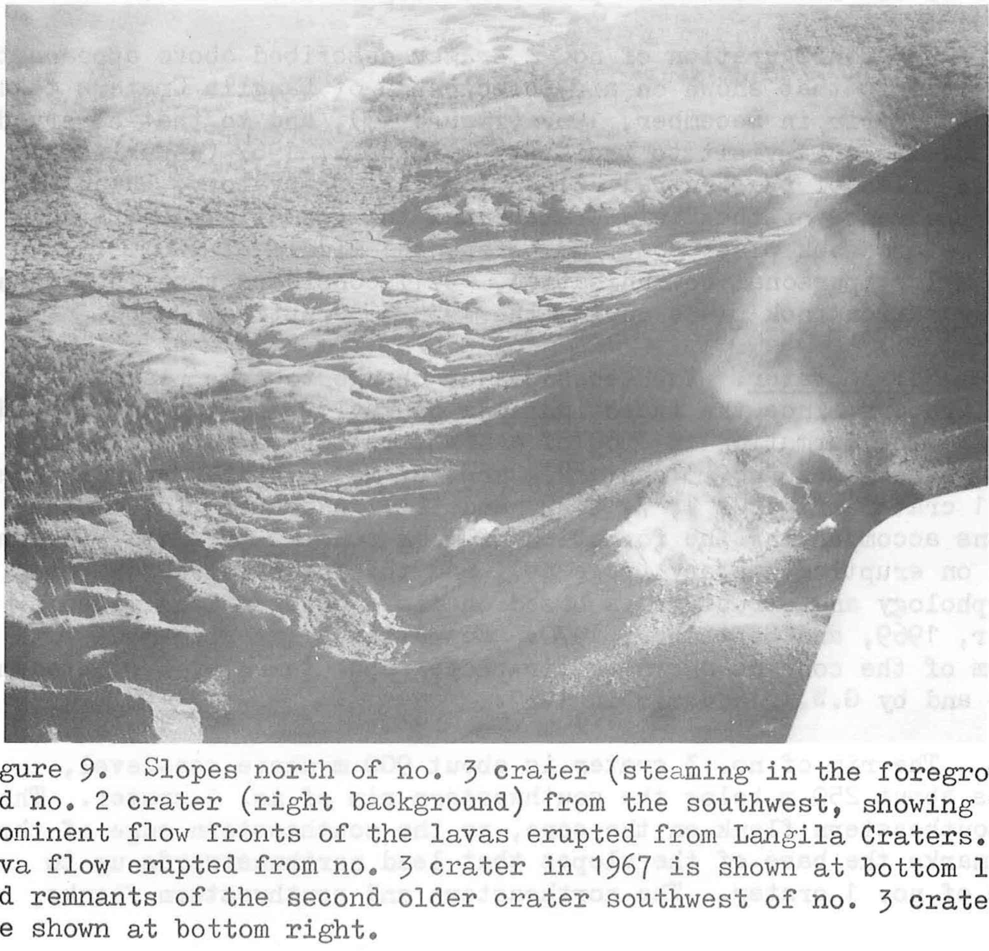

Figure 9. Slopes north of no. 3 crater (steaming in the foreground) and no. 2 crater (right background) from the southwest, showing the prominent flow fronts of the lavas erupted from Langila Craters. The lava flow erupted from no. 3 crater in 1967 is shown at bottom left, and remnants of the second older crater southwest of no. 3 crater are shown at bottom right.

estimated to be probably at least 150 m. On the northeastern side, the crater rim showed a prominent camber, with a bomb-covered surface dipping southwest towards the centre of the crater (figures 7 and 10). This surface probably represents a remnant of the eastern side of the eastern crater described by Taylor, Best, and Reynolds (1957).

The walls of no. 2 crater consist entirely of fragmental deposits, and lava flows appear to be absent from the succession. Lava blocks and some breadcrust bombs are concentrated in thick layers, especially in lower parts of the crater wall, but lapilli and ashes are the most common constituent of crater wall exposures. Well bedded layers of lapilli are exposed in the upper part of the northeastern crater wall, but elsewhere bedding is less well defined. In places, there are clear indications of large-scale cross-cutting relationships and inward dips, which almost certainly reflect deposition of fragmental material from different eruptive centres - now obliterated - within no. 2 crater.

On November 11th, 1970, a continuous series of small avalanches was noted from the steep crater walls; these appeared to have been initiated by strong gusts of wind that spiralled within the crater. Emissions of water vapour emerged mainly from the bottom of the crater, but a strong fumarole was present just below the southwestern rim.

The outer slopes of the cone dip uniformly at about 30°. Erosion gullies cut into the outer flank, and expose deposits of fragmental materials similar to those in the crater walls. On flat exposed surfaces, lava blocks and bombs are concentrated, the lighter interstitial clasts of the fragmental deposits having been removed by wind to produce a "lag" deposit. On the northern slope of the cone remnants of old lava flows are preserved (figure 8).

The configuration of no. 2 crater described above appears to be identical to that shown on air-photographs of Langila Craters taken by G.W. D'addario in December, 1967 (figure 10), and to that observed by R.F. Heming on a visit to the Craters in July, 1967 (unpublished report in files of the Central Volcanological Observatory, Rabaul). The disappearance of the "Twin Crater" and the formation of a single vent therefore took place sometime before the middle of 1967. G.A.M. Taylor (personal communication, 1971) considers that this change in configuration took place during the 1954-56 eruptive period.

<u>No. 3 crater</u>. The second major change to take place at Langila Craters since the investigations of Taylor, Best, and Reynolds (1957) was the formation in 1960 of a new satellite cone with summit crater - here named "no. 3 crater" - west of no. 2 crater and northwest of no. 1 crater (figures 1, 7, 8, 9, and 12). A description of the eruptions accompanying the formation of this cone is presented in the section on eruptive history (page 17), and the following description of its morphology and structure is based on field observations made in November, 1969, and September, 1970. Comparisons are also made with the form of the cone as shown on air-photographs taken by C.D. Branch in 1964 and by G.W. D'addario in 1967.

The rim of no. 3 crater is about 900 m above sea-level, which is about 250 m below the southwestern rim of no. 1 crater. There is no southeastern flank on the cone, as the southeastern edge of the crater marks the base of the slopes that lead northwestwards up to the rim of no. 1 crater. The northeastern and southwestern flanks, however, are well defined, and the long northwestern slopes merge with the valley floor between Talawe volcano and Langila Craters.

No. 3 crater is roughly circular, with a diameter of about 150 m. Between 1969 and 1970, the southeastern rim was a few metres higher than the northwestern rim, but on the photographs taken in 1967 by G.W. D'addario the altitude of all parts of the rim is shown to have been more or less constant. Figure 12 illustrates this change in crater shape; it also shows that the depth of the crater has increased since the 1967 photographs were taken. Whereas in 1967 the crater floor appeared to be flat, and to show a concentric arrangement of circular ridges only a few metres below the crater rim, the crater in September, 1970, had a maximum depth of about 60 m in its southern part. Figure 9 also shows that in December, 1967, a shallow depression - remnants of a second older crater - were present southwest of no. 3 crater. This depression was also observed by D'addario in January, 1967 (personal communication, 1971), but it was not visible in 1969 and 1970.

A photograph taken of Langila Craters by C.D. Branch in November, 1964 (B.M.R. negative number GA/4646) shows the cone of no. 3 crater in an early stage of development; the height of the cone is estimated as about half that of the crater rim in 1970. In the photograph, white vapour is being emitted from no. 3 crater, but no. 1 and no. 2 craters appear to be inactive.

Emission of water vapour and sulphur dioxide was almost continuous when the crater was viewed at close quarters in 1969 and 1970, but cessation of these emissions for a few hours on September 3rd, 1970, enabled the northern rim to be reached. From this vantage point, the bottom of the crater was seen to be sealed, and to contain a small pool of steaming yellow-green water. Numerous points in the crater wall emitted water vapour and thick fumes, mainly of sulphur dioxide and hydrogen sulphide, and they were depositing sublimates (including sulphur). Lava blocks and scoriae covered all surfaces of the cone, and similar fragmental deposits, with lapilli and ash, appeared to be the sole constituent of the crater walls.

Activity at Langila Craters late in 1967 was investigated by G.W. D'addario on 30th December, 1967 (personal communication, 1971). D'addario observed and photographed the Craters from the air, reached the northern slopes of no. 3 crater on foot, and noted that a lava flow had been erupted from it (figures 9 and 12). The lava flow was cold; and as R.F. Heming did not observe the flow on his visit to the Craters on 8th July, 1967 (unpublished report; Central Volcanological Observatory, Rabaul), it is concluded the lava was extruded sometime between July and December, possibly in November or early December, when bright glows were seen above the Craters (see page 22). The flow was not seen on visits to the craters in 1969 and 1970, and it is assumed that the fragmental products of later eruptions had buried it. (G.A.M. Taylor also observed a small lava flow on the rim of no. 3 crater in January, 1961, but, as with the flow produced in 1967, it appears to have been buried by later fragmental deposits; see page 17).

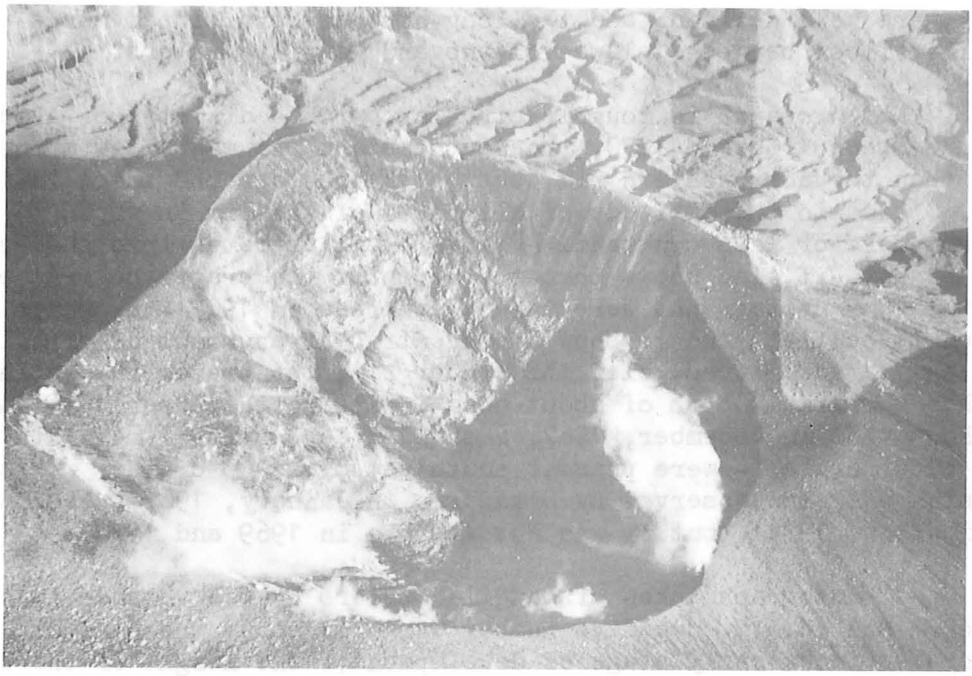

Figure 10. Aerial view of no. 2 crater from the South.
Photograph taken 30/12/67 by G.W. D'addario.

Figure 11 Explosive eruption from no. 3 crater.
Photograph taken 30/12/67 by G.W. D'addario.

The 1967 lava flowed northwestwards from no. 3 crater and, at the base of the cone, it turned northwards, and became channelled into a steep-sided gully. At the turning point, part of the flow overrode the western wall of the gully, and flowed into a second gully to the west of the first one. The main body of lava, however, continued down the first gully for 290 m reaching a point 1136 m above sea-level (G.W. D'addario, personal communication, 1971). Prominent lava levées were present nearer the cone, but these diminished towards the snout of the flow. The lava was an "aa" flow: its upper surface consisted of a jumbled mass of scoriae and blocks. D'addario collected a sample from the lava flow, and this was submitted to the Australian Mineral Development Laboratories (AMDL), Adelaide, for petrographic description and chemical analysis (AMDL Report numbers: AN2961/68 and MP2961/68).

In September, 1970, a sample, petrographically similar to the one described in the AMDL Reports, was collected from a lava flow in the wall of a gully draining directly off the northwestern flank of no. 3 crater (sample 0063A in Table 1). This sample, therefore, could have been taken from the flow erupted from no. 3 crater in 1967. However, in the field, this could not be definitely established as, when extrapolated southeastwards, the flow projected beneath the base of the cone of no. 3 crater, and it may, therefore, have originated from no. 1 crater.

<u>Other satellite cones, and lava fields</u>. Langila Craters are the most prominent cluster of satellite vents on the flanks of Talawe. There are, however, other satellite cones north and east of Talawe that also form prominent topographic highs; these are indicated and labelled on figure 3.

The largest of the satellite cones, Gulu (or Bulu; Fisher, 1939), is about 1.5 km east of no. 1 crater; its height is given as 2586' (1093 m) above sea-level by Taylor, Best, and Reynolds (1957). Gulu has a small, thickly timbered summit crater which is breached on its northern side. In line with Gulu to the southwest are two smaller cones, labelled E* and D in figure 3. Like Gulu, these cones are extinct, covered by thick bush, and have small summit craters (150-200 m in diameter). Two and a half kilometres east of Gulu lies another satellite cone, designated F in figure 3.

On the northeastern coast there are three satellite cones, all covered by vegetation, and referred to as G, H, and J on figure 3. G is a kunai-covered, north-south ridge about 1.5 km south of the Cape Gloucester airstrip, and in almost direct line with Langila Craters 6 km to the south. As described on page 28, lava from this cone is unusual in containing a high percentage of olivine phenocrysts compared to other lavas from the Cape Gloucester area.

North and northeast of Langila Craters, numerous lava flows with well-preserved flow fronts, lava levées, and blocky surface structures fan out towards the coast (figures 3, 8 and 9). The flows are covered only by kunai grass and scrub, and are clearly of Recent origin. On the air-photographs of the area (figure 6), the flows are seen to have originated from Langila Craters and Gulu cone, and they

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* Taylor, Best, and Reynolds (1957) refer to cone E as "Observation Point", as it was from here that eruptions from Langila Craters were viewed in 1954.

demonstrate that, although explosive activity has dominated the eruptive history of the Craters during the past thirty years (see section on eruptive history), extrusion of lava has been a common phenomenon during the past one or two hundred years. Newly erupted lava flows may have been observed by Powell (1883) who viewed the Cape Gloucester area in 1878; he gave a graphic description of the appearance of the terrain from the north, stating "... there must have been some hundred or more volcanoes all belching fire and smoke, indeed the land seemed all on fire". This description, as pointed out by Taylor, Best, and Reynolds (1957), may refer to the fact that at this time "not only were the numerous parasitic cones on the slopes of Langila active, but fresh lava flows covered extensive areas". The fresh lava flows were perhaps steaming, leading Powell to mistake them for numerous volcanoes in eruption.

Discussion

From the foregoing descriptions, it is clear that, throughout the Quaternary, the volcanological development of the Cape Gloucester area has involved eruptions from numerous sources. Changes in the positions of these sources were not random; rather, they appear to have been characterised by shifts along well-defined lines that presumably represent linear faults up which magma was able to move. It is the purpose of this section to identify these lines of volcanism, and to summarise the volcanic history of the area.

The most obvious alignment of volcanoes is that of the three major volcanic centres in the area - Tangi, the Aimaga Complex, and Talawe - which form a north-south line more or less perpendicular to the general east-west trend of New Britain and the islands to the west (figure 3). This structural configuration is similar to the chain of volcanoes comprising Willaumez Peninsula (170 km east of Cape Gloucester) which extends northwards from the north coast of New Britain, perpendicular to the east-west trend of the volcanic arc (figure 1).

The degree of dissection on Tangi is greater than that on any other volcano in the Cape Gloucester area, and Tangi clearly produced its last eruption before either Talawe or the Aimaga Complex became extinct. Dissection on Tangi is similar to that of the Hydrographers Range, a Pleistocene andesitic stratovolcano in northeastern Papua. Employing potassium/argon dates, Ruxton and McDougall (1967) concluded that the Hydrographers Range underwent its final stages of construction between 0.65 and 0.70 million years ago. Ruxton and McDougall described the dissection of the volcano as "in a late planeze-early residual mountain stage" (terminology of Kear, 1957): "On the flanks..., little dissected triangular sectors (planezes, Cotton, 1952) occur between deeply incised consequent streams. These give way upward and inward to radially arranged accordant mountain ridges with mature weathering profiles preserved on their crests". Tangi shows these same erosional features (see page 3), and as its height and structure are also comparable to that of the Hydrographers Range, it is assumed that volcanic activity on Tangi must have terminated at about the same time (650,000 to 700,000 years ago).

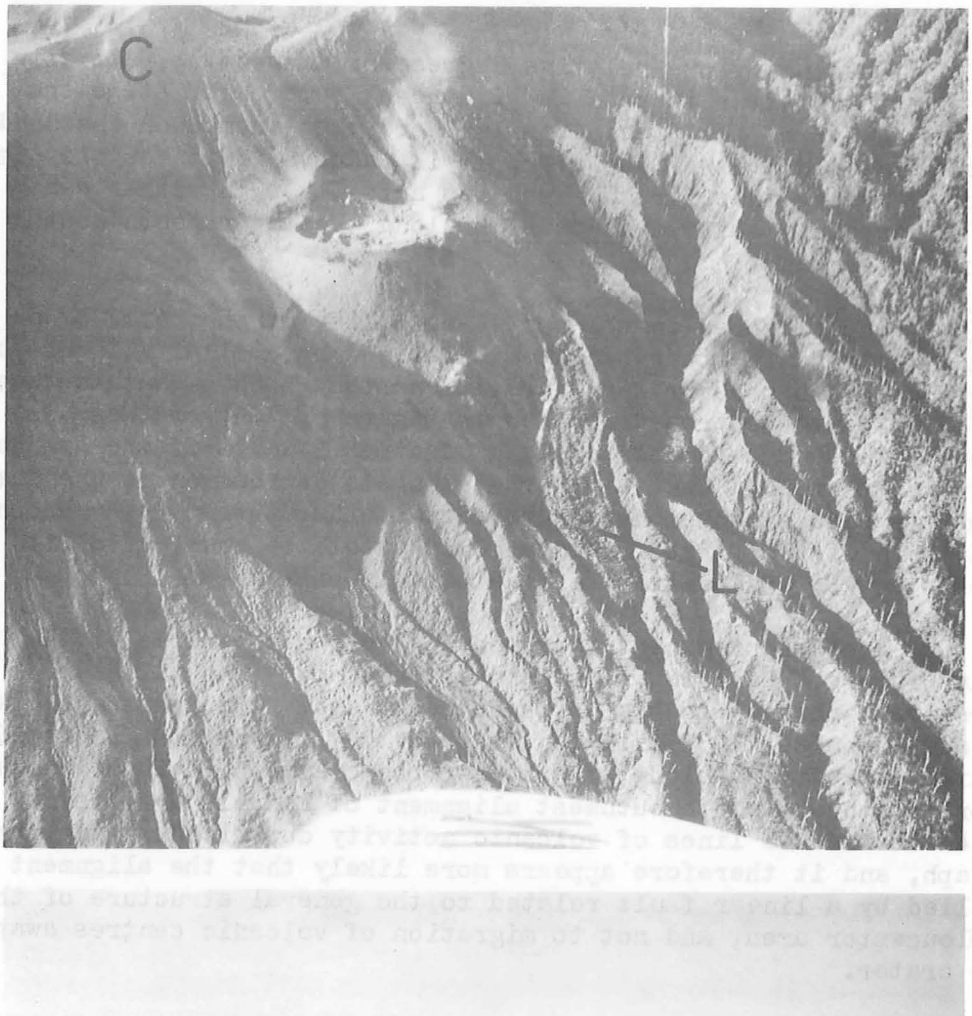

Figure 12. Comparative photographs of the northwestern side of Langila Craters. The upper photograph, taken 30/12/67 by G.W. D'addario, shows the shallow symmetrical form of No. 3 crater, the lava flow of 1967 (L), and the minor crater on the northwestern rim of No. 1 crater (C). The lower photograph, taken 2/11/69, illustrates the change in shape of the No. 3 crater rim, and shows that the 1967 lava flow was concealed by later deposits (Neg. No. M/981)

Judging by the relative degrees of dissection, activity from Talawe continued after that of Tangi, and at some later stage the volcanic centres of the Aimaga Complex were also formed on the saddle between Tangi and Talawe. However, it is unknown if it was the Aimaga Complex or Talawe that first ceased its activity. In either case, activity certainly shifted northwards along the major north-south fracture after Tangi had become extinct.

Superimposed on the north-south line of the three major volcanic centres are other lineaments defined by smaller volcanic cones in the area. Two more or less parallel northnortheast-southsouthwest lines of volcanic centres are shown in figure 3. One of these is defined by the summit crater of Tangi centres A and C of the Aimaga Volcanic Complex, and centre F; the elongate depression at the summit of centre A is also oriented northnortheast-southsouthwest. The second line, to the north of the first, includes Gulu satellite cone, satellite centres E and D, and centre B of the Aimaga Complex.

Another prominent alignment of volcanic centres is that of Langila Craters. Munlulu Crater and craters no. 1 and no. 2 are progressively younger to the northnortheast and, as suggested by Taylor, Best, and Reynolds (1957), it is possible they represent a successive migration of activity along an arc from the crater of Talawe. However, the northnortheast-southsouthwest alignment of Langila Craters is parallel to the two lines of volcanic activity described in the preceding paragraph, and it therefore appears more likely that the alignment is controlled by a linear fault related to the general structure of the Cape Gloucester area, and not to migration of volcanic centres away from Talawe crater.

Recent eruptions from Langila Craters have not continued on the same northnortheasterly trend. In 1960, the formation of no. 3 crater west of no. 2 crater marked a change in the general pattern of eruptive foci, and in future it will be of interest to see whether this change signifies the end of the formation of new vents on the same northnortheasterly line and the beginning of activity on a new line, or if no. 3 crater is merely a satellitic cone on the flank of a volcanic line that will continue to grow northnortheastwards.

In conclusion, the geological development of the Cape Gloucester area may be summarised as follows. Firstly, the volcanoes Tangi and Talawe emerged from the sea as separate volcanic islands off the western end of New Britain. Although these volcanoes grew from a north-south fracture, the Tangi eruptions seem to have been concentrated along a short east-west line as the cone of Tangi (and its summit crater) is elongate in an east-west direction. As Tangi and Talawe grew, the cones coalesced, and joined the western side of Mt Schrader on mainland New Britain. Activity ceased at Tangi, but continued in the north where Talawe grew further, and centres A, B, and C of the Aimaga Complex were constructed, forming a third major volcanic complex in line with, and on the saddle between, Tangi and Talawe. Smaller satellite vents broke out, notably on the northern and eastern flanks of Talawe, the positions of many of these being controlled by northnortheast-south-southwest lines of weakness oblique to the major north-south line. Talawe and the Aimaga Complex became extinct, and Recent activity was restricted to Langila Craters which formed east of Talawe crater, and migrated northnortheastwards.

ERUPTIVE HISTORY OF LANGILA CRATERS UP TO 1970

Introduction

Few active volcanoes in Papua - New Guinea occupy a more suitable site for observation than do Langila Craters.

Situated within 8 km of Cape Gloucester airstrip, which at present receives a minimum of two aircraft a week, and close to the regular air route which links mainland New Guinea with Rabaul, many eruptive events from Langila Craters have been reported to the Central Volcanological Observatory Rabaul within a few hours of having taken place. Yet, throughout the 1950's and 1960's, the most consistent source of information has been the Roman Catholic Mission at Kilenge, from where Father McSweeney and his associates forwarded descriptions of much of the eruptive behaviour set out below. With the establishment of the Cape Gloucester Patrol Post to the east of Langila in 1955 came another reliable reporting source. Information has also been received from Sag Sag Anglican Mission, and occasionally from small cargo vessels which service the north of New Britain and other islands in the vicinity. Finally, there are the accounts of numerous volcanologists who have inspected Langila Craters over the last three decades.

All this information has been assembled at the Central Volcanological Observatory, Rabaul, and it is from this source that much of the eruptive history has been compiled. Information has also been extracted from Volcanological Report Forms (which were initiated in 1954) and from the Monthly Reports of the Observatory. Details of the reporting source are given only where the writers consider that qualification is neccessary; minor items of information which are considered unreliable have been omitted. Some descriptions have been modified slightly, so as to conform with the terminology acceptable in volcanological literature.

Certain important aspects of the activity, such as the opening of a new vent in 1960, and vague reports of activity at vents hitherto considered dormant, are poorly documented, though some details are available.

The conditions that prevailed at Langila Craters between 1952 and 1956 are described at length by Taylor (1952a, 1952b, and 1956), Best (1956a,b), Reynolds (1955), and Fisher (1959). Almost all the information contained in these accounts is incorporated in Taylor, Best, and Reynolds, (1957), and a summary of these data adequately describes the eruptive history for that period.

Notes on the instrumental observations carried out at Langila Craters are given separately, and an attempt has been made to outline the cause of instrumentatal failure.

Very little is known of the eruptive history of Langila Craters before the observed resurgence of activity in 1954. Information received from native villagers in the area suggests that an eruption took place between 1890 and 1900 (Fisher 1939), and Taylor, Best, and Reynolds (1957) concluded, from a description given by Powell (1883), that the craters were in eruption in 1878.

Eruptive History

Observations made before the 1954 eruption. In 1938 no. 2 crater showed no signs of fumarolic activity, whereas the Chimney Crater (situated within no. 1 crater) and fumarole vents which were situated outside no. 1 crater rim were emitting gas (Fisher, 1939). The general condition of no. 1 crater remained much the same up to 1970, whereas between 1938 and 1944 fumarolic activity developed in the Twin Craters of no. 2 crater, and aerial photographs taken in 1947 indicate that the Twin Craters were also reamed out at some time during the intervening period. Support for assuming this change in condition was afforded by the presence of dead vegetation in and around no. 2 crater (Taylor, Best, and Reynolds, 1957).

In May, 1952, vapour emission from a new source was observed by Father McSweeney of the Kilenge Roman Catholic Mission. Acting on this report G.A.M. Taylor make an inspection of the summit region of Mount Langila, and concluded that a recent increase in the emission of gas from vents within no. 2 crater had taken place. Numerous ascents of Langila Craters were made during July and August, 1952, and much information was obtained. The increase in the volume of gas emitted, the high concentration of sulphur dioxide, the abnormally high temperatures recorded, and the occurrence of subterranean noises, were all considered phenomena which could possibly preceed an eruption (Taylor, Best, and Reynolds, 1957).

Further observations were made in October and November, 1952. Though no definite trend in the activity could be established, instrumental observations showed that abnormal conditions still prevailed, and that eruptive activity might be expected (Taylor, Best, and Reynolds, 1957).

Activity between 1954 and 1956. A resurgence of activity from Langila Craters occurred on 18th May, 1954, substantiating the predictions of the volcanologists concerned. Voluminous emissions of vapour and gas issued from no. 2 crater, and this activity was punctuated by explosive phases during which ash and bombs were ejected. The outbreak was preceeded by a gradual increase in the emission of white vapour, which later took on a yellow colour, and was first noticed on 1st May by Mr K. Ryall, master of the M.V. 'Irene'. There followed a protracted period of activity which lasted until March, 1956; this is fully described by Taylor, Best, and Reynolds (1957), who present an events chronology of the main explosive phases. This eruption was characterised by periods of intermittent explosive activity, separated by lengthening periods of calm. From September, 1954, to March, 1956, activity was noticably more intermittent, with explosive events occurring in October and November, 1954, and in February and June, 1955. Numerous explosions may have occurred at times not shown in the events chronology, but the authors excluded any information which could not be substantiated. They concluded that the events were typically 'vulcanian', with the intermittent explosive activity indicative of a magma of low temperature and high viscosity. A relationship was inferred between the eruptions and conditions of regional stress beneath the Bismarck Sea volcanic chain. Evidence also pointed to the effect of luni-solar influences on the eruptive activity.

Activity in 1958. Explosive activity was resumed on 21st April, 1958, and was accompanied by rumbling and small tremors. Falls of fine ash were reported in the Kilenge area on the 24th and 25th April, and on the 25th voluminous ash clouds ascending to over 3000 m above sea level were observed from near Kilenge village.

A particularly strong explosive phase commenced on 20th May at 1249 hrs(LT), when a column of dark ash-laden vapour ascended to 3000 m above sea level. The Assistant District Officer, Mr Webb, witnessed this event from Sag Sag Anglican Mission, and during the following 36 hours he observed explosions every 1-2 minutes. Fine ash fell over an area to the northwest of the Craters, 5 mm being recorded at Kilenge Mission. Within 2.4 km of the crater the forest on the northwest flanks of Langila Craters was stripped of light vegetation, and large ejected blocks produced impact craters over one metre deep, at distances up to 1.6 km from the summit.

The source of this eruption was no. 2 crater, and the power of the initial explosion on the 20th appears to have exceeded that of any other single event witnessed. Voluminous vapour columns were observed until early June, after which a decline is activity ensued.

Activity in 1960 and 1961. Explosive activity from Langila Craters was resumed on the 19th December, 1960. The initial outburst, of three days duration, was described by Father McSweeney as having consisted of thunder-like rumblings, accompanied by voluminous ash-laden vapour emissions. An inspection by G.A.M. Taylor on the 11th and 12th January, 1961, established that this activity was centred on a new vent, between 100 and 200 metres in diameter, situated on the northern flanks of no. 1 crater. This vent is named "no. 3 crater" (page 10).

Intermittent outbursts of varying intensities continued from the crater for the next three months. No. 2 crater showed mild activity until the middle of January, when vigorous explosive activity recommenced.

A summary of activity reports received at the Rabaul Observatory follows.

January, 1961: Renewed activity was first reported to the Observatory on the 9th, and was described as consisting of continual vigorous white vapour emission punctuated by intermittent, voluminous ash-laden vapour ejections from no. 3 crater. A glow was seen above the rim of no. 3 crater during the morning of the 17th, and a small blocky lava flow was reported by Taylor to be filling a valley immediately below the crater. Light falls of ash were reported from a number of nearby villages, and an area of forest 3-4 km to the northwest of the crater was seen to have been stripped of leaves. Vigorous explosive activity commenced from no. 2 crater on the 18th, and continued until the 24th. Both craters were obscured by cloud until the 7th February.

February: Rumblings were heard on the 5th. Intermittent ash ejections from no. 3 crater were seen daily between the 8th and 15th; no activity was reported from no. 2 crater.

March: No. 3 crater seemed less active than during February, although observations were hampered by heavy cloud. One large explosion was reported around the middle of the month, and small ash ejections were seen up to the end of the third week.

April-May: No explosive activity was reported.

June: Explosive activity recommenced from no. 3 crater on the 12th. Further ash ejections were reported on the 19th and 23rd.

July: Noises "like a motor truck" were heard from the direction of the Craters on the 12th. Four small ash-laden vapour clouds were ejected from no. 2 crater on the 24th and similar activity was recorded each day until the end of the month. No. 3 crater emitted only white vapour during this period.

August: Small ash ejections, averaging one or two a day, issued from no. 2 crater on the 1st, 7th-9th, 11th, 15th, 16th, 18th, 19th, and the 21st. An aerial inspection made by J.H. Latter on the 29th revealed only minor white vapour emission.

September: White vapour clouds passed over Sag Sag Mission on the 1st, 2nd, 4th, 8th, 23rd, and 26th. These probably originated from no. 2 crater.

Activity in 1962 and 1963. Renewed activity commenced in March, 1962, and was first reported by Mr T. Hicks, the District Officer. The source of the activity was described as the northern vent (presumably no. 2 crater), from which fine ash was ejected intermittently to heights of 500 m above the vent. No more details were given.

The following tabulation summarises the information accumulated throughout the remainder of year, and also throughout 1963.

9th April, 1962.	An eruption at 1340 hours (LT), with ash clouds ascending to 2300 m above sea-level, was observed from Sag Sag Mission.
16th August.	Muffled explosions heard at Sag Sag Mission at 2056 hours (LT) and later, with ash falling at Kilenge Mission.
29th December.	Aircraft reported explosions at 1325 hours (LT) with ash clouds rising to 3000 m above sea-level. The source of the eruption appears to have been no. 2 crater. Reports of explosions and ejections of ash on the 12th were also received at the Volcanological Observatory, but these were not substantiated.
19th-27th Jan. 1963.	Volcanologist J.H. Latter carried out a ground inspection of a peculiar low-pressure vent which had been located half way between the Cape Gloucester airstrip and the craters. (The origin of this vent is uncertain, and there is no reference to it after February, 1963). During his stay at Cape

19th-27th Jan. 1963. (Cont.)	Gloucester, Latter heard numerous explosions, and ash was seen falling on the flanks of no. 2 crater. No. 3 crater was emitting white vapour continuously.
21st February.	Ash clouds were erupted at 1445 hours (LT), and they rose to 2400 m above sea-level. This report was received from Sag Sag Mission.
1st March.	An aerial inspection by C.D. Branch revealed that 'spearheaded projections' of ash were rising to 600 m above no. 3 crater. Similar activity had been seen by a Patrol Officer in February, but was not reported to the Rabaul Observatory.
1st May.	A report from an unknown source indicated that Langila Craters were "extremely active", and that extensive ash cover was affecting the outlying areas.
2nd May.	C.D. Branch carried out an aerial inspection, and observed that ejections of light brown ash from no. 2 crater were ascending some 2000 m. A strong white vapour emission characterised the activity at no. 1 and no. 3 craters.
10th August.	A Mr J. Green reported that no. 1 crater was the source of a grey/black ash column, which rose to over 1000 m above the summit.* This was observed at 0800 hours (LT). Later, a similar type of eruption column issued from no. 3 crater.
11th August.	At 1000 hours (LT) no. 3 crater produced a further discharge of grey/black ash, and no. 1 and no. 2 craters emitted white to grey vapour.

Activity in 1965. A report of renewed activity was received on 23rd January from aircraft pilot Captain R. Hay. "Smoke", accompanied by vertical explosions of ash, had been observed at 0800 hours (LT) on that day. Subsequent enquiries revealed that emissions of grey to brown vapour had been witnessed for several weeks (report from Cape Gloucester Patrol Post). A summary of the year's other events is given below.

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* Several references to explosive activity from no. 1 crater are present in the files at the Central Volcanological Observatory. At no time has such activity been confirmed by the volcanologists and, taking into account the close proximity of no. 1 and no. 2 craters, it is considered that the crater has been incorrectly identified.

21st February: Father McSweeney reported activity on the morning of the 21st, which consisted of weak ejections of ash accompanied by loud rumbling noises. During the night a glow above Langila Craters was observed, but the crater producing this effect was not identified.

March-April: Activity was confined to the emission of white vapour from no. 1 and no. 2 craters.

May: On an unspecified date, vapour clouds issued from no. 3 crater, accompanied by loud explosions. This activity was witnessed by Father McSweeney.

June: Mild emission of white vapour from all three craters continued throughout the month.

July: Mild activity continued, but it appears to have been punctuated by strong explosive pulses of short duration. On the 17th, an airline pilot reported the first of these explosions, witnessed while en route to to Rabaul. He described how rocks were ejected to 1200 m above sea-level, and fine ash to 4000 m above sea-level. An inspection on the 18th by G.W. D'addario and D.D. Middleton revealed only fumarolic activity from no. 2 crater, no. 1 and no. 3 craters being inactive. On the 27th, a report of further activity was received from an airline pilot, who observed at 1438 hrs (LT) a 'gas cloud' rising up from Langila Craters. As with the first report, the location of the active vent was not given. On the 28th, D'addario returned to Cape Gloucester, where he was informed by residents that no. 3 crater had produced numerous explosions and an ash-fall on the 27th. During his visit D'addario observed only white to light grey vapour emission from no. 2 and no. 3 craters. D.D. Middleton replaced D'addario on the 29th, and carried out seismic recording until 5th August. Several minor explosive ejections of ash from no. 3 crater were observed during this period, notably on 30th July. An overall decrease in activity was assumed. The main area affected by the fallout from the July activity was limited to within several hundred metres of no. 3 crater.

August: Audible explosions were reported on the 8th, and ash fell at Kilenge Mission and the Cape Gloucester airstrip on the 9th and 14th. Emissions of ash-laden vapour continued intermittently until the 22nd. It is not certain which vent was active, though some reference is made to no. 3 crater.

September-December: Very mild activity continued; stronger ejections of ash-laden vapour took place on 25th and 27th October. A steady decline in activity was then resumed, though vapour emission increased between 1st and 4th November. There were no ash ejections during December.

Activity in 1966. Langila Craters showed mild, intermittent explosive activity during the first part of the year: this appears to have been confined to no. 3 crater, but several reports of activity received do not identify the active vent (or vents). The data are summarised in the following tabulation.

January.	The mild fumarolic activity was interrupted by an ash ejection on the 21st. The active crater is not known.
April.	Small ash ejections from no. 3 crater occurred on the 3rd, 6th, and 30th.
May.	Several small ash ejections issued from no. 3 crater on unspecified dates.
June.	Moderate explosive activity, accompanied by rumblings, took place on the 5th, between the 6th and the 9th, and on the 20th. Numerous rumblings were heard on the night of the 17th.
August.	A large explosion occurred on the 2nd, and ash fell on Kilenge Mission for one hour. Rumblings at frequent intervals were heard at the Mission on the 4th.

No further activity was reported during the remainder of 1966, and no volcanological investigation was undertaken.

Activity in 1967. Langila Craters showed mild explosive activity from no. 2 crater during the first half of the year. A major phase of explosive activity commenced in July; this continued into 1968, and was confined to no. 2 crater until near the end of 1968, when no. 3 crater commenced eruption.

January: Activity commenced on the 19th from no. 2 crater with the ejection of several small ash-laden vapour clouds. Explosions were heard on the 22nd at Kilenge Mission. No. 3 crater emitted only white vapour during this time. On the 23rd, the Patrol Officer at Cape Gloucester Patrol Post reported a new parasitic crater, situated on the northeastern flank of no. 2 crater. An aerial inspection was made by G.W. D'addario on the afternoon of the 23rd. He reported that white vapour was issuing from no. 2 and no. 3 craters, but no reference was made to a new parasitic crater.

February: Several ash ejections issued from no. 2 crater. No dates were given.

May: Several light falls of ash were recorded on the Cape Gloucester airstrip, though no reports of explosive activity were received from the Kilenge Mission.

June: Ash ejections from no. 2 crater occurred on the 1st and 5th. A very loud explosion on the 20th heralded a major phase of activity which continued until the end of the year. This initial activity was centred on no. 2 crater, from which a voluminous ash-laden vapour cloud was ejected to a height of about 6000 m above sea-level. The explosion was accompanied by a weak earth tremor, felt Intensity II (MM) at Kilenge Mission. A number of smaller events followed at irregular intervals during the morning. An aerial inspection later in the day revealed only white vapour emission.

July: The main phase of activity commenced on the 1st, with a rumbling explosion from no. 2 crater. Major explosions, averaging two per day, occurred on the 2nd, 3rd, 6th, and 8th. Between the 8th and 14th, a ground inspection was made by R.F. Heming. During this period, an average of six ash ejections per day was observed. The majority were small, usually noiseless events which sent a grey-brown ash cloud rising a few thousand metres above the crater rim. White vapour emission was the only activity evident from no. 3 crater. Further explosions occurred on the 28th and 30th, and on the 30th a heavy ash fall was recorded at Kilenge Mission.

August: A large audible explosion in the no. 2 crater, accompanied by the ejection of voluminous ash clouds, occurred on the 17th. Frequent rumblings were heard between the 24th and 28th. Incandescent material was seen draping the crater rim on several evenings. Further explosions were noted on the 29th, 30th, and 31st.

September: Loud rumblings continued almost unabated during the month. Explosions from no. 2 crater were recorded on the 20th (twice), 21st, 28th, and 30th.

October: Rumblings were heard on most days. Small explosions from no. 2 crater were reported on the 6th, 8th-14th, 17th, 22nd, and 25th-31st.

November: Rumblings and ash ejections occurred continually throughout the month. A bright glow was seen above no. 2 crater on the 3rd. The Volcanological Report for November from Kilenge Mission lists activity from three vents on the 19th. Unfortunately, the centres were not designated.

December: The activity continued and gathered intensity during the first part of the month, so that by the 21st explosions occurred at 10 minute intervals. A bright crater glow was seen on the evenings of the 14th and 17th, and on several occasions near the end of the month. A report received on the 26th suggested that the focus of activity had shifted to no. 3 crater. Aerial and ground inspections made by D'addario on the 30th confirmed this. At that time grey and white vapour ejections from no. 3 crater were averaging twenty per day, whereas only fumarolic activity was evident from no. 2 crater. A small blocky lava flow, 400 metres in length, which had recently issued from no. 3 crater was found to be cold when inspected by D'addario on the 30th (see page 11).

<u>Activity in 1968</u>. The 1967 eruption continued into 1968, with ash ejections finally ceasing on the 18th February. Activity during the remainder of the year, as reported from Kilenge Mission, was confined to small outbursts in March, April, and May.

January: During January and February daily telegrams were received from a Volcanological Assistant who was stationed at the Cape Gloucester airstrip. Ejections from no. 3 vent averaged 15 per day for the month, with peaks of 22, 29, 25, and 26 ejections recorded on the 8th, 11th, 15th, and 22nd, respectively. Ejection of both white and grey vapour was noted during this period, with a decreasing proportion of ash laden vapour ejections towards the end of the month. Rumbling explosions accompanied almost every ash ejection. A brief glow, originating from the ejection of incandescent boulders, was seen on the nights of the 3rd and 22nd.

February: The number of ejections from no. 3 crater declined erratically, and had ceased by the 18th. An average of 10 ejections per day were observed for the month up until the 18th; peaks of 24 and 23 ejections being recorded on the 2nd and 8th, respectively. Incandescence was seen on the evening of the 1st, 4th, 8th, and 11th. White vapour emission continued into early March.

March: Soft rumblings were heard at Kilenge Mission on the 24th.

April: Two loud explosions were heard on the 1st.

May: One loud explosion with accompanying ash ejection occurred on the 16th, and ash fell on Kilenge Mission.

Activity in 1969. There is only one report of activity during 1969. This was on the 29th September, when a single rumbling explosion was heard at Kilenge Mission, and an ash-laden vapour cloud was seen above the volcano. The active crater is not known.

Activity in 1970. Activity from no. 2 crater resumed in May, and continued until October. No. 3 crater remained inactive apart from fumarolic emission. Fumarolic activity was seen on the northern rim of no. 1 crater on occasions throughout the year.

The following tabulation summarises the reports received at the Central Volcanological Observatory.

May	From the 20th onwards, small emissions of white vapour were observed from no. 2 crater.
June	Ash laden vapour ejections from no. 2 crater were seen on the 1st, 6th, and 8th.
July	One ash ejection occurred on the 4th. The main phase of activity commenced on the 12th, when several moderate ash emissions were observed. The number and intensity of ejections increased over the following two weeks, and by the end of the month ejections averaged one per hour. Incandescent boulder slides were evident at this time.
September	Small ash ejections were seen on the 8th and 23rd; white vapour emission continued.
October	Vapour emission from no. 2 crater ceased during the month.

Instrumental Observations

During investigations of Langila Craters, varying instrumentation has thrown more light on the phenomena associated with eruptive activity. Though it is fair to state that little success was achieved in this field in the 1950's and 1960's, the experience gained enhances the possibility of predicting eruptions at some future date. The data obtained are summarised below.

Thermal investigations. The investigation carried out in June - August, 1952 (Taylor, Best, and Reynolds, 1957), brought to light the existance of abnormally high temperatures in no. 2 crater, which were consistantly over 200°C. These observations were made with a 200° maximum recording thermometer. Results obtained from an electric pyrometer proved unreliable.

The second investigation in October - November, 1952 (Taylor, Best and Reynolds, 1957), suggested that temperatures had fallen some 20-30°C, but no clearly defined trend was apparent.

During the eruption in 1954, Reynolds (Taylor, Best, and Reynolds 1957) recorded temperatures of 95-97°C at small fumaroles on the southeast rim of no.2 crater. No measurements were possible within the crater.

Composition of the gas. The June - August, 1952, investigation showed that as well as water vapour, much sulphur dioxide was being emitted from no. 2 crater; this had caused extensive damage to vegetation near the vent. Evidence also pointed to the existence of sulphur trioxide which caused great physiological discomfort to the volcanologists. Hydrogen sulphide was detected at distances more remote from the crater.

In October - November, 1952, the only noticeable change was an increase in the emission of hydrogen sulphide, which was more easily detected within the crater region. During this investigation condensates were collected and subsequently analysed. The results confirmed that the emanations contained sulphur dioxide and sulphur trioxide, while the variation in acidity indicated that the acid gas concentration more than doubled between July and August, 1952. The full details of the analyses are given by Taylor, Best, and Reynolds, (1957). Unfortunately, no further sampling was carried out until the eruption in 1954, and hence progressive changes in gas composition, as an indicator of increasing eruptive potential, could not be assessed.

Tilt. During the October-November, 1952, investigation, a cement block was constructed on the northeastern slope of Langila Craters, approximately 170 m below no. 2 crater rim. A simple bubble-type tiltmeter was installed, which registered an abnormal crustal movement, commencing with a fall towards the crater of five minutes of arc over a period of twenty-four hours. This was followed by a gradual rise of eight minutes over a period of eight days. Further anomalous tilting was recorded, and it was concluded that the irregular trend was unrelated to movement associated with changing volcanic conditions, but was probably associated with a 'seismic crisis' at Umboi Island (Taylor, Best, and Reynolds, 1957).

In August, 1954, a tiltmeter installed at Kilenge Mission recorded ground movement over a period of nine days, at a time when the explosive activity was not pronounced. A plot of the readings failed to reveal any definite trend which could be related to tumescence or deflation of the volcano.

With renewed activity in May, 1958, a tiltmeter was reinstalled at Kilenge Mission. The readings were found to vary over a wide range, and no conclusions regarding the trend could be drawn. G.A.M. Taylor (Monthly Report for May, 1958) inferred that regional unrest, similar to that envisaged in 1952, was responsible for the anomalous readings.

Seismic Activity. In 1952 several crudely constructed devices for recording earthquake ground motion were tried at Langila Craters, but with little success. During October and November, 1952, several shocks were recorded, but were later found to be related to a disturbance on Umboi Island (Taylor, Best and Reynolds, 1957).

During the eruption of 1954, a crude seismograph was constructed at Aipati village, and later at Kilenge Mission; neither proved successful. Whereas numerous shocks were felt by local inhabitants during the eruption, the absence of a good seismograph eliminated the possibility of classifying the earthquakes into those of a tectonic nature and those of volcanic origin. No continuous volcanic (harmonic) tremor, characteristic of prolonged phases of explosive activity, was recorded.

In May, 1958, a Willmore Seismograph was installed at Kilenge Mission during a period of activity, but no movements of volcanic origin were detected over a recording period of fifty-eight hours.

In January, 1961, some fairly positive results were obtained during an eruptive phase, from the Willmore Seismograph recording at Kilenge Mission. Three volcanic shocks were recognised on the records, and a small microseismic disturbance was tentatively attributed to movement of magma within or beneath the volcanic pile.

Seismic recording was carried out at Kilenge Mission from 29th July to 1st August, 1961. No results were given, but a recent examination of the seismograms failed to reveal any disturbances of volcanic origin.

In January, 1963, and November, 1964, a Willmore Seismograph was again operational for short periods at Kilenge Mission, and then at the site of a bomb explosion near the Mission. No volcanic shocks were recorded.

During a period of activity in July, 1965, one week's recording proved more successful. The Willmore Seismograph at Kilenge Mission recorded many emergent shocks of volcanic origin, which underwent a gradual decrease in number over a three day period, at a time when an overall decrease in the volume and frequency of ash ejections at the summit was observed. Strong microseismic activity masked the shocks, which could only be successfully analysed for the period of recording between 2200 hours (LT) and 0600 hours (LT).

A Willmore Seismograph station was again established at the airstrip during January and February, 1968. Its operation was hampered by technical difficulties. A number of small shocks of probable volcanic origin was, however, recorded during the first half of January.

A seismograph station was set up at the Cape Gloucester airstrip for a short period in June, 1970, during a phase of explosive activity from no. 2 crater. Battery failure, which has proved to be one of the major problems with portable seismic equipment, prevented any useful records being obtained.

Discussion.

The eruptive history of Langila Craters is known, in detail, for only the last two decades. Since the resurgence of activity in 1954, there have been but three years (1957, 1959, and 1964) when eruptions have not occurred, and one year (1969) when activity was limited to one short event. Langila Craters can be regarded, therefore, together with Manam, Bagana and possibly Ulawun, as one of the most active volcanic centres in the Territory.

Protracted periods of activity have characterised events since 1954, and the intermittency of explosive phases has often rendered the separation of distinct eruptive episodes impracticable. Many months of 'activity' have been represented by little more than normal vapour emission, which has, itself, fluctuated over the years.

The few facts known about the 19th century activity strongly suggest that lava flows were produced, but the only effusive events recorded in more recent times originated at the new, no. 3 crater, when a small blocky lava flow was expelled in 1961, and another in 1967. Generally, the observed activity has varied from almost pure steam explosions to episodes in which ash-laden vapour was emitted in sufficient volume to cover the surrounding country with veneers of fine ash. During stronger explosive phases large ejected blocks (or bombs) have produced spectacular impact craters on the flanks of the Craters, and at times incandescent bombs have been erupted in sufficient quantity to produce glowing collars around the crater rim. No calculations have been made of the volume of material ejected at any one stage, and it would be difficult to assess the percentage of primary material erupted, because considerable reworking of previously deposited tephra is evident.

The most important event on record was the opening of a new vent, and the subsequent growth of the cone of no. 3 crater.

Interpretation of the reports forwarded by observers suggests that nuées ardentes have not been expelled at Langila Craters since the 1954 outburst. However, recent developments at Ulawun Volcano (Davies, 1970) indicate that this phenomenon cannot be excluded from the eruptive record of basaltic volcanoes, purely on compositional grounds.

Instrumental measurements to date have been too fragmental for many conclusions to be drawn. However, sufficient work has been done to indicate that there is considerable potential for future development in this direction.

Thermal measurements made in 1952 indicated temperatures of over 200°C; these were considered at the time to be abnormally high. Whether this is true, and whether these readings represent pre-eruption conditions (cf. Tavurvur crater, Rabaul, where temperatures of up to 390°C preceeded the 1941 eruption; unpublished report, Central Volcanological Observatory), or whether these readings can be considered, normal (cf. Mount Lamington, where temperatures of over 200°C have been recorded 19 years after the last eruption; unpublished report, Central Volcanological Observatory) has yet to be firmly established.

Tumescence and deflation of the volcanic pile during eruptive episodes are phenomena now recognised as being somewhat diagnostic of some volcanoes. The failure of tiltmeter observations to reveal any significent movements at Langila Craters may indicate that such movements are not associated with activity from this centre. Or again, it may point to deficiencies in tiltmeter siting.

Seismograms obtained during periods of activity at Langila Craters are notable in that they contain a number of discrete volcanic shocks. This is in contrast to the situation at other volcanic centres, notably Manam Island, where seismograms obtained show that discrete shocks are extremely rare, a prominent harmonic tremor being the major expression of seismic activity.

PETROLOGY

One hundred and eleven rocks from the Cape Gloucester area have been examined in thin section. Modal analyses for thirty-three samples are given in Table 1, and the localities of these are listed, and divided into 5 groups, in Table 2.

J.K. Lovering described a suite of 10 specimens from the vicinity of Langila Craters in an appendix to the Report by Taylor, Best, and Reynolds (1957). In addition, petrographic descriptions of samples from the Cape Gloucester area, collected by volcanologists of the Central Volcanological Observatory, were supplied by AMDL (Report numbers MP2492/67, MP2961/68, MP279/69). Descriptions from both these sources indicate that the rocks were of the same mineralogy as many of those described here.

In common with other lavas from Quaternary volcanoes in New Britain those of the Cape Gloucester area are highly porphyritic, and the most common phenocryst mineral is plagioclase (cf. Johnson, 1970a,b). This is illustrated in Table 1 which shows that about half of the thirty-three rocks have more than 40 percent phenocrysts, and in all but three samples plagioclase is the most common type of phenocryst. Other phenocryst minerals are clinopyroxene (augite), pleochroic orthopyroxene, olivine, and iron-titanium oxide; aggregates of all these phenocryst minerals are also common.

The mineral contents of the Cape Gloucester samples indicate that the lavas are tholeiitic basalts and "andesites" *sensu lato* (hypersthene-normative, with silica values up to about 63 wt. percent). Probably none of the lavas is dacitic, and rhyolites appear to be absent from the area.

Plagioclase. Most lavas from the Cape Gloucester area contain more than 20 percent plagioclase phenocrysts (see Table 1), and chemical analysis of these rocks will almost certainly show high contents of alumina. Samples in which plagioclase phenocrysts are absent or deficient (less than 5 percent) contain prominent olivine phenocrysts (Table 1).

In common with plagioclase-rich lavas from other Quaternary volcanoes in New Britain, the plagioclase phenocrysts are complexly zoned; many of them show oscillatory zoning. Most of the larger phenocrysts (up to 3 or 4 mm long) show narrow "dust" zones of fine-grained crystalline inclusions (parallel to the compositional zones), and inclusions of glassy groundmass, some containing numerous opaque grains. Grains of other phenocryst minerals are included in, or form aggregates with, the plagioclase phenocrysts.

As shown in the following tabulation, most of the compositions of plagioclase phenocrysts from five rocks, determined by the Carlsbad - Albite twin method, fall in the labradorite-bytownite range.

Sample number	Anorthite-content of Plagioclase phenocrysts
0004D	An 70, 67, 67, 69, 64
0014	An 72, 78
0021A	An 55, 62, 63, 67, 66, 81
0026F	An 64, 86, 72, 72, 64
0027B	An 68, 69, 66, 64, 69, 74

Clinopyroxene. Augite is the most common type of ferromagnesian phenocryst: it is present in all the samples listed in Table 1, and ranges between 2 and 20 percent by volume. The amount of augite does not appear to be related to the proportion of any other variety of phenocryst in these rocks. Many augite phenocrysts are slightly zoned. Some have cores of orthopyroxene, and there are all gradations between these and grains which are dominantly orthopyroxene with overgrowths of clinopyroxene.

Augite phenocrysts appear to be more common in lavas from the Cape Gloucester area than in those from Ulawun and Likuruanga volcanoes and Lolobau Island, at the eastern end of the Bismarck Volcanic Arc (cf. Johnson, 1970a,b).

Orthopyroxene. Pleochroic orthopyroxene (hypersthene or bronzite, with pale green to reddish-brown pleochroism) is present as phenocrysts in many lavas. It is most abundant in rocks deficient in olivine phenocrysts (less than 1 percent), and it is absent, or present only in small amounts, in rocks with a few percent of olivine phenocrysts. Rocks with orthopyroxene phenocrysts also contain more phenocrysts of iron-titanium oxides than those deficient in orthopyroxene. Many orthopyroxene phenocrysts have rims of augite, and on a few smaller phenocrysts narrow rims of clinopyroxene are developed on the prism faces of the crystal.

Olivine phenocrysts are present in all but four of the thirty-three rocks listed in Table 1, but in the majority of these the amount is 1 percent or less. Rocks especially rich in olivine phenocrysts are from centre C of the Aimaga Volcanic Complex (0026D; 9 percent olivine phenocrysts), and from satellite cone G (0051; 18 percent olivine phenocrysts). Rocks from the vicinity of Langila Craters (group 1 in Table 1) are notably deficient in olivine phenocrysts.

In some rocks, the olivine phenocrysts are euhedral. In others, their anhedral habit suggests that resorption of olivine may have taken place.

A striking feature of phenocryst olivine in many Cape Gloucester rocks is the poor development, or absence, of Ca-poor pyroxenes at the phenocryst peripheries: even in rocks with well-crystallised groundmasses , the olivine phenocrysts may have no pyroxene "reaction" rims, or else pyroxene development is incipient. This contrasts with lavas from volcanoes along the north coast of New Britain in which coronas of pyroxene are well-developed on olivine phenocrysts (Johnson, 1970a,b). However, in some Cape Gloucester lavas, pyroxene coronas are sufficiently developed to identify orthopyroxene as the mantling pyroxene. Orthopyroxene may also constitute the narrow, fine-grained pyroxene coronas of other olivine phenocrysts, but in these cases identification is uncertain, and the pyroxene could be pigeonitic. The pyroxene coronas indicate that these olivine-bearing Cape Gloucester lavas have silica-saturated, tholeiitic basalt compositions in which phenocryst olivine bears an "reaction relationship" with Ca-poor pyroxene.

In several olivine-bearing rocks, partial or complete coronas of iron-titanium oxide are developed on olivine phenocrysts, and in a few examples the oxide corona is surrounded by a zone of hypersthene (or fine-grained pyroxene of undetermined composition). Complete pseudomorphs of iron-titanium oxides (with or without an accompanying pyroxene zone) are rare.

In a few samples, olivine phenocrysts are partly or completely replaced by "iddingsite". One petrographic feature that distinguishes these pseudomorphed olivines from those in lavas from Ulawun and Likuruanga volcanoes and Lolobau Island (figure 2; Johnson 1970a,b), is that in some the replaced phenocrysts are rimmed by iron-titanium oxide grains, or orthopyroxene, or both. This indicates that the phenocryst olivines were pseudomorphed by iddingsite <u>after</u> they had produced rims of pyroxene and iron-titanium oxide. The opposite relationship is shown in olivine-bearing lavas from volcanoes in the eastern part of the arc; in these, olivine phenocrysts were iddingsitised before they had opportunity to react with liquid to form pyroxene and iron-titanium oxide coronas (Johnson, 1970a,b).

<u>Iron-titanium oxide</u> phenocrysts are present in most Cape Gloucester lavas. They are absent or rare (as small phenocrysts) in many rocks with olivine phenocrysts, but they constitute up to 2 percent of rocks with a few percent orthopyroxene phenocrysts; typically, iron-titanium oxide grains are enclosed by orthopyroxene phenocrysts. This relationship is the same observed in lavas from other Quaternary volcanoes in New Britain, that oxide phenocrysts are best developed in the less basic rocks.

<u>Groundmass mineralogy</u>. The majority of samples from the Cape Gloucester area have fine-grained groundmasses in which it is difficult to identify all the constituent minerals. The most common and easily recognised phases are plagioclase, clinopyroxene, orthopyroxene, iron-titanium oxide, and glass.

In most rocks, augite is the most readily identified clinopyroxene, but other compositions are known to be present. In samples 0043 and 0044, for example, the groundmass is particularly coarse-grained, and pigeonite (2V of 0-30^{o}) is easily recognised as an important groundmass consituent. Moreover, in other rocks with finer-grained groundmasses, the presence of pigeonite is also indicated by low 2V; however, in these cases estimation of 2V values is more difficult. Electron microprobe analyses by Lowder (1970) of groundmass clinopyroxenes in basalts and basaltic-andesites from Willaumez Peninsula (figure 2) showed a complete range in compositions between pigeonite, subcalcic augite, augite, and ferro-augite. These phases are almost certainly also present in many Cape Gloucester rocks, although it is not possible to identify them all optically.

Silica polymorphs are also present in the groundmass of many Cape Gloucester lavas. Cristobalite, showing networks of irregular cracks, is found as an interstitial phase in several rocks (for example, 0024A and 0029D), and distinctive twinned "arrow heads" of tridymite are also present in cavities of some samples (for example, 0005A and 0006A); in most cases, these cavities are also partly or completely filled with isotropic glass. Several rocks contain small laths with low birefrigence, low refractive indices, and straight extinction, which are also probably silica; however, the polymorph of this silica phase has not been identified.

Small groundmass grains of olivine are found in some rocks which also contain olivine phenocrysts without "reaction" rims of pyroxene (for example, 0010A, 0026D and F, 0031A, 0047, in Table 1). In these lavas, therefore, olivine appears to have crystallised both as phenocryst and as groundmass phases, without being resorbed by silica-rich residual liquid, or reacting with the liquid to form coronas of Ca-poor pyroxene.

Discussion. Lavas of the Cape Gloucester area appear to be predominantly basalts and "andesites" (sensu lato). Most of the "andesites" contain small amounts of olivine phenocrysts, and they are therefore probably low in silica content.

The principle volcanic centres of the area - Tangi and Talawe volcanoes and the Aimaga Volcanic Complex - have each produced lavas of similar mineral content, and within any volcano no progressive petrographic differences have been distinguished between the earliest erupted flows and later ones. Exceptions are the Recent lavas and bombs erupted from Langila Craters on the flank of Talawe volcano: these are consistantly poorer in olivine compared to many other lavas from the Cape Gloucester area (Table 1). It seems, therefore, that the rocks of Langila Craters were produced from a magma slightly less basic than the one producing many of the older lavas in the area. However, olivine-poor lavas are also found on Tangi, Talawe, and the Aimaga Complex, and it is certain that the Recent eruptions of Langila are in no way unique, and that they are not any more fractionated than other rocks from the Cape Gloucester area.

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TABLE 1. MODAL ANALYSES OF 33 ROCKS FROM CAPE GLOUCESTER AREA.

Group	Sample number (prefix 32NG)	volume % phenocrysts					total % phenocrysts
		Plagio-clase	Olivine	Ortho-pyro-xene	Clino-pyro-xene	Fe-Ti oxides	
1	0001B	26	<1	4	8	2	40
	0020	30	<1	5	10	2	47
	0021A	38	-	3	8	1	50
	0021C	27	<1	4	8	2	41
	0023	30	<1	4	7	2	43
	0024B	26	<1	3	9	2	40
	0063A	33	<1	2	7	1	43
2	0002C	8	2	<1	3	<1	13
	0004D	23	<1	4	17	<1	44
	0036A	22	<1	2	9	2	35
	0037	21	4	-	3	<1	28
	0040	12	3	0.5	2	0.5	18
	0041	17	4	<1	4	<1	25
	0047	19	3	<1	16	<1	38
	0052	21	<1	2	4	<1	27
3	0026D	<1	9	<1	7	<1	16
	0026F	28	4	-	20	-	52
	0027B	24	-	4	14	<1	42
	0028A	32	1	<1	6	1	40
	0029A	22	1	<1	13	<1	36
4	0009	28	-	4	13	2	47
	0010A	23	3	-	2	-	28
	0013	33	-	6	10	2	51
	0014	29	1	7	10	1	48
	0030C	26	<1	6	14	2	48
	0031A	4	7	-	7	-	18
	0033A	29	<1	7	8	2	46
	0034B	17	2	1	10	-	30
5	0003	18	1	2	13	1	25
	0005A	22	<1	4	13	<1	44
	0043	22	<1	3	11	1	37
	0044	20	<1	1	12	<1	33
	0051	-	18	<1	10	<1	28

TABLE 2. LOCALITY INDEX FOR SAMPLES OF TABLE 1.

Group	Sample	Locality description
1. Langila Craters (see figure 7)	0001B	bomb from northeastern part of no. 1 crater.
	0020	bomb from western rim of no. 2 crater.
	0021A) 0021C)	bombs on southwestern corner of no. 2 crater.
	0023	in situ lava, northern inner wall of Munlulu Crater.
	0024B	bomb on floor of Munlulu Crater.
	0063	in situ lava, gully at base of cone of no. 3 crater.
2. Talawe volcano	0002C	boulder in stream bed, western end of airstrip.
	0004D	boulder in stream, eastern slopes.
	0036A	in situ lava flow, stream west of Aipati.
	0037) 0040) 0041)	in situ lava flows in second stream west of Aipati; 0041 is the youngest, and 0037 the oldest of three flows.
	0047	in situ lava flow at coast, south of Tauali.
	0052	in situ lava flow; main stream, ca. 3 km south of airstrip.
3. Aimaga Volcanic Complex	0026D) 0026F)	boulders in stream draining eastern side of Centre A.
	0027B	boulder in stream west of Orelmo.
	0028A	boulder in stream on eastern side of Centre B.
	0029A	boulder in stream on western side of Centre B.
4. Tangi Volcano	0009	boulder in stream, southeastern slopes.
	0010A	boulder in stream, southeastern slopes.
	0013	clast in rudite at coast north of Walawalapua.
	0014	beach boulder south of Ura.
	0030C	boulder in stream on northern slopes.
	0031A	boulder in stream on northern slopes.
	0033A	boulder in stream on northern slopes; ca. 430 m a.s.l.
	0034B	block in landslide area near summit; ca. 1330 m a.s.l.
5. Other localities	0003	boulder in stream draining northeastwards into Borgen Bay.
	0005A	boulder in stream draining western slopes of Mt Schrader.
	0043) 0044)	in situ lava flows, 700 m east of Sag Sag Mission in Gima River.
	0051	in situ lava near summit of satellite cone G.