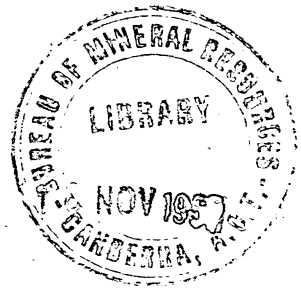
COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Report No. 33



THE TULUMAN VOLCANO, ST. ANDREW STRAIT, ADMIRALTY ISLANDS

BY

M. A. REYNOLDS and J. G. BEST

Issued under the Authority of Senator the Hon. W. H. Spooner,
Minister for National Development
1957

LIST OF REPORTS

1. Preliminary Report on the Geophysical Survey of the Collie Coal Basin.—N. G. Chamberlain, 1948.
2. Observations on the Stratigraphy and Palaeontology of Devonian, Western Portion of Kimberley Division, Western Australia.—Curt Teichert, 1949.
3. Preliminary report on Geology and Coal Resources of Oaklands-Coorabin Coalfield, New South Wales.—E. K. Sturmfels, 1950.
4. Geology of the Nerrima Dome, Kimberley Division, Western Australia.—D. J. Guppy, J. O. Cuthbert and A. W. Lindner, 1950.
5. Observations of Terrestrial Magnetism at Heard, Kerguelen and Macquarie Islands, 1947-1948 (carried out in co-operation with the Australian National Antarctic Research Expedition 1947-1948).—N. G. Chamberlain, 1952.
6. Geology of New Occidental, New Cobar and Chesney Mines, Cobar, New South Wales.—C. J. Sullivan, 1951.
7. Mount Chalmers Copper and Gold Mine, Queensland.—N. H. Fisher and H. B. Owen, 1952.
8. The Ashford Coal Province, New South Wales.—H. B. Owen, G. M. Burton and L. W. Williams, 1954.
9. The Mineral Deposits and Mining Industry of Papua-New Guinea.—P. B. Nye and N. H. Fisher, 1954.
10. Geological Reconnaissance of South-Western Portion of Northern Territory.—G. F. Joklik, 1952.
11. The Nelson Bore, South-Western Victoria: Micropalaeontology and Stratigraphical Succession.—I. Crespin, 1954.
12. Stratigraphy and Micropalaeontology of the Marine Tertiary Rocks between Adelaide and Aldinga, South Australia.—I. Crespin, 1954.
13. The Geology of Dampier Peninsula, Western Australia.—R. O. Brunnschweiler, 1957.
14. A Provisional Isogonic Map of Australia and New Guinea showing Predicted Values for the Period 1955-5 .—F. W. Wood and I. B. Everingham, 1953.
15. Progress Report on the Stratigraphy and Structure of the Carnarvon Basin, Western Australia.—M. A. Condon, 1954.
16. Seismic Reflection Survey at Roma, Queensland.—J. C. Dooley, 1954.
17. Mount Philp Iron Deposit, Queensland.—E. K. Carter and J. H. Brooks, 1956.
18. Petrology and Petrography of Limestones from the Fitzroy Basin, Western Australia.—J. J. E. Glover, 1956.
19. Seismic Reflection Survey, Darriman, Gippsland, Victoria.—M. J. Garrett, 1955.
20. Micropalaeontological Investigations in the Bureau of Mineral Resources, 1927-52.—I. Crespin, 1956.
21. Magnetic Results from Heard Island, 1952.—L. N. Ingall, 1955.
22. Occurrence and Distribution of Oil in, and properties of, Glauconitic Sandstone at Lakes Entrance, Victoria.—R. F. Thyer and L. C. Noakes, 1955.

REPORT 33.

ERRATA

p. 2, line 16, and line 4 from bottom: For Cone 2 read Cone 3.

p.14, line 7: for Cone 3 read Cone 4.

p.19, para 2, last line: for magnetic read magmatic.

Plate 13, fig.2: Cone 2 is at extreme left of picture.

p.28, line 3 from bottom: after November, insert 1953.

p.29, line 4: after 18th, insert 1955.

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DEPARTMENT OF NATIONAL DEVELOPMENT

Minister: SENATOR THE HON. W. H. SPOONER, M.M.

Secretary: H. G. RAGGATT, C.B.E.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Director: P. B. NYE, O.B.E.

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This Report was prepared in the Geological Section

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CONTENTS

(Volcanic Activity)

ILLUSTRATIONS

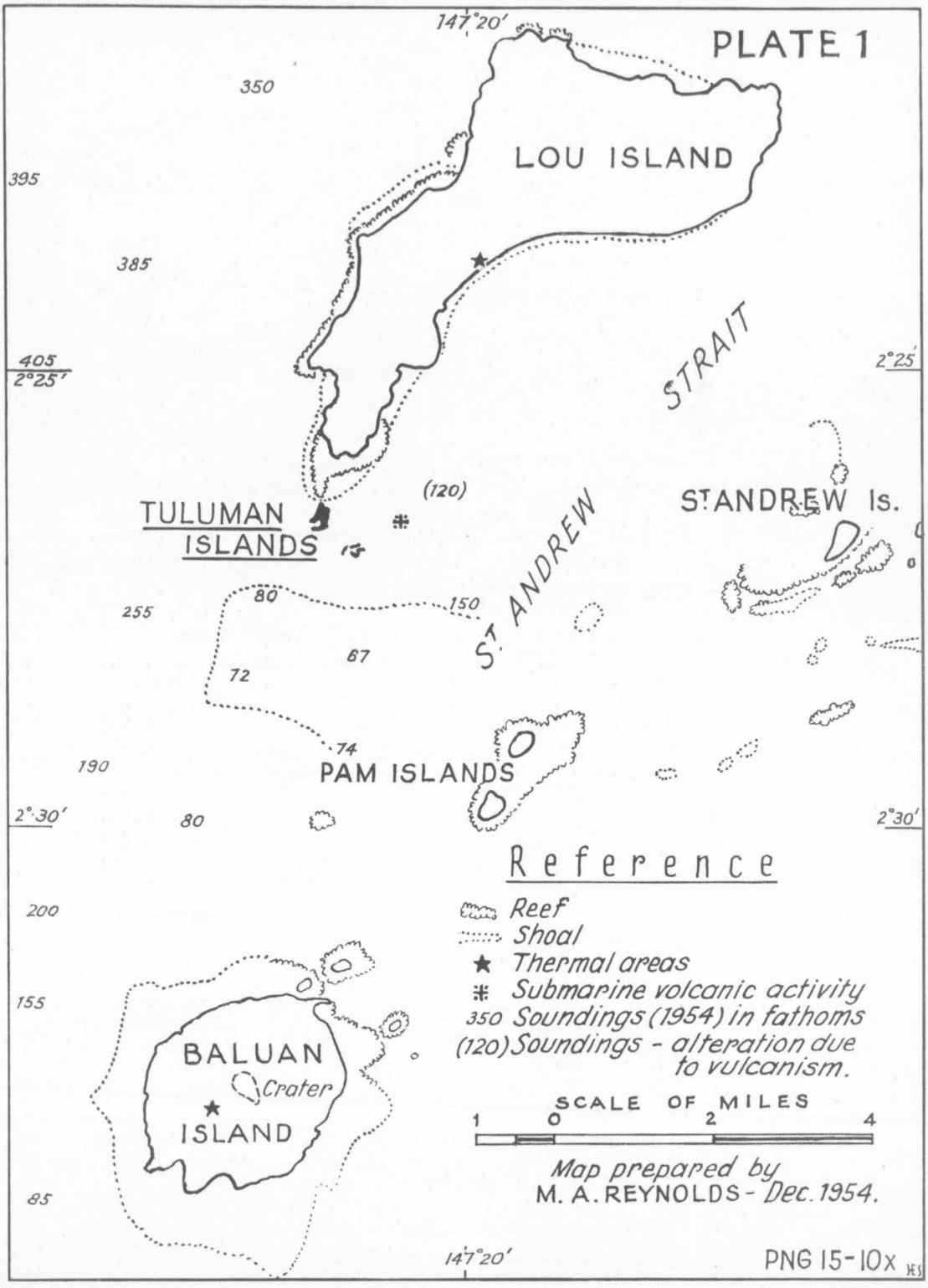
PLATE 1
147°20'
350
LOU ISLAND
395
385
405
2°25'
STRAIT
2°25'
(120)
TULUMAN ISLANDS
St ANDREW Is.
St. ANDREW
80
150
255
67
72
74
190
PAM ISLANDS
2°30'
80
2°30'
Reference
Reef
Shoal
Thermal areas
Submarine volcanic activity
350 Soundings (1954) in fathoms
(120) Soundings - alteration due to vulcanism.
SCALE OF MILES
1 0 2 4
Map prepared by
M. A. REYNOLDS - Dec. 1954.
200
155
BALUAN
Crater
ISLAND
85
147°20'
PNG 15-10X

SUMMARY

This report deals with the volcanic activity at Tuluman Volcano in St.Andrew Strait, 25 miles south of Lorengau in the Admiralty group. In the first of the three papers which constitute the report, a description is given of the activity from June 1953, when the eruption began, to the end of July 1954.

Part II describes further submarine activity in October and November 1954, and the condition of the active centres at that time.

In Part III a more detailed description of the eruptive activity is given and the eruption and the associated phenomena are reviewed at some length.

Volcanic activity in the St.Andrew Strait has originated from at least five separate centres, from one of which another cone has been formed by a branching-off from the main conduit. As a result, three islands, two of which have been subsequently joined, have been built up above sea level. The name Tuluman Islands is proposed for these islands, and individual cones are numbered according to the chronological order in which they have been formed. The geographical position of the Tuluman Islands and their topography are also discussed.

A study of the volcanic activity led to the following conclusions :

(a) The original formation of molten lava in the magmatic reservoir must have been a slow process, and magmatic gases have been the source of the thermodynamic energy.

(b) The intermittent activity during the eruptive periods resulted from release and accumulation of gases in the magma column.

(c) Surface manifestations of submarine activity resulted from the floating to the surface of gas-charged masses of vesiculated lava which have solidified on the outside. The removal of hydrostatic pressure when the masses reach the surface of the sea allows gases contained within the masses to escape, sometimes with explosive force.

(d) After lava extrusion from the submarine vent, gas pressure is temporarily relieved and a plug forms in the upper part of the conduit. The sealing of the vent is also attributed in part to the effects of hydrostatic cooling and pressure and to the combined lateral pressures of sediments through which the dome is penetrating and lava of which the dome is composed.

(e) After the flow of lava which builds the cone above sea level, the next release of accumulated gas results in the disintegration of the plug with explosive violence and formation of a deposit of large angular fragments, mainly pumice and tachylyte. Thereafter the liquid lava and gases are free to escape and the consequent expansion of the gases results in explosive activity sufficient to pulverise the lava with which it is associated. The thick pumiceous deposits are formed by this action.

(f) Spasmodic explosive activity continues until all the energy from gas accumulated in the magmatic column has been expended.

(g) A slightly different explanation is required for the different sequence of beds exposed on the island above Cone 5: this is attributed to a premature upsurge of magma and release of pressure resulting from compression of the earth by strong luni-solar influences.

(h) Apart from the mud eruptions from some centres, the explosive phase completed the activity from cones which have been built up above sea level; gaseous energy is probably completely expended and the magma column solidified. But there can be renewed activity from submarine cones, since the release of pressure during any one eruptive period is only small compared with that released when the cone has been built up above sea level, and is therefore only partial. The fact that there has been renewed activity from submarine cones has been used in support of a theory that the cones are separate identities.

(j) The line formed by joining positions determined for Cones 1, 2, 5, and 6 has a convexity to the north-west corresponding with the arcuate form of Lou Island, which is believed to represent a remnant of the rim of a large crater. An unstable zone could exist along the inner margin of this crater rim and the Tuluman Islands may have formed in this zone. Secondary radial fracturing is advanced as a reason for the positions of Cones 2 and 4.

The activity from January to April 1955 is described in chronological order, and this is followed by a discussion of the lava and ejectamenta. Lava flows consist of three main rock types: pumice, black glass (tachylyte), and a fine-grained basaltic (?) rock; agglomerates and dust deposits with interspersed pumice, pumice lapilli, and bombs are also described.

After a brief discussion of temperatures and gases encountered from vents on the Tuluman Islands, the association of seismic activity and tilt movements with eruptive periods is considered. No volcanic tremors preceded or accompanied periods of activity. Concussion waves from explosions caused buildings on neighbouring islands, and the unconsolidated deposits on the Tuluman Islands, to move. The pronounced movement shown by the tiltmeter installed on Baluan Island during March - April, 1955, indicated some correspondence with volcanic activity. The direction of the tilt was explained as due either to subsidence in the St.Andrew Strait caldera or uplift in the central crater area of Baluan Island. The first explanation is considered the more logical in view of the conclusions reached in other sections of this report. Attempts to correlate tectonic earthquakes from 1940 onwards with volcanic activity were not successful.

Small spirals of white vapour clouds were noticed during activity in February 1955.

Luni-solar influences have applied during periods of volcanic activity in the St.Andrew Strait. The strongest effects were noticed (a) when the sun and moon were in equatorial positions near the zenith in the latitude of the activity; and (b) on the three occasions when the sun and moon were occupying zenith positions close to the Tropics of Cancer and Capricorn and were in opposition.

On occasion there were responses when the moon was at the zenith in the latitude of the volcano.

The most interesting feature of the activity between May - July 1955 was the mud eruptions from Cones 2 and 4. Theoretically, they represent a decadent phase of volcanic activity from this centre, and they may have been caused by an upward surge in the magmatic reservoir due to luni-solar influences.

Increased thermal activity in the area near Baun village on Lou Island coincided with two periods of renewed activity at Cone 1 in the Tuluman Islands: the area is possibly connected by subsidiary fissures to Cone 1.

During the preparation of this report another feature of the activity became evident; although the significance is not immediately obvious, it may be important in future diagnosis. If the period June 1953 until July 1956 is divided into three intervals, June 1953 - September 1954, October 1954 - May 1955, May 1955 - July 1955, there is a general movement of activity from Cone 1 to centres to the south-west in each of these intervals. If Cones 2 and 4 are regarded as situated on secondary radial fractures, the movement of the centres of activity has been along the line proposed (p. 21) as possibly corresponding to a zone of weakness paralleling the north-west crater rim of the St.Andrew Strait caldera.

PART I

PRELIMINARY REPORT - TULUMAN VOLCANO, LOU ISLAND, ST.ANDREW STRAIT, NEW GUINEA.

by

G. J. Best

(Records 1954/58, October 1954)

Introduction

On the 12th July 1954, I was informed by signal that explosive activity had recommenced at the vents in St.Andrew Strait, between Lou Island and Baluan Island, 25 miles south of Lorengau in the Admiralty group. I arrived at Baluan on the evening of the 15th July.

En route to Momote on the evening of the 14th a brief aerial inspection was made of the active area. Two small craters were visible above sea level and some minor explosions originated from the western crater during this inspection.

I left Baluan on the 21st July. During this week, 15th-21st, as no further explosive activity was manifest, two ground inspections were made of the western crater. On July 22nd mild activity (mainly effusive) started again at the eastern crater.

The name Tuluman (tuluman being the word for hot in the Manus language) has been proposed for this new volcano. The name embraces the whole of the structure, that is, the two small cones above sea level as well as the submarine portion. The two small structures above sea level are referred to as East and West Tuluman craters.

Previous Activity

According to a report by Miklouho Maclay (1885) an eruption occurred at this locality in March, 1883. He witnessed activity on the night of 28th March 1883, and considered that it was "very likely" that it was from the volcano "on the small island called by the natives Loo, and from which they obtain the obsidian for their weapons and implements". It now seems probable that the activity that he records actually took place at the same locality as the eruptions described in this Report. The eruptive period with which the present series of reports is concerned began with submarine volcanic activity on 27th June, 1953.

Since June, 1953, the vents in St.Andrew Strait have been active on three occasions: the first eruption began on 27th June and ceased on 6th July; the second, of much longer duration, began on 14th November and continued intermittently until 18th February 1954; the third period began on 10th July 1954, and eventually two small cones were built up above sea level. By 27th July eruptive activity had ceased and the volume of steam being emitted was gradually diminishing.

The Recent Eruption

About 0100 hours on 10th July 1954, a submarine eruption began near the focus of the two previous eruptions. The initial activity was almost inaudible at Baluan Island (about 4 miles to the south) and no premonitory tremors were felt in any of the surrounding islands.

Mr.J. Landman, Assistant District Officer, Baluan, stated that the early stages of this eruption differed from the previous two, in that material appeared to be ejected more frequently, and much less steam was generated. This was undoubtedly because the crest of the submarine structure was by this time very close to sea level.

As the eruption progressed it became clear that two vents were operative. On 11th July a small cone was built up above sea level in the eastern portion of the active area. Thereafter activity declined at this centre and intensified at the western focus until 13th July, when the second cone appeared above sea level about 300 yards to the north-west of the original cone. Explosive activity then declined at this vent and ceased on the evening of 14th July. By this time the emission of vapour had practically ceased at the eastern crater.

During the following week the emission of volatiles (mainly steam) gradually declined at the western crater.

On the morning of 21st July activity recommenced at the eastern crater. Thanks to the co-operation of the Qantas pilot, the writer, at the time en route from Momote to Rabaul, was able to make a brief aerial examination of this new phase of activity. Activity was purely effusive: lava was being pushed out from a small vent and flowing outwards in a series of slow-moving concentric waves. Where it entered the sea dense columns of steam were rising, while from the orifice (a little west of the centre) a bright orange plume of vapour was rising languidly and drifting away to the north-west.

Subsequently minor explosive emissions occurred at this vent and by 27th of July fumarolic activity only was in evidence.

Structure

The Admiralty Chart of the Admiralty Islands (prepared in 1944) reveals in St.Andrew Straits, between Lou Island and Baluan Island, a shoal area (shallowest point 67 fathoms) which coincides approximately with the focus of recent activity and probably the presence of the old submarine volcano referred to by Miklouho-Maclay.

Since June 1953 volcanic agencies have built up on this foundation a structure about 450 feet high, culminating in two minor craters, the rim of the higher being about 40 feet above sea level (Plate 1). These two craters are surrounded by a shoal half to three quarters of a mile in diameter. Since most

of the structure is submarine, it is not possible without a hydrographic survey to compute the volume of material contained in it, but it is probably more than 100 million cubic yards. ✱

East Tuluman Crater (Cone 2 of Reynolds, see p. 13)

At the time of the ground inspections (18th and 19th July) the East Tuluman crater was practically awash. It consisted of an arcuate-shaped ridge of fragmental material about 100 yards in diameter, the breach being disposed on the eastern side. Minor steam vents were active around the rim.

West Tuluman Crater (Cone 3 of Reynolds, see p.13)

West Tuluman crater , about two acres in extent and 40 feet high, consisted of an arcuate-shaped crater breached and open to the sea on the western side.

The prevailing south to south-easterly winds have caused most of the fragmental products to fall north of the crater, even connecting it with the reef fringing the southern tip of Lou Island.

Superficially the northern portion of the structure appears to be composed entirely of fragmental products; but as lava flows crop out on the southern side they are probably present but buried on the northern side.

The products of explosive activity are predominantly pumice and comminuted pumice with subordinate amounts of scoriaceous, vesicular, and massive vitreous lava fragments.

Numerous volcanic bombs are scattered about the outer slopes, particularly on the northern side. These bombs vary appreciably in size and texture. The two commonest types are, first, a large slab-like mass (up to 20 to 30 cubic feet), pumiceous on one face and grading through a scoriaceous and vesicular median section to a massive vitreous phase with a well developed bread-crust structure; and secondly, a massive vitreous core grading out to a pumiceous periphery. The first type probably represents portions of partly chilled lava flows explosively ejected, and the second results from lava explosively expelled in the liquid state.

During the explosive phases fragmental material was thrown to considerable heights. As they were incandescent and emitted vapour, their trajectory could be readily discerned by night and day. Mr.Landman timed the descent of one such projectile at fifteen seconds, i.e. about 3,600 feet.

The south-east portion of West Tuluman crater is composed largely of flow lava. Marked structure particularly along the flanks of the flows indicates that the lava was quite liquid when expelled. Except where they have been suddenly chilled by sea water the flows do not exhibit the smooth or ropy

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✱ Reynolds (p. 8 infra) places the island in the zone between Loh Island and the shoal; the depth there is 120 fathoms.

surface of the typical pahoehoe flow: this is undoubtedly due to the escape of large volumes of volatiles which has produced a high proportion of vesicular to pumiceous material.

At the time of the ground inspection the flows were still quite hot, and the survey of the south-east portion of the crater is only an approximation, as it was not possible to walk around it.

The crater, about 500 feet long and 350 feet wide, was flanked on all but the western sides by cliffs 10 - 20 feet high. In the western end a breach about 200 feet wide permitted access by the sea, which had inundated the floor of the crater. A narrow plateau about 20 feet above sea level was developed between the northern edge of the crater and the foot of the main crater rim. This plateau in its western extremity descended to a narrow beach flanking the north-west "head" of the crater and in its eastern extremity merged into the southern arm of the crater rim. Strong peripheral cracking was developed around this plateau close to the crater edge, particularly in the eastern portion.

At the time of the ground inspection, four and five days after explosive activity stopped, sea action had already considerably modified the outer flanks of the cone. Cliffs had been cut on the windward (southern) side and much of the material so derived had been redistributed along the north-eastern portion to form a wide bench.

Numerous ebullient springs were discharging volatiles and hot water from the floor of the inundated crater. Particularly strong spring activity was located about midway along the southern side of the crater. In the south-east corner of the crater a bright green pool, the surface of which was slightly above the general water level in the crater, was steadily discharging hot water supplied by the ebullient springs within it.

Temperature The only temperatures obtainable of ebullient springs were from the green pool. These were surprisingly low: 74° to 76°C.

Beneath the flank of one solidified flow a temperature of 240°C was recorded. This temperature is suspect and could not be checked as during the operation several feet of insulation were burnt from the thermocouple leads. This damage could not be repaired in the field.

Volatiles Steam was the main volatile emitted. Part was generated by the contact of hot lava and sea water; the remainder was connate steam.

Mr.Landman reported that during the eruption bright yellow clouds were at times a component of the vapour. This phenomenon may have resulted from the ejection of finely divided sulphur crystals. Deposits of comminuted pumice containing a high proportion of fine sulphur crystals were noted particularly on the north-west flanks of the structure. Such crystals could have been deposited by fumarolic activity within the submarine structure during the preceeding quiescent period.

During the ground inspection the concentration of acid gases and hydrogen sulphide was found to be surprisingly low, and at no time was it necessary to don a respirator. Acid halides appeared to be absent and sulphur dioxide and hydrogen sulphide were present in only minor concentrations. It was somewhat surprising therefore to find that after a couple of hours in this atmosphere my stainless steel wrist watch was heavily tarnished. This tarnishing of stainless steel objects had previously been encountered at Mt.Langila in 1952 and had on that occasion been ascribed to the high concentration of acid gases in the exhalate.

In the vicinity of the lava flows an odour similar to that produced by heated tar was most marked. Efforts to trace this odour to a particular vent proved fruitless and the impression was gained that it was emanating from the slowly cooling flows.

Reynolds during his investigations at Mt.Langila in May and June this year (1954) encountered a somewhat similar odour while in the vicinity of the active crater during a lull in the explosive activity.

Location of Tuluman Volcano

Compass bearings taken on various features in this area, when plotted on the 1: 63,360 military sheet "Lou - Admiralty Islands", show wide discrepancies with the same features on the map.

Captain Wilding of the M.V. Bulolo on 22nd November, 1953, witnessed explosive activity at the then submarine vents. He carefully determined the geographical location of this focus and also determined its position relative to Lou Island.

His plots are as follows;

Geographical co-ordinate of active focus on 22/11/53: 2° 26.8'S., and 147° 19.1'E.

Position referred to Lou Island: 0.9 miles on a bearing 167° true from the southernmost tip of Lou.

These two positions when plotted on the military sheet reveal a discrepancy of about 2.2 miles in the azimuth 137°.

Mr.J. Landman, who witnessed the activity from its inception, states that there has been very little wandering of the focus of activity. Thus the co-ordinates determined by Captain Wilding have been accepted as the co-ordinates of Tuluman Volcano.

Conclusion

Further eruption may take place; but because of the pattern of the activity in the recent past it is considered that it is unlikely to prove a danger to the population of the surrounding islands.

REFERENCE

MIKLOUHO-MACLAY, N.de , 1885: On volcanic activity on the islands near the north-east coast of New Guinea. Proc.Linn.Soc. N.S.W.,9 (4), 965.

PART II

SUBMARINE VULCANISM EAST OF TULUMAN VOLCANO, ST.ANDREW STRAIT, ADMIRALTY ISLANDS. OCTOBER-NOVEMBER, 1954

by

M.A. Reynolds

(Records 1955/79)

Introduction

From 26th July, when activity at Tuluman Volcano was reported to be decreasing, there was a period of quiescence until 20th October, apart from one explosion on 3rd August. A signal received on 20th October from the Assistant District Officer, Baluan Patrol Post (Mr. E.G. Hicks) stated that submarine activity had begun east of the Tuluman Volcano craters at 0910 hours, and that it consisted of considerable steam output with intermittent explosions and "ground rumblings". No change in the activity of the Tuluman craters was reported.

I left Rabaul at 0700 hours on 23rd October, and reached Baluan at midday on 24th October. Observations were maintained from the time of arrival until 7th November. Ground inspections on both Tuluman craters were conducted during this period, and some additional information on their condition is given in this report.

Activity in this area up to 27th July, 1954, has been discussed by Best, and will not be further mentioned here.

Location

The point at which most of the extruded blocks appeared and explosions occurred was three-quarters to one mile east of the West Tuluman crater, and about a half a mile east-north-east of East Tuluman crater. The positions of West and East Tuluman craters and the position of the October-November activity were plotted on Chart Aus.054 by the master of the "Poseidon", Mr.J. Kemsley:

	Lat.S.	Long.E.
West Tuluman Crater	2°26'25"	147°18'45"
East Tuluman Crater	2°26'50"	147°19'00"
Submarine Activity	2°26'25"	147°19'20"

These positions, however, are not in accordance with those determined with magnetic compass by Best in July (p 7 supra) and myself in October. Charts and maps of the area give different positions to the islands, and there are discrepancies in their outlines.

For the purpose of this report, a composite map (Plate I.) has been constructed from Chart Aus.054, "Admiralty Islands, Eastern Approaches" (March 1944), and map S145-E14600/60x120, "Manus and Adjacent Islands", (scale :

PLATE 2.

Vapour clouds from blocks of floating lava. 27th October, 1954.

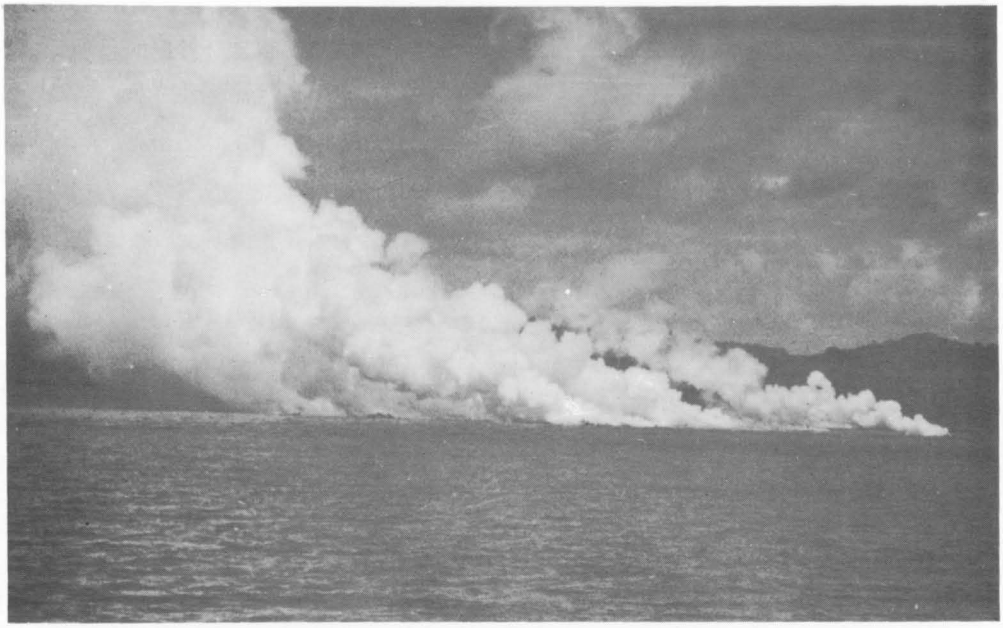


Figure 1.

Taken from 200 yards south-east of active centre. Lou Island in background.

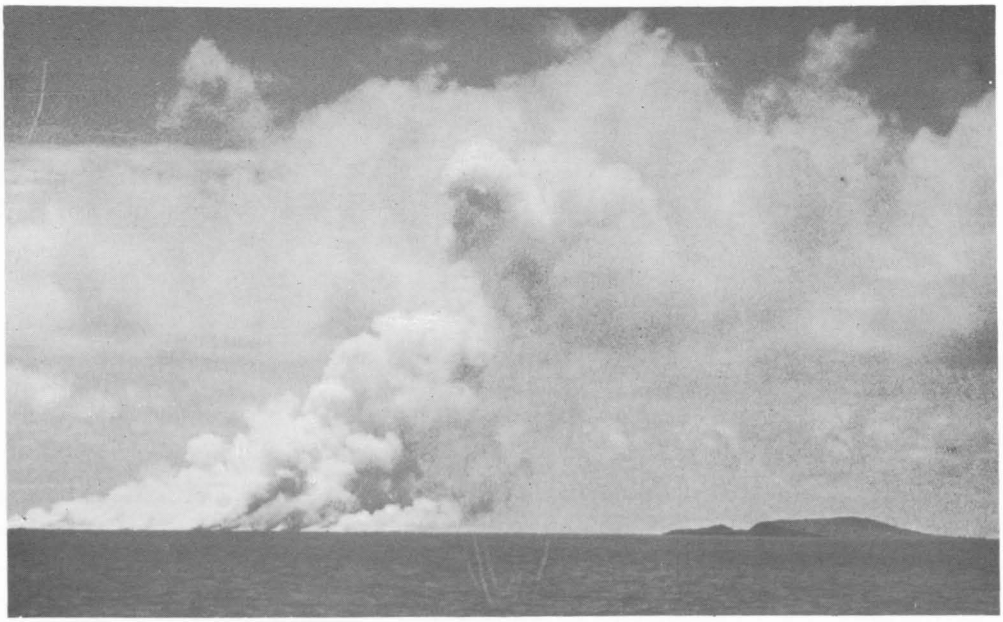
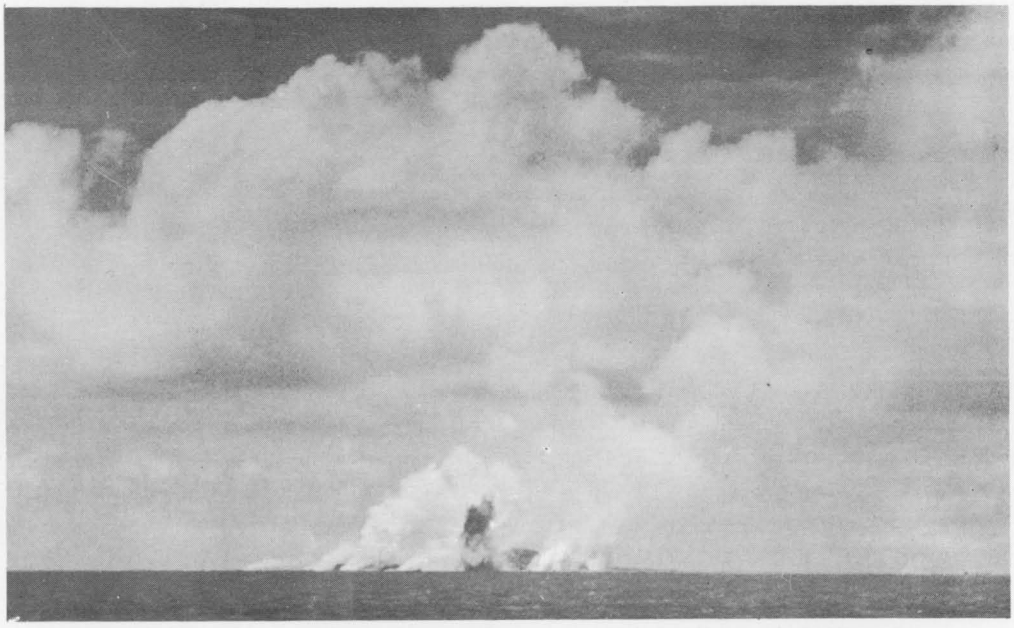


Figure 2.

From north-east. West Tuluman Crater on right.

PLATE 3.

Explosion at 1310 hours, 27th October, 1954, from east. West Tuluman Crater due west of active centre.



1 inch equals 4 miles, prepared by the U.S. Army Corps of Engineers, 1944). The positions of the Tuluman Volcano craters and submarine activity have been determined from magnetic compass bearings taken from Baluan Island and from West Tuluman crater.

Natives of Baluan Island stated that the submarine activity during October 1954 was in the same position as the original activity in June 1953, but this cannot be verified. Mr.Landman, Assistant District Officer, Baluan, in July 1953 gave the position of the first outburst in a signal to the vulcanologist as "approximately four miles north of Baluan in direction most southerly point Lou Island". This corresponds to the position of West Tuluman crater, and as the co-ordinates of submarine activity determined in November 1953 are approximately those of East Tuluman crater, it is more logical to assume that there has been a migration to the east of the centre of activity, and that the last eruption occurred in a new area. ✱

The Nature of the Activity

Submarine vulcanism in St.Andrew Strait began again at 0910 hours on the 20th October, 1954, at a point about half a mile east-north-east of East Tuluman crater. At this time there was a succession of violent explosions with emissions of large volumes of steam and vapour. The initial activity was followed by similar explosions, which decreased in intensity until the afternoon of 21st October, when activity ceased. At 1500 hours on 22nd October mild activity started again, and continued until 5th November, when intensity declined, and ceased on 6th November. It was during this second period that the writer made the following observations:

1. Explosions and emissions of large volumes of vapour coincided with the arrival at the surface of the sea of large blocks of lava (Plate 2).
2. The steam given off could be attributed entirely to the small portion of the lava mass that was visible above the water.
3. An upwelling of water preceded the arrival of a lava mass at the surface; and an explosion sometimes coincided with its arrival, when dust and rock fragments were ejected to heights of generally less than 100 feet above sea level. The noise which accompanied the explosion was comparable with the rumbling of thunder (Plate 3).
4. Although the arrival of the largest masses at the surface did not always have a regular periodicity, it was discovered that their appearance could usually be expected at intervals of about ten minutes.
5. Steam and gas escaping from the lava mass formed a white cumulus cloud which was carried by the prevailing wind, while the mass itself slowly submerged. When most of the gas content had been freed, the mass disappeared

✱ In my second report (below) I have accepted the native theory and called the June 1953 and October 1954 activities eruptions from Cone No.1. This is not explained in the report.

below the surface; usually in less than ten minutes.

6. Seismic activity was noted only when the writer was on either East or West Tuluman craters, and these tremors coincided with the explosions at the surface. There were no marks on the records of the shock recorder installed at Baluan which could be attributed to seismic activity.

7. Very little evidence was noticed of gases other than steam, though as the masses were approached only from the windward side, gases were not easily observed. A faint smell of burning tar was noticed when the area was visited on the "Poseidon", and during the same trip patches of yellow froth were noticed in the vicinity of Tuluman volcano. The froth, presumably formed by volatiles of sulphur or its compounds, may have emanated either from the volcano or from the area of submarine activity. Sulphuretted hydrogen and sulphur dioxide were detected among gases from East Tuluman Crater, but only in very small amounts.

8. Temperatures were measured at the thermal area on the south-west side of Baluan (Plate I) during the October 1954 investigation. The maximum on this occasion was 94°C., which is 7° above the maximum recorded by Best in July 1953. The temperature at the thermal area on Lou Island had also increased, according to the natives who used this ground for cooking purposes (verbal report from Mr.F. Kleckham, Lorengau). Temperatures on West Tuluman crater, however, had decreased. Those measured at sea level on the inside of the southern rim of the crater were 44°C., 47°C., and 62°C., the latter being 14° lower than the maximum recorded by Best in July 1954. As the natives could not be induced to take their canoe over the areas where gas ebullition was greatest, sea temperatures could only be obtained at the northern and eastern edges of the East Tuluman crater. These were 52°C. and 53°C.

The conclusion drawn from these observations is that lava was being extruded from a new centre of activity or from a vent on the eastern side of Tuluman volcano. The lava, suddenly chilled, broke up into masses which were highly charged with gas and floated to the surface. That these masses reached the surface at red heat was evident from watching the area at night. At the surface, with the sudden reduction of external pressure, the gases escaped, sometimes with explosive violence. The gases, predominantly steam, were intermixed with the steam formed as a result of the reaction between red-hot lava and sea water, to form white cumulus clouds. As the gas escaped the lava mass lost its buoyancy and eventually sank. Pumice was probably produced independently of these masses at the point of emergence of the lava, and floated to the surface, to be carried for long distances by the sea.

Additional Information on Tuluman Volcano

West Tuluman crater Lava flows which were at high temperatures during the July 1954 investigation had cooled to normal by October, and the temperatures at points of gas ebullition were less; green alga (?) had already attached itself to rock surfaces on the southern outer egde of the crater.

East Tuluman crater The western and northern limits of the crater are made up of two small islands composed of lava; the southern and eastern limits are bounded by a much larger island which is made up of lava and pumice. A ground inspection of the latter island revealed that lava flows were essentially the same as those on West Tuluman Crater, and that strong peripheral cracking, convex to the south-east, had developed. Smaller minor fractures had formed across this section of the island, and were generally set at right angles to the direction of major cracking. An elongate arm which stretches to the east from the northern limit of the lava is composed of horizontally bedded pumiceous deposits, very probably laid down by the sea on lava flows that have sunk during cooling and contraction.

The highest point on these islands is at the south-east corner, and was about ten feet high at the time of the investigations. Several thermal areas occur, mainly between the two sets of islands, but it was not possible to obtain temperatures in any of these positions.

PART III

VOLCANIC ACTIVITY AND THE FORMATION OF THE TULUMAN ISLANDS IN THE ST.ANDREW STRAIT, MANUS DISTRICT JANUARY - JULY, 1955

by

M.A. Reynolds

(Records 1955/95, Sept.1955.)

INTRODUCTION

The first activity in 1955 began at the "East Crater" ✱ of "Tuluman Volcano" on 10th February, 1955, and the sequence of events from that date until 18th February was described in a preliminary report (Reynolds, February 1955).

On 18th February I left Baluan to inspect other volcanic centres, and observations of further activity were recorded by the Assistant District Officer, Baluan, until I returned on 18th March. At this time a submarine source about one-third of a mile south of a new island formed at the end of February was mildly active. Lava emission from this new submarine cone continued until early May. Details of subsequent events have been reported by officers of the Department of Native Affairs.

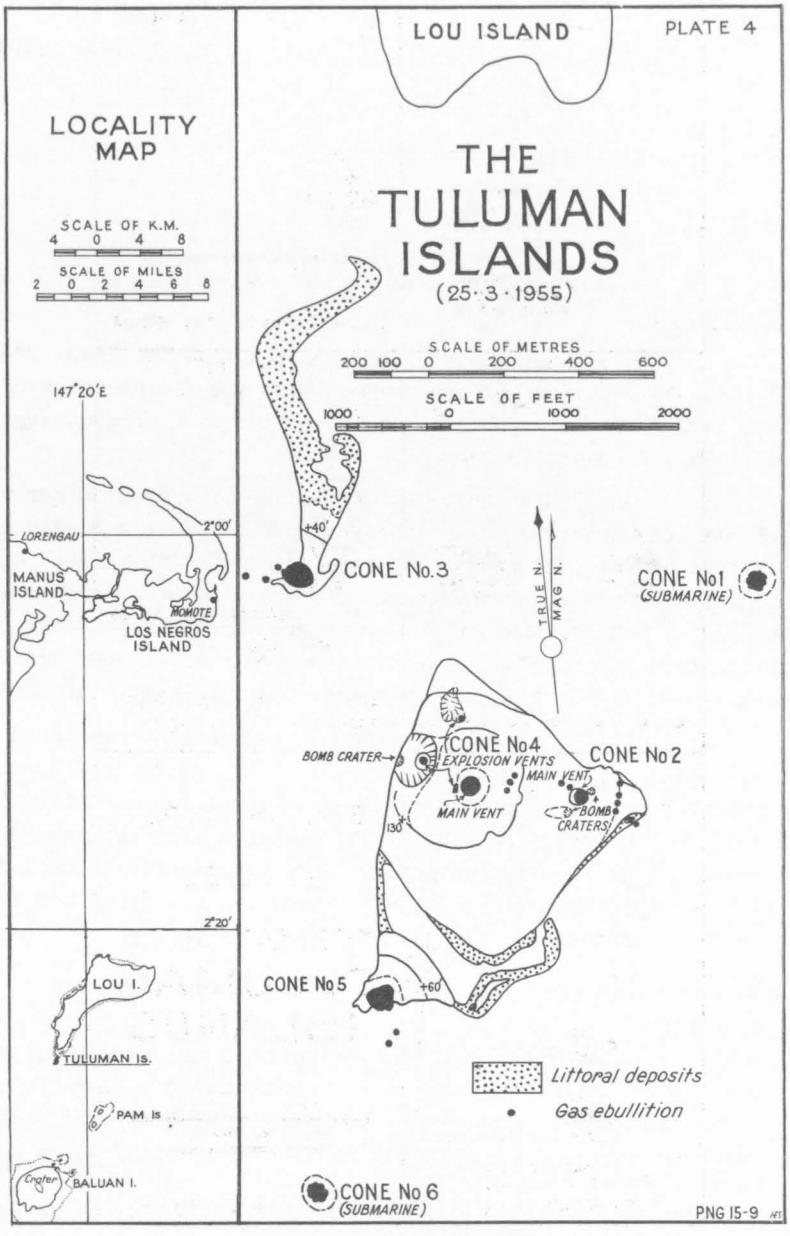
The co-operation given by the District Commissioner and Administration personnel in the Manus District is gratefully acknowledged. In particular, the information supplied by the Assistant District Officer of Baluan Patrol Post, Mr. E.G. Hicks, has been of inestimable value in maintaining an accurate account of events. Officers of the R.A.A.F. and R.A.N. and pilots of commercial aircraft must also be thanked for their assistance on various occasions.

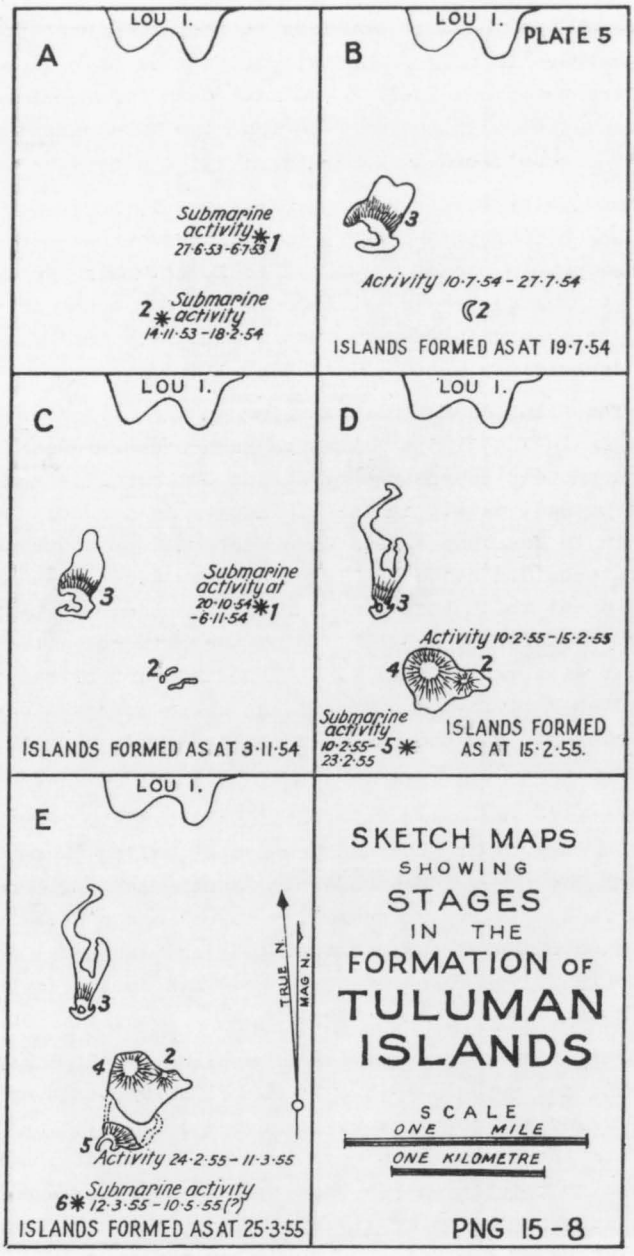
THE TULUMAN ISLANDS

Nomenclature

As a result of volcanic activity in July 1954, two islands were formed, Best (1954) proposed that they should be called "Tuluman Volcano", and the individual islands were referred to as "East and West Craters". ✱ Subsequent activity has resulted in the formation of a new cone adjoining that called "East Crater" and another cone to the south. The nomenclature is reviewed here and a tentative system is suggested which will be more flexible and can be applied if other new islands form (Plate 4).

✱ Names included in inverted commas in the introductory remarks are those employed in earlier reports but changed on pp.13-14of this report.


LOU ISLAND
PLATE 4
LOCALITY MAP
SCALE OF K.M.
4 0 4 8
SCALE OF MILES
2 0 2 4 6 8
147°20'E
2°00'
LORENGAU
MANUS ISLAND
MOMOTE
LOS NEGROS ISLAND
2°20'
LOU I.
TULUMAN IS.
PAM IS
Crater
BALUAN I.
THE TULUMAN ISLANDS
(25·3·1955)
SCALE OF METRES
200 100 0 200 400 600
SCALE OF FEET
1000 0 1000 2000
+40'
CONE No.3
TRUE N
MAG N
CONE No1
(SUBMARINE)
BOMB CRATER
CONE No4
EXPLOSION VENTS
MAIN VENT
MAIN VENT
CONE No 2
BOMB CRATERS
130°
CONE No 5
+60'
Littoral deposits
Gas ebullition
CONE No 6
(SUBMARINE)
PNG 15-9


LOU I.
A
Submarine activity 27·6·53 - 6·7·53
1
2
Submarine activity 14·11·53 - 18·2·54
LOU I.
PLATE 5
B
3
Activity 10·7·54 - 27·7·54
2
ISLANDS FORMED AS AT 19·7·54
LOU I.
C
3
Submarine activity at 20·10·54 - 6·11·54
1
2
ISLANDS FORMED AS AT 3·11·54
LOU I.
D
3
Activity 10·2·55 - 15·2·55
4
2
Submarine activity 10·2·55 - 23·2·55
5
ISLANDS FORMED AS AT 15·2·55.
LOU I.
E
3
4
2
5
TRUE N.
MAG N.
Activity 24·2·55 - 11·3·55
6
Submarine activity 12·3·55 - 10·5·55 (?)
ISLANDS FORMED AS AT 25·3·55
SKETCH MAPS
SHOWING
STAGES
IN THE
FORMATION OF
TULUMAN
ISLANDS
SCALE
ONE MILE
ONE KILOMETRE
PNG 15-8

The nature of the volcanic activity in the St.Andrew Strait is such that, although there is only scant evidence of the main line of weakness, it is believed that individual cones have been formed along a fissured zone. The conduits, although derived from the same parent magma, are, with one exception, considered as separate entities above the ocean bed.

To overcome the difficulty of nomenclature, it is proposed that cones which have already been built up above the surface of the sea and such islands as may be subsequently formed should be included under the name of Tuluman Islands. The individual cones are numbered in the order in which they were formed; their naming is deferred until they have been surveyed and their positions accurately plotted (Plate 5).

Cone 1 (Submarine): The first submarine vulcanism in the St.Andrew Strait in recent years began in June 1953; although lava was extruded from the same source or from another source nearby during October 1954 and May 1955, no island at present exists in the vicinity. As a result of the activity which began in May 1955 a lava dome was built up above sea level on 6th June, but it subsided below sea level on 26th June, when activity ceased. The position at which this dome appeared at the surface is different from that established as the site of the original activity in June 1953. But that site was determined only on the surface manifestations of the submarine activity, and prevailing ocean currents were not taken into consideration; and the island which appeared in June 1955 probably was the summit of Cone No.1.

Cone 2 (Plate 6, figure 1): Two cones were built up above sea level during the period 10th-27th July 1954: the one previously called "West Crater" was formed west, and the other ("East Crater") south-west, of Cone 1. The position of the surface activity of submarine vulcanism in November 1953 was determined by an officer of the M.V."Bulolo", and was close to that determined by Best (1954) for "East Crater", and this island is therefore given precedence in the order of numbering.

Cone 3 (Plate 6. figure 1): This designation is applied to the other island, "West Crater", formed during July 1954. It cannot be proved that the formation of this island was preceded by submarine activity; but volcanic activity continued in the St.Andrew Strait from 9th until at least 13th April 1954, although no details, other than that dense black and grey cloud lay over the area on the 13th, are available. The cloud was seen from the M.V."Bulolo" by Mr.E.G. Hicks; the other information concerning the period of activity was obtained from brief references entered in an old diary kept at the Baluan Patrol Post.

Cone 4. This cone was built up during the volcanic activity of 10th - 15th February 1955, and formed a large island which overlapped the western end of the island of Cone 2. Although not observed because of the dense

vapour cloud over the area at the time, Cone 2 was active while the larger island above Cone 4 was forming. This was deduced from investigations after activity had ceased; and the concurrence of activities and the nearness of the two craters suggest that the conduit to Cone 4 is an apophysis branching from the conduit to Cone 2.

Cone 5: Initial activity from this centre was submarine and coincided with, or commenced soon after, the first eruptions of Cones 2 and 3 on 10th February 1955. Cone 5 was built up above sea level on 23rd February south of Cone 4. The island formed by Cones 2 and 4 is joined to that of Cone 5 by sand-bars built up by ejectamenta from the explosive phases of Cone 5 and by sediments deposited during tide fluctuations.

Cone 6 (Submarine): The activity from this source started on 12th March 1955, and lava was extruded almost continuously from this cone until about 10th May, when it was still submarine. Cone 6 is estimated to be about one third of a mile south of the crater of Cone 5.

Geographical Position

The true position of the Tuluman Islands cannot be plotted by means of prismatic compass triangulation when existing maps and charts of the area are inaccurate. A map of the area (Plate 4) as at 25th March 1955 is included with this report to show the approximate positions and outlines of the islands and the locations determined for the submarine cones.

Physiography

Cone 3 The northernmost of the islands is that formed above Cone 3, Plate 5, which shows the various stages in the development of the island group, shows that the shape of this island has altered since first mapped by Best. The elongated portion of the island stretching from the northern crater rim to the reef at the southern end of Lou Island is composed of a sedimentary deposit of pumiceous rocks and sand. The highest part of the island is the northern rim of the crater. This is about 40 feet above sea level, but when last visited was only about 80 yards long: the eastern and western sections had been eroded away, leaving vertical cliffs of pumice dust exposed at each end (Plate 7, figure 1). Most of the dust deposits which previously formed the upper portion of the southern and eastern rim of the crater have been eroded away and the underlying lava-flow exposed. A narrow bar built up of pumice fragments and coarse-grained sand has isolated a small pool of sea-water at the eastern end of the crater, which was inundated by the sea through the breach in the western side during its formation in July 1954.

When the island was visited on 15th February, 1955, a deposit of fine dust lay over the southern half. The dust came from the active Cones 2 and 4, and lay most thickly (five inches) over the lava flows at the

PLATE 6.

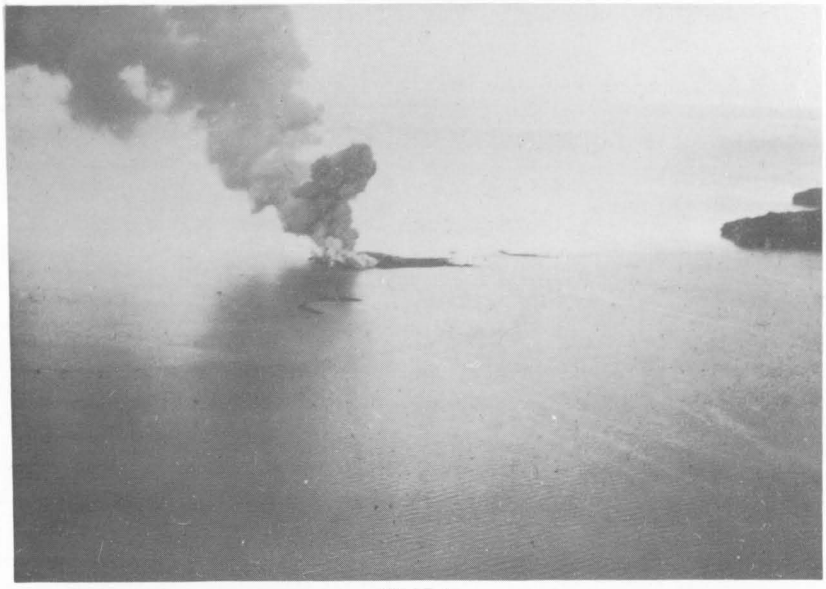


Figure 1.

Islands above Cones 2 and 3: Lou Island on right. Cone 2, represented by small horse-shoe island in foreground, is quiescent. Cone 3 is active. 14th July, 1954, 1745 hours.

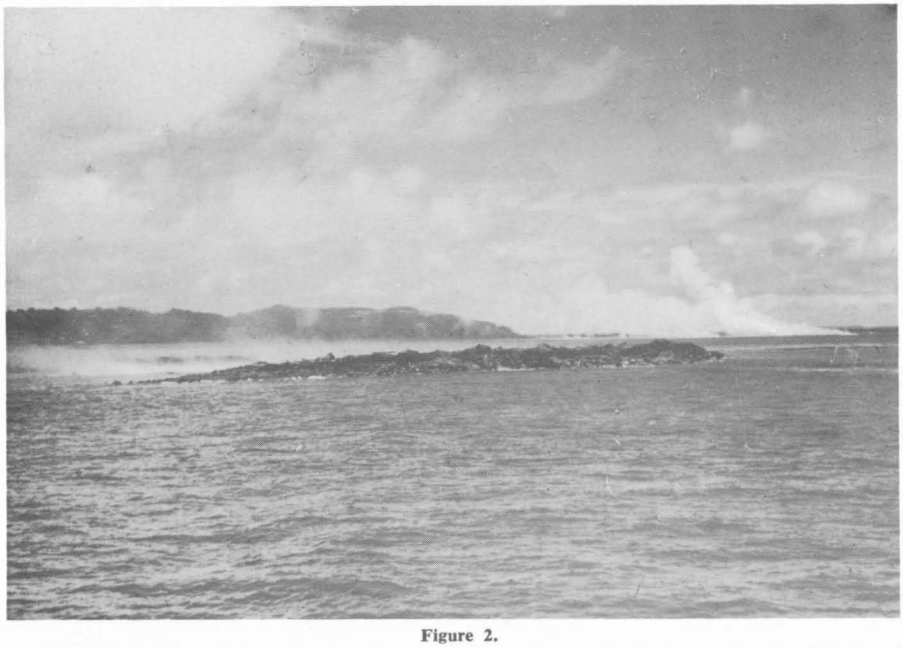


Figure 2.

Easternmost of three small islands above Cone 2. Vapour clouds from submarine activity at Cone 1 on right and Lou Island on left. 27th October, 1954.

PLATE 7.

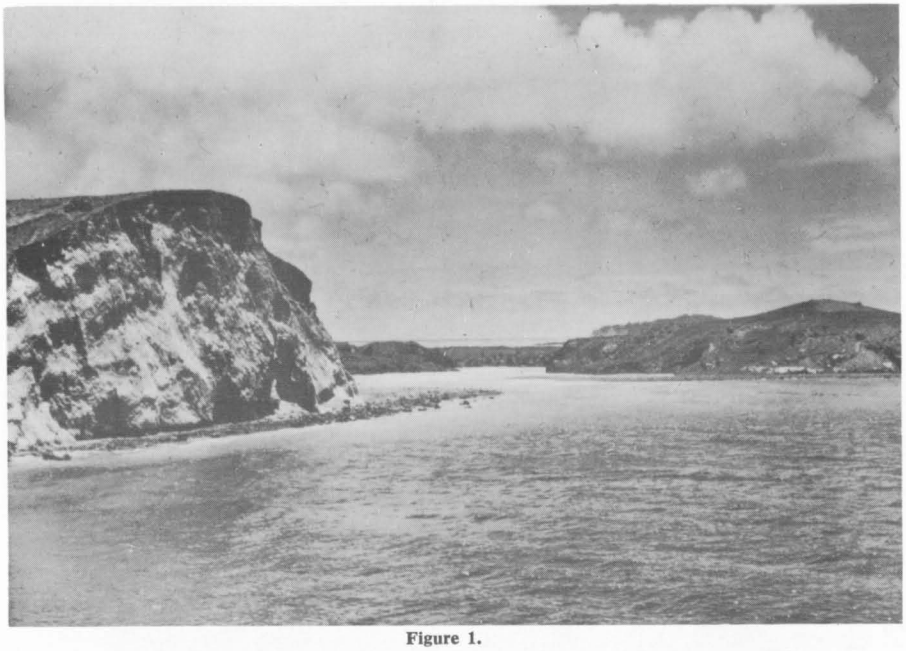


Figure 1.
Crater of Cone 3, inundated by sea; from north-west. 27th October, 1954.

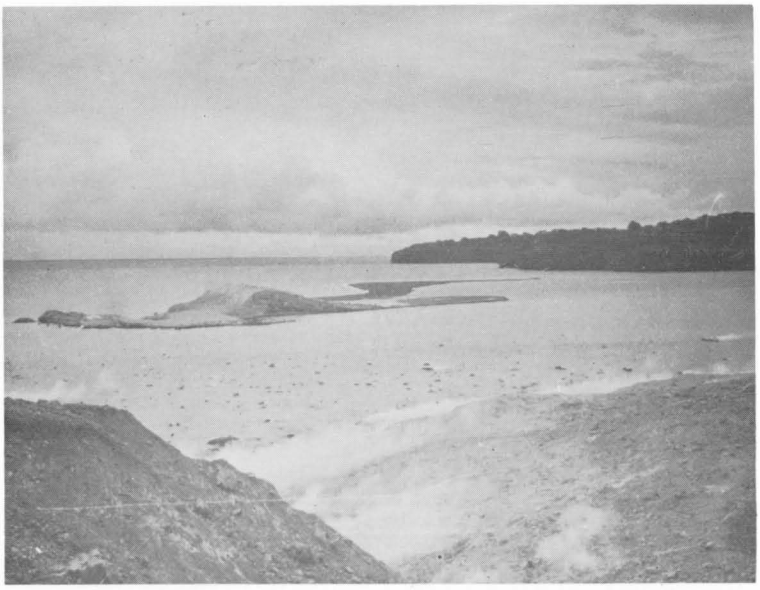


Figure 2.
Island above Cone 3, from island above Cone 4. Note effects of erosion on eastern side, and sedimentary deposit extending from behind northern crater rim towards Lou Island. Floating lava from Cone 5 can be seen in passage between islands. 16th February, 1955.

PLATE 8.

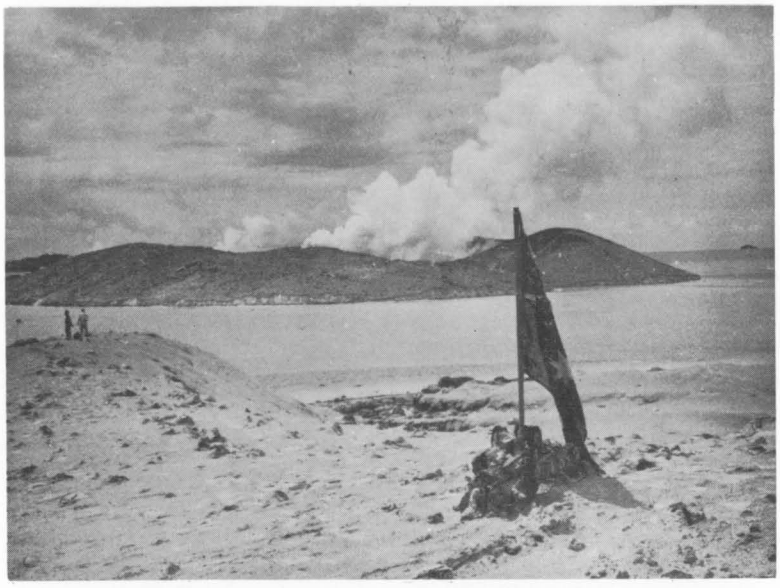


Figure 1.

Summit of Cone 4 from north-west, showing breach in original crater rim (behind flag). Note layer of pumice dust (from February activity of Cones 2 and 4) over Cone 3 in foreground. 15th February, 1955.

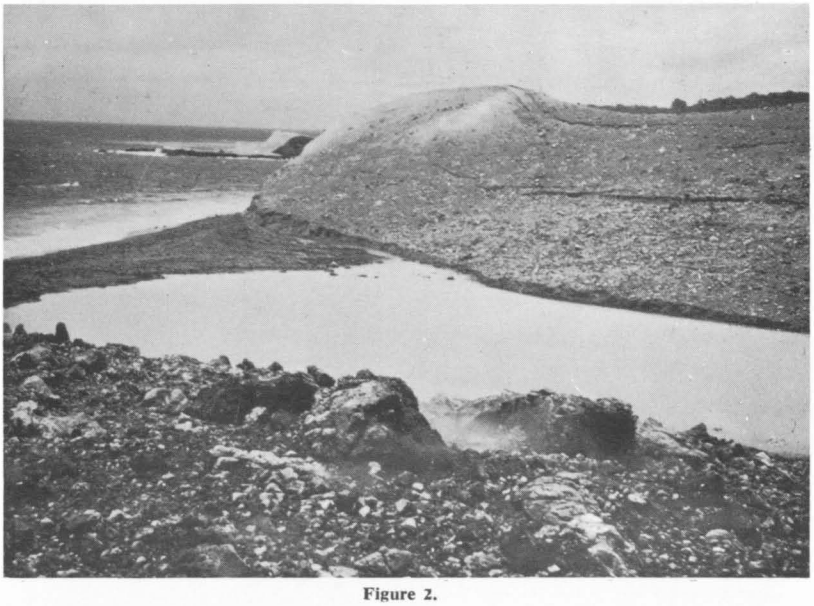


Figure 2.

South-west portion of Cone 4, from summit of Cone 5, showing bar of fragmentory material joining the two islands on western side. Cone 3 is background. 24th March, 1955.

PLATE 9.

Dense vapour cloud from main vent of Cone 4, from northern rim. 16th February, 1955.

PLATE 10.

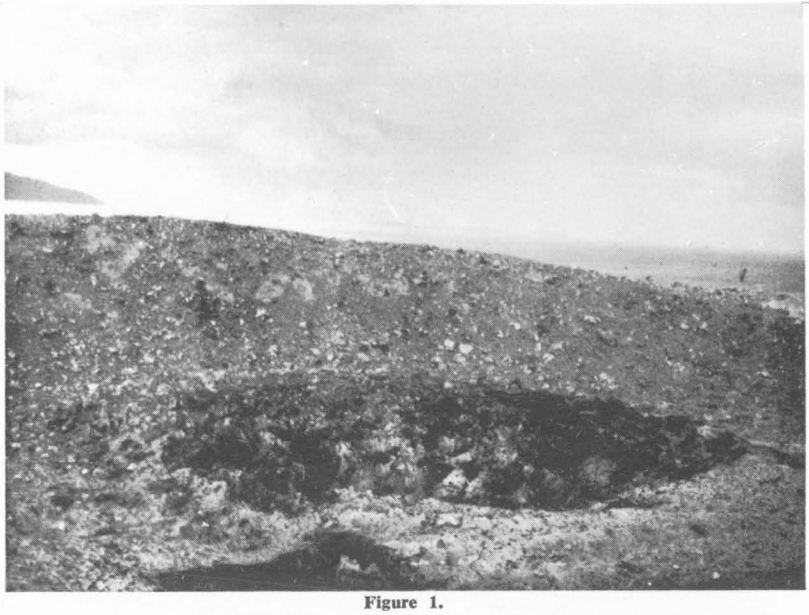


Figure 1.

Main vent of Cone 4, showing mound of pyroclastic material and small explosion vent. From south-west. 24th March, 1955.

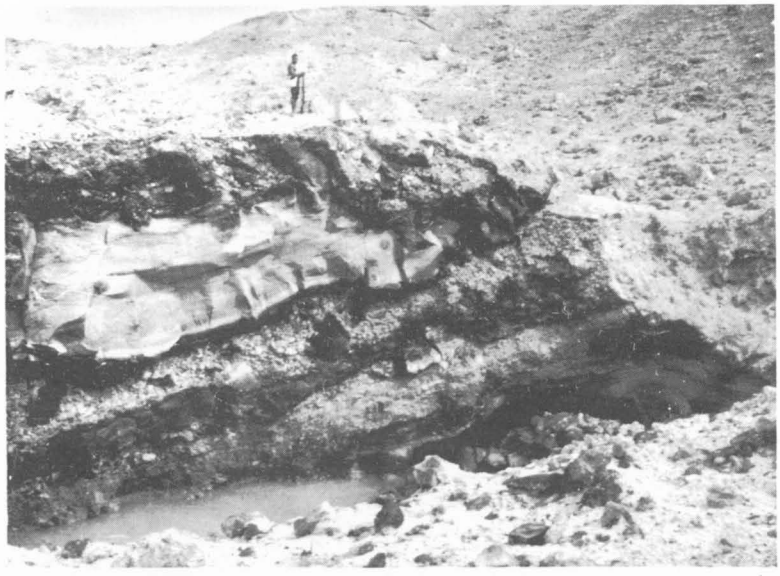


Figure 2.

Section exposed in east wall of explosion vent shown in Figure 1. 24th March, 1955.

south end of the island. Most of this deposit has since been removed by wind and sea (Plate 7, figure 2).

Cone 2 At the end of November 1954, Cone 2 was represented above sea level by three small elongated islands composed of lava, with a narrow peninsula about 200 yards long built up of pumice fragments at the north-eastern end of the easternmost island (Plate 6, figure 2). At that time the maximum height above sea level was ten feet. Before the eruption which began on 10th February 1955, the island group rose about fifteen feet higher above sea level. During the February eruption a deposit of pumice dust with some larger ejectamenta - more prominent at the base - was formed above the lava flow; the flow was exposed at sea level only on the northern and eastern sides when the island was exam - ined in March. The maximum thickness of the deposit of fragmentary material and dust was estimated to be thirty feet near the crater. The dimensions of the island formed cannot be given because the western portion is obscured by deposits from the simultaneous eruption of Cone 4.

The main crater of Cone 2 is about 150 feet in diameter and 20 feet deep at the eastern end where the inner wall is steepest, and contains near the base a cavernous vent through which vapour and gas are continually escaping. Fumaroles were noted during March near the crater, along a low escarpment aligned north-south near the eastern end of the island, and at the eastern margin of the island in a small inlet of the sea in the beach deposits. Other fumaroles occurred along narrow fissures arranged concentrically around the crater and formed as a result of the subsidence of the lava plug within the crater.

Two other small craters lay near the main crater. One was about fifteen yards from the north-eastern rim of the main crater and joined to it by a narrow depression. The other small crater, south-west of the main crater, was at the eastern end of an elongated furrow. The first was possibly formed by the explosion of a lava bomb from Cone 2, and the second is attributed to the explosion of a lava bomb which evident- ly fell near the western rim of Cone 4 and scoured out the furrow before exploding.

Cone 4 (Plate 8) The building up of the summit of Cone 4 above sea level and its attachment to Cone 2 has resulted in the formation of the largest island in the group. Cone 4 is composed above sea level of volcanic dust with small amounts of coarse-grained ejectamenta. Lava out- crops were noted in the main vent, in a smaller contiguous vent to the west, and at sea level at the north-east margin of the island, where it is over- lain by a thick deposit of unconsolidated agglomerate.

The main crater occupies more than a quarter of the area of the island, and at one stage during the eruption was even larger. The rim of the larger original crater is continuous on all sides except the western,

where it has been breached by explosive activity from the small crater whose centre is 70 yards east of the western end of the island (Plate 8, figure 1). Subsequent activity from the main vent resulted in the formation of a low ridge east of the explosion crater, which links the northern and southern portions of the original rim. The main vent is a steep-sided depression 160 feet in diameter and about 30 feet deep, surrounded by a mound of pyroclastic material up to 30 yards wide in places. The centre of the depression was not visible during February because of the dense cloud of vapour emanating from it (Plate 9). By March, however, the activity had subsided and it was possible to see the bottom of the depression, which was occupied by green-coloured water through which there was an ebullient escape of gas. A smaller vent elongated in a north-south direction lies to the west of the main vent and is separated from it by the mound of pyroclastic material referred to above. The mound here is only ten yards in width and the dimensions of the small vent are approximately 20 by 15 yards. This vent has vertical walls and a pool of water at the base (Plate 10).

The small explosion crater 70 yards east of the western end of the island is about 45 yards in diameter at the rim. The inner slopes are steep and form an almost perfect inverted cone to the base, where there is a small circular pool of water which has been stained brown. The surface of the water in each of the three vents is at sea level, and the water probably accumulated by infiltration of the sea through the underlying porous lava. When originally visited in February, the island extended farther to the west, and two small craters about 20 feet in diameter were seen near the western margin. The more southerly of these was attributed to a lava bomb explosion and the northern appeared to be a small explosion vent. By March 24th half of the southern crater had been eroded away and was separated from the sea by a narrow beach deposit. The northern crater had been completely inundated by the sea and was represented by a thermal area, from which vapour could be seen escaping only as waves receded. On the north-west side of the island a shallow depression had been formed, possibly by an explosive discharge of gas and vapour from a small vent near the upper rim.

On 12th February the highest point on Cone 4 was on the south-west rim of the crater and was about 130 feet above sea level. Since then concentric fissures have been formed around the main crater and there has been subsidence within it. As a result, the height at the position referred to above was only 100 feet above sea level on 31st March 1955. The map prepared of the Tulumban Islands was based on a survey conducted on 24th March, when, although some fissures were noticed, subsidence had not begun. Further recent subsidences have resulted in the formation of new centres of activity on the island. These are discussed later on pages 34-36.

Sediments of pyroclastic origin which have formed beaches around the island are shown on the map as they existed on 24th March 1955. These deposits will be redistributed as a result of the alterations in the direction of the ocean tides and currents in this area.

Cone 5: The summit of Cone 5 was altered several times after its first appearance above sea level on 23rd February, 1955. At one stage, the island was a symmetrical cone about 200 feet high and three times its present area. The whole of the southern and western portions of this island were disintegrated during violent explosive activity on 4th March. The island as surveyed on 24th March was composed only of the north-east portion of the crater, with a narrow peninsula delineating the western margin of the main vent, which was inundated by the sea. The peninsula is formed by the remnant of a lava flow which dips to the south-west, and of overlying fragmentary material. Deposits from two phases of the explosive activity were recognised in the steep wave-eroded cliffs on the western side of the island (Plate 11, figure 1). During the first of these phases the crater walls were built up by volcanic dust and were similar to those of Cone 4. Deposits of agglomerate interbedded with lava flows, the most prominent of which outcrops at sea level at the tip of the peninsula, built up a smaller inner crater rim during the second phase.

The southern margin of the island is indented for 60 yards by the northern section of the main vent. The crater walls and the cliffs formed east of the crater along the southern side of the island are almost vertical. The north-eastern section of the island is formed by the outer slopes of the first-formed crater rim and is composed mainly of thick pumiceous dust deposits overlain by a deposit, one foot thick, of coarse angular fragments of tachylyte and pumice with occasional large lava bombs. As a result of this superficial deposit, formed during the second or later phase of activity, the island is much darker in appearance than other islands in the group. The highest point on the island is at the eastern end of the outer crater rim and is approximately 60 feet above sea level.

The island is joined to the island of Cones 2 and 4 by a narrow bar at the western end, and elsewhere by littoral deposits of pumice and tachylyte gravel. The embayment between the two islands (shown on the map) was later sealed at the eastern end to form a shallow lake through which some vapour and gas were escaping.

VOLCANIC ACTIVITY

Mechanism of Activity

The previous parts of this report have included remarks on the extrusion of lava from submarine sources, the accompanying activity, and eruptions after the cones have been built up to sea level. These remarks have now been considered in the light of observations made during the later eruptions, and a theoretical outline of the mechanism of the activity has been prepared. This is divided into three sections, the first dealing with the origin of the magma, the second with the submarine formation of the cone, and the third describing the activity when the cone has built up to sea level.

Origin of the Magma

The reservoir that supplied the material of the cones formed since June 1953 is thought to be intimately related to the source from which the volcanic materials constituting the islands round the St. Andrew Strait were derived. The chamber may have formed, and molten lava accumulated, by the incursion of abyssal magma; or semi-fluid magma in an existing chamber may have been liquified by gas accumulation. Either process must have been very gradual, because no seismic activity was noticed locally before the eruption of June 1953. This lack of seismic activity also suggests that the second hypothesis is the more likely. The slow accumulation of gas within a chamber of constant volume would build up high pressures and, according to combined laws of Boyle and Charles, temperatures sufficient to convert the magma into liquid lava. Perret (1950) points out that although a liquid as such is "noncompressible and non - extensible" it may absorb gas. Under certain consitions the gas "may come out of solution and vesiculate the mass; the liquid will then have acquired the property of extension through the presence of a myriad distributed bubbles of expansible gas and by the same token it is now capable of compression". When the pressure had risen sufficiently to rupture the wall of the chamber at its weakest point, the lava would escape; in St. Andrew Strait conduits from the reservoir penetrated the crust about 700 feet below sea level.

Submarine Activity

The lava first ejected is pumiceous and contains much gas; as the outer portions are quenched by the sea water, they break off and float to the surface as large blocks. At the surface the hydrostatic pressure on the blocks abruptly drops, and the gases escape, often explosively so that the blocks are fractured and particles thrown into the air, sometimes higher than 500 feet (Plate 11, figure 2). Red-hot lava exposed by the fracturing comes suddenly into contact with the water, forming dense clouds of steam which, as many of these reactions take place simultaneously, rises as a column, sometimes 7,000 feet high. The blocks of lava float for a while but eventually sink (Plate 12).

Figure 1.

Lava flow and agglomerate exposed above scree deposits in eroded western cliffs of island above Cone 5. 24th March, 1955.

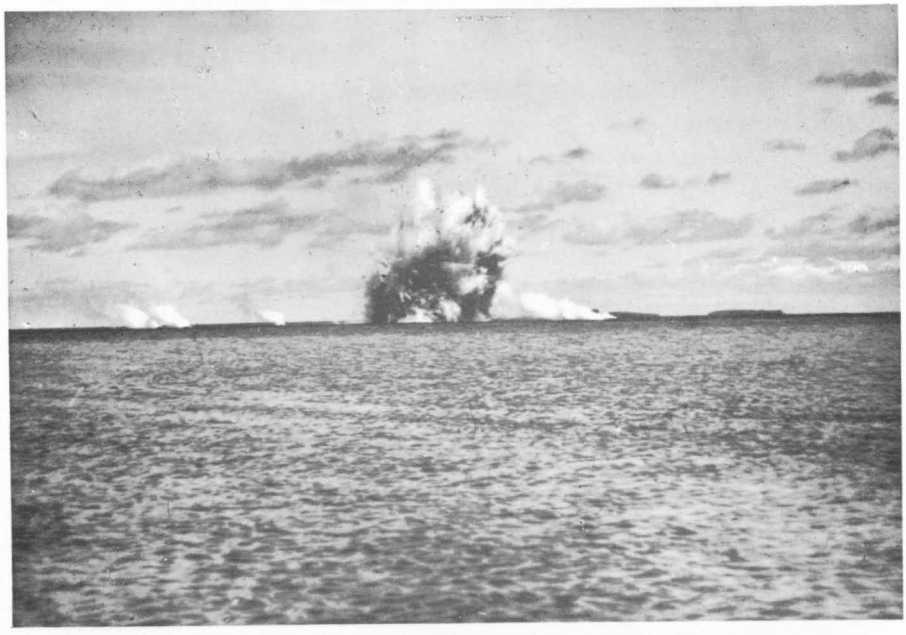


Figure 2.

Explosive release of gas from lava masses reaching surface. Cone 1. 3rd November, 1954.

PLATE 12.

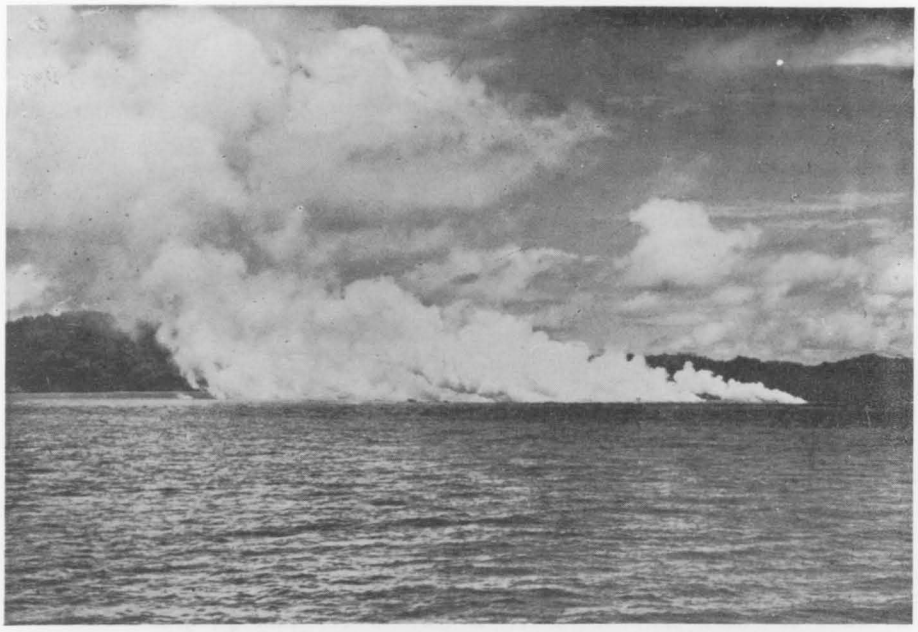


Figure 1.
Vapour cloud from floating lava masses. 27th October, 1954.

Figure 2.
Lava masses from Cone 6. 24th March, 1955.

These events, however, are not continuous. The periods of explosions and formation of clouds are generally interspersed with irregular intervals of comparative quiescence when, according to atmospheric conditions, the clouds are either dissipated or gather above the area to form a high cumulus-shaped cloud. The irregularity can be explained by assuming that during a lava flow from the submarine vent a certain amount of pressure is released and that the lava in the upper portion of the conduit solidifies because it is cooled by sea-water and because release of pressure causes a drop in temperature of the lava. Gas would accumulate again beneath the plug until the pressure was sufficient to eject the plug or temperatures were of such an order as to remelt it, and lava would again flow from the conduit. During the repetition of this process, the dome is built up towards the surface of the sea. Perret (1950, p.38) describes a similar spasmodic trend to the formation of liquid lava in a discussion on the conduit heat. He states:

> "I have for long believed in the functioning here (in the conduit) of a simple thermo-dynamic process. Possibly this scheme may not have been previously envisaged because it depends upon two well known principles which must be considered as acting together. These are, first, that the upthrusting force which has lifted the magma against gravity extrusively though the crustal layers and beyond into the volcanic edifice, far from being constant, is in reality extremely variable, intermittent, often even rhythmic. Upward pressure is sure to be followed by stasis, and this in turn by resumption: no fact of observation is more firmly established. The second point is the well known development of heat by compression of a gas".

Two other factors probably also act in the sealing of the vent while gas is accumulating. These are the hydrostatic pressure and the combined lateral pressures of sediments through which the dome is penetrating and the lava of which the dome is composed. This explanation would also account for the fact that sea water has not been able to gain access to the molten lava within the magnetic chamber.

Activity at Sea Level

The formation and composition of the islands are summarized so as to emphasize common features that bear on the nature of the activity:

Cone 2: Its initial appearance above sea level in July 1954 was preceded by submarine activity in November 1953 in a position approximating that of the cone. The northern and eastern margins of the present island, formed in February 1955, reveal a basal lava flow overlain by a thin bed of unconsolidated agglomerate and pumiceous dust deposit.

Cone 3: The details of submarine activity before an island was formed above Cone 3 in July 1954 are not complete and it is impossible to say whether the activity in April 1954, mentioned in the section on nomenclature, was the forerunner to the formation of this island. At the southern end of the island a well defined lava flow is overlain by

unconsolidated agglomerate. The thick pumiceous dust deposit which forms the northern crater rim, the most prominent feature of the island, was formed after the agglomerate.

Cone 4: Because Cone 4 is so close to Cone 2, and was formed above sea level in February 1955, while Cone 2 was active, it is considered to have resulted from the branching of an apophysis from the conduit of Cone 2. A short period of submarine activity may have preceded the formation of the island, but from the time that activity began until the presence of an island was revealed, the area was enveloped in a dense cloud of vapour. This period was so short that the apophysis must have formed at shallow depth below sea level. The general sequence of basal lava flow, unconsolidated agglomerate, and thick deposit of pumiceous dust has also been recorded for the island above Cone 4.

Cone 5: The formation of the island here on 23rd February, 1955, was preceded for twelve days by submarine activity. There is no evidence of an initial lava flow and overlying unconsolidated agglomerate beneath the dust deposit forming the outer crater rim. These beds may, perhaps be missing because of the activity which gave rise to the second inner crater, the composition of which is discussed later in this section.

When the cone has reached sea level the only factor preventing the escape of gas within the magma is the lava plug: atmospheric pressure can be discounted as a force opposing its escape. From the above summary of the composition of the islands, the conclusion has been drawn that after the flow of lava which builds the cone above sea level, the next release of accumulated gas disintegrates the plug with explosive violence, and forms a deposit of large angular fragments, mainly pumice and tachylyte. Thereafter the liquid lava and gases are free to escape, and the gas consequently expands explosively, pulverizing the lava with which it is associated. The thick pumiceous dust deposits are formed by this action. As a result of the rapid escape of large volumes of gases, the pressure within the conduit is relieved and the lava consequently solidifies. Gas accumulates for a short period until the pressure is again sufficient to eject the solid lava plug and another explosive phase occurs. This procedure continues until all the energy from gas accumulated in the magmatic column has been expended.

In Cone 5, the outer crater rim was probably formed in the manner described above, but the inner deposit of agglomerate with its associated lava flows was formed rather differently. The source and extent of these flows could not be determined during the ground survey because their outcrops are only revealed clearly in the vertical western cliffs, and even there they are partly obscured by a coating of dust formed by collapse of the walls during erosion. However, they and the interbedded agglomerate deposits are all

considered to have formed during a second phase of activity. The nature of the deposits suggests that the volume of gas vesiculated in the lava column before the second phase began was less than in the previous phase and consequently the pressure was insufficient to pulverize the mass to the same extent when the vent was freed of the plug. The removal of the plug may, in fact, have been due to a premature upsurge of the magma from the conduit as a result of luni-solar influence . It is estimated that the second phase occurred during March 7th and 8th when the sun and moon were in opposition at zenith positions very close to the latitude of the Tuluman Islands. The sudden removal of the plug from the conduit allowed gas remaining at depth to escape, and the phase culminated during the next two days in what was described in a signal as the most violent explosions at Cone 5 since activity began on 23rd February.

Activity stops at any cone when lava in the conduit solidifies because the gas content has been reduced. In submarine cones comparatively little gas escapes in any one active period and the cone becomes active again when sufficient gas has accumulated; but in surface cones the explosive activity releases much gas.

Once the explosive phases are over activity ceases, except for some minor mud eruptions: this suggests that most of the cones are discrete.

Notes (not published) prepared by Best in 1953 describe the Lou, Pam, and Mok Islands as remnants of the rim of a large strato-volcano with the St.Andrew Strait representing a submarine caldera. Baluan Island at the southern extremity of the strait is regarded as a parasitic cone.

The line formed by joining the positions determined for Cones 1, 2, 5 and 6 is convex to the north-west, corresponding with the arcuate form of Lou Island. Although it cannot be said on the evidence available that this is the main line of weakness, it is possible that, owing to subsidence within the postulated St.Andrew Strait caldera, an unstable zone could exist along the inner margin of the crater rim represented by Lou Island. Secondary radial fracturing would account for the activity at the positions of Cones 3 and 4.

Activity, January - April, 1955

Activity arranged in chronological order

January 1st - February 10th, 1955: People travelling between Manus and Baluan Islands noticed that the small islands which formed during July 1954 and were previously called "East Crater" were emerging from the sea, and that the highest point before the eruption was 25 feet above sea level.

February 10th: Activity began at 1345 hours with a single steam explosion which formed a white cloud that ascended vertically to a height of 800-900 feet above sea level. This was witnessed by Assistant District Officer

E.G. Hicks from M'bunai on the south-east coast of Manus, a distance of about 22 miles from the Tuluman Islands. According to A.D.O. Hicks, who had travelled from Baluan Island to M'Bunai that morning, no premonitory warning, other than the emergence of the islands described above, was noticed.

Another explosion at 1347 hours formed a black cloud which ascended to the same height. Thereafter white cloud billowed out continuously with intermittent explosions. Examination of the area from an Administration trawler revealed that vapour clouds were rising from a circular zone about 200 yards in diameter in the vicinity of Cone 2 and the sea to leeward was covered with large blocks of steaming lava. The focus of the activity appeared to be the centre of Cone 2. A red glow was visible from M'bunai during the night.

February 11th: Vigorous activity continued until 1000 hours, and the white vapour cloud ascended to heights of 5,000 to 6,000 feet above sea level. Between 1000 and 1200 hours the type of activity changed, and thereafter black clouds of ejected material were seen to ascend periodically to heights of almost 1,000 feet. Dust accumulated in the vapour clouds, which turned grey. Closer inspection that afternoon showed that explosions were continuous, and that the black clouds from explosions either ascended vertically before billowing out at 1,000 feet or spread out at sea level and then built up with a "Christmas tree" effect with rocks continually being ejected from them. The island above Cones 2 and 4 had by this time formed above sea level: and that night, as activity continued, showers of red-hot ejectamenta rained down on the slopes. Large blocks of lava from a new submarine vent (Cone 5) appeared south-west of the new island during the afternoon.

February 12th: (Plates 13 and 14): Activity as above. Other features noted from the air included an occasional yellow-orange colour in the vapour cloud from the crater of Cone 4; a small volume of vapour emission from the crater of Cone 2, accompanied by the jet-like extrusion of a black material to several feet above the main vent (probably projection of fine dust by steam jets); and a froth of reddish-brown material in the area where lava was reaching sea level from submarine activity of Cone 5. When the trawler "Poseidon" visited the area later the same day, it was noticed that for periods of several seconds steam escaped with a roar as though from the safety valve of a locomotive. Each escape either ceased as suddenly as it started or culminated in a strong explosion, ejecting great volumes of vapour, dust, and many bombs. The bombs were projected to a height of about 500 feet and fell within 200 yards of the crater. Near the active cones, the smell of burning tar was encountered. Other gases noticed were sulphur dioxide, which was also detected during the aerial inspection in the morning, and sulphuretted hydrogen. As the trawler sailed beneath the dense vapour and dust clouds pisolites descended from them and

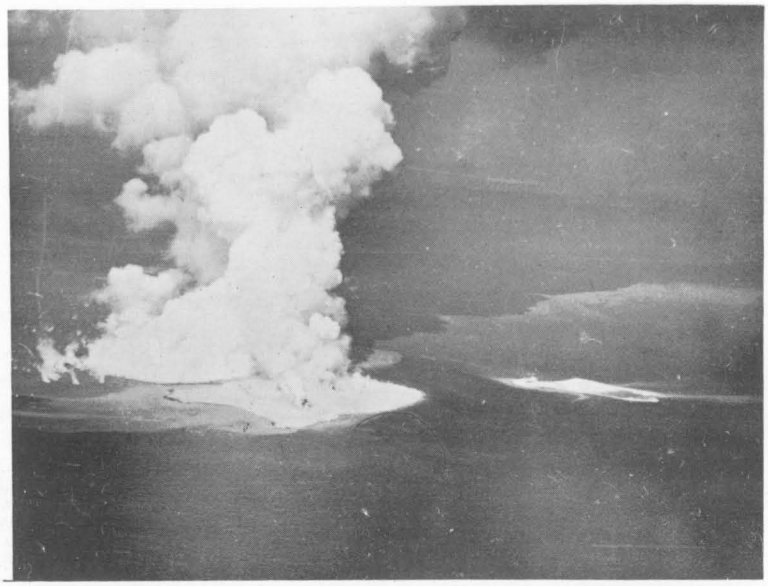


Figure 1.

Dense vapour clouds from Cone 4; lava flow from Cone 5, behind; small vapour emission from Cone 2, east end of island; Cone 3 at right. 12th February, 1955.

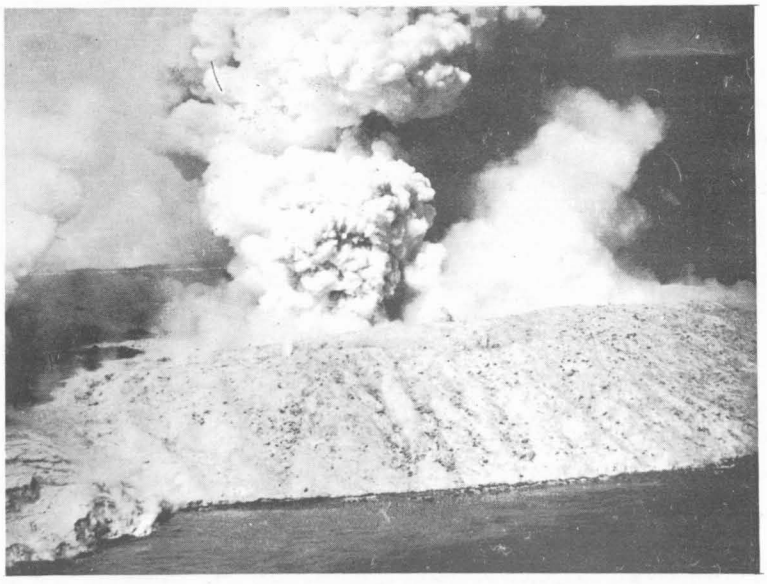


Figure 2.

Island of Cone 2 covered by pyroclastic deposits from Cone 4 and joined to it. 12th February, 1955.

PLATE 14.

Figures 1 to 3.

Showing formation of vapour and dust cloud rising to 2,000 feet about a minute after explosion at Cone 4. 12th February, 1955.

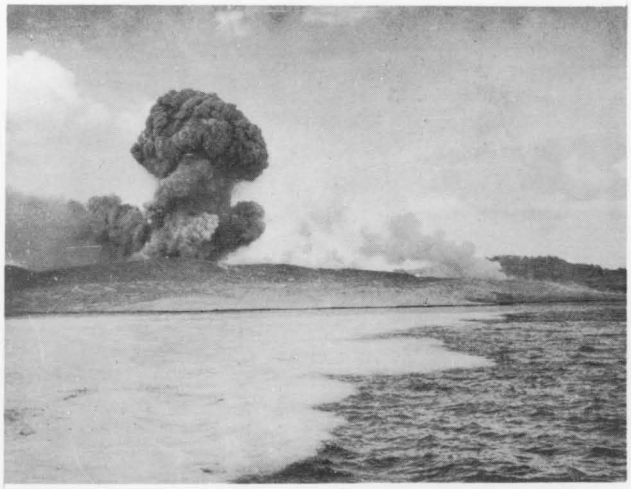


Figure 1.

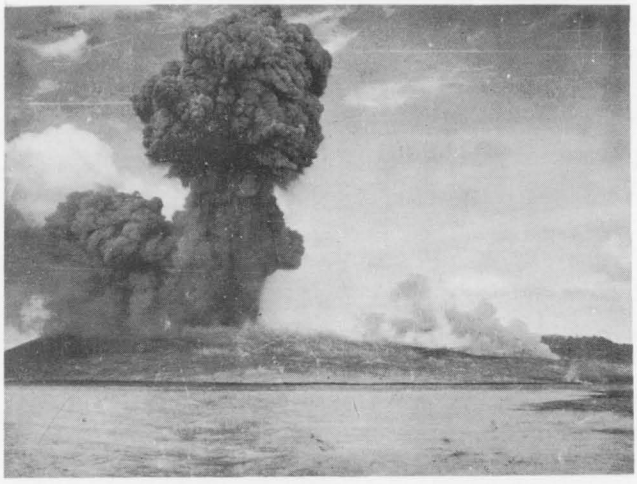


Figure 2.

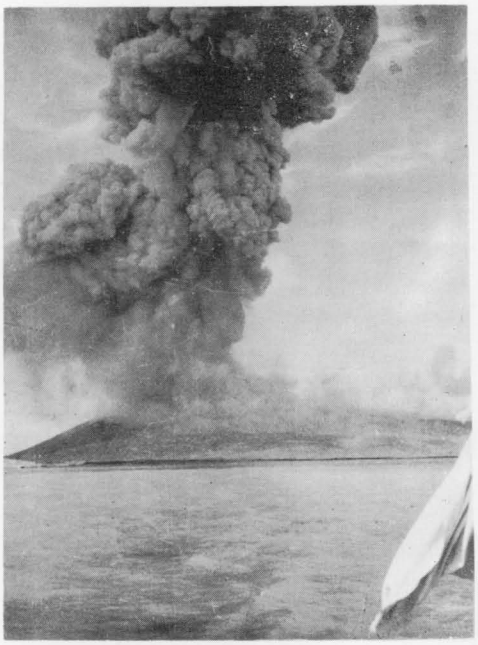


Figure 3.

fell on the decks; pumice lapilli up to an inch in diameter, ejected by explosions, also landed on the trawler, which was at least half a mile from the island. A.D.O. Hicks pointed out that the breach that could be seen on the western side of the island (formed by a secondary explosion vent) did not exist when he visited the area on the 11th. The activity diminished in intensity during the afternoon, but explosions and occasional roars of escaping gas were heard throughout the night.

February 13th: Emission of vapour and gas as voluminous, white (sometimes orange) cumulus clouds from Cone 4 continued and was accompanied by an occasional explosion. Lava ceased to be extruded from Cone 5 (submarine) during the morning. During the afternoon twelve explosions occurred, on the average, every hour, ejecting large volumes of vapour and dust and some bombs, as well as numerous smaller explosions during which only vapour and gas were forcefully emitted. During periods of quiescence, the greatest of which was 27 minutes, vapour clouds were often coloured orange . During the night activity was similar to that witnessed in the afternoon but appeared to be more intense. The roars of escaping gas were more pronounced and the aerial concussion from explosions was felt quite noticeably in the A.D.O's house on Baluan Island, particularly between 2200 hours and midnight, when explosions were definitely more violent than usual. During these two hours there was a continuous red glow from the crater, even during periods of quiescence. Some dust descended on Baluan Island.

February 14th: The activity all day was similar to that described above for February 13th, but was not so intense.

February 15th: There was some explosive activity until 0900 hours but thereafter no further explosions were noticed until 2130 hours, when a brief period of intense explosive activity commenced. Vapour and gas were emitted with formation of white cumulus clouds during the day, and a brief inspection of the crater revealed fountains of dark brown to black dust being projected by what appeared to be steam jets to a few feet above the lip of the main vent. The dust, however, was not thrown out by this action and either remained suspended in the jet or dropped back into the vent.

February 16th: No further explosions were witnessed from Cone 4, and the only activity was a mild emission of vapour and gas. Activity from Cone 5 (submarine) was renewed at about 0600 hours.

February 17th to 23rd: The discharge of vapour from the craters of Cones 2 and 4 diminished. Vapour clouds from the blocks of lava extruded from the submarine source (Cone 5) increased in volume and explosions became more violent. On the evening of the 23rd a new island appeared to be forming above Cone 5 about 400 yards south-south-west of Cone 4.

February 24th: Continuous loud rumbling came from Cone 5, and occasional violent explosions ejected bombs to 1,000 feet above sea level. Numerous lava blocks, still glowing and steaming, some of many tons displacement, drifted ashore at Baluan Island. The most characteristic feature until 2200 hours was the increase in noise. The craters of the other cones were quiet.

February 25th: The new island had disappeared during the night and activity was again submarine and less violent.

February 26th to 28th: The submarine source was intensely active, with explosions regularly at about five minute intervals. Vibrations were felt on Baluan Island as a result of the stronger explosions, some of which were heard as far away as Bundralis, 46 miles away on the north coast of Manus. Activity over this period was witnessed also from Bipi Island, west of Manus, 70 miles away from the Tuluman Islands.

March 1st: Violent explosions as above continued, with masses of ejectamenta hurled to between one and two thousand feet above sea level and presenting a fiery spectacle by night. Loud continuous rumbling was associated with this activity. The area occupied by lava masses was estimated to be 800 yards wide and the cloud formed had obscured the other islands to the north for several days from Baluan.

March 2nd: Explosions were still frequent and violent and another island was built up above sea level.

March 3rd: At 1030 hours the island was disintegrated during three terrific explosions; thereafter the cone was in continuous violent eruption, ejecting a constant column of material to heights of over 1,000 feet above sea level, and showers of huge glowing rocks were distributed over a wide area. A new island was formed that night and made visible by the deposits of glowing material on the outer slopes. The loud rumbling grew louder.

March 4th: The summit of the cone was estimated to be about 70 feet above sea level, and the island was about 250 yards wide during the morning. The crater was 500 yards south of the crater of Cone 4 and a low saddle of ejectamenta joined the two cones. Violent activity continued, and by 1400 hours the estimated height of Cone 5 above sea level was 140 feet and the island's diameter was about 300 yards. Shortly after dusk, the island was a perfect cone 200 feet high, but between then and midnight the intense activity resulted in disintegration of a large portion of it. At midnight noise and explosions ceased, and a submarine lava flow from just south of the remnant of the island (the original crater area) resulted in the entire eruption area's being enveloped in a dense steam cloud.

March 5th to 7th: Submarine activity adjacent to the island, now only 50 feet high, continued with some rumbling until 1200 hours on 7th, when a violent eruptive phase began. There was loud roaring that night and aerial concussion

from explosions again caused vibrations to buildings on Baluan Island.

March 8th: The intense activity which began at noon on the 7th continued, and during the morning vapour and dust clouds were coloured brick-red to orange. It was reported from the Pam Islands that an inch-thick dust deposit had formed over the islands, and that water stocks and gardens had been spoiled (salts formed from sublimation products of the eruption, and finely disseminated amongst the dust which was carried over the area by the prevailing wind from the north-west, probably caused water contamination and poisoning of the garden crop).

March 9th to 11th: The violent activity culminated at 0400 hours on 9th in what were described in a signal as the "most violent explosions (of the) current phase with concussion rocking buildings (on) Baluan and (projection of) flaming geysers (of) gases (and) ejectamenta to hitherto unprecedented height". There was no wind, and black dust clouds from eruptions mushroomed at 6,000 feet. Frequent lightning flashes occurred within the electrically charged dust-clouds and the "characteristic roaring swoosh and rumbling (were) most consistent". Explosive activity continued thereafter until 1700 hours on the 11th. The island appeared to have been reduced still further by this phase of the activity.

March 12th: Apart from the small volume of vapour emitted, activity at Cone 5 was negligible. Lava was extruded from a new submarine source (Cone 6) about 600 yards south of Cone 5 (estimated from the position at which lava masses appeared at the surface).

March 13th to April 30th: Submarine activity from Cone 6 continued with periods of varying intensity until the end of April. The periods of greatest intensity were as follows:

> From the evening of 20th March lasting for approximately 48 hours; April 4th to 11th, and 16th to 18th (periods of many explosions and formation of dense cumulus clouds occurred intermittently between periods of quiescence).

There was a period of almost complete quiescence from 0800 hours on 19th April until 0700 hours on 22nd April.

Lava and Ejectamenta

The members of the Tuluman Islands are composed of lavas, unconsolidated agglomerates with fragments of lava, glass, and pumice, and thick dust deposits with bombs and lapilli scattered throughout.

Lava Flows (Plate 15)

The individual flows which form the basal sections of the islands are composed of three main types of effusive rock:

(i) The upper section of the flow is formed mostly of grey to dark grey pumice, highly vesiculated, with some large cylindrical vesicles more than six inches in length and two inches in diamater. Most of the vesicles are tubular, of small diameter and elongated parallel to the direction of flow. This alignment of vesicles gives a "fibrous" appearance to the pumice.

(ii) The second of the rock types is a black glass which is considered to be tachylyte, although no analysis has been made. It occurs as a crust over pumice, interlaminated with pumice, in massive bands, or as laminae in the third type of effusive rock. Specimens from the massive bands are heavy and show very few vesicles on macroscopic examination. There are some amygdales of a white to colourless and transparent mineral.

(iii) The effusive rock which is predominant in the basal section of a flow is very fine-grained, dark coloured, generally heavy, and often shows flow texture as a result of fine vesiculation. In appearance, the rock appears to be basaltic, but this has yet to be verified by microscopic examination.

The flows in the Tuluman Islands are pahoehoe lavas (Perret, 1950); this is indicated by the continuity of surfaces of the various flows. These surfaces are thin glassy crusts which have been burnished during movement; they are brown (owing to oxidation) or light grey in colour and have a shiny, fibrous appearance. The strong vesiculation of the upper, pumiceous, portions of the flows, is not in accordance with the tiny vesicles generally described in typical pahoehoe lavas. This, however, is atributed to the nature of the activity in the conduit and subsequent rapid cooling. The glassy crusts that commonly envelope the pumice in the actual lava flows are finely vesiculated only in the direction of flow and are not vertically perforated as would be expected if large volumes of gas appeared during the flow. This indicates that the pumice in a frothy liquid state in the upper part of the conduit lost most of its gas content and became a viscous, almost plastic, mass before the lava flow began. The initial flow of lava from the vent would consist of the less viscous lava which was below the pumice in the conduit. This enveloped and carried the pumice from the conduit during its outward movement. Rapid cooling resulted in the formation of glass from the lava and in the solidification of the pumice, the whole forming a crust below and through which subsequent lava forced its way. These underlying lavas lost their heat more slowly and the minerals had begun to crystallize before the mass solidified. Hence the lava grades from very fine-grained basalt-like rock at the base to glass and pumice in the upper sections of the outcrops exposed on the islands.

PLATE 15.

Figure 1.
Lava flow, still hot, eastern side of Cone 3. July, 1954.

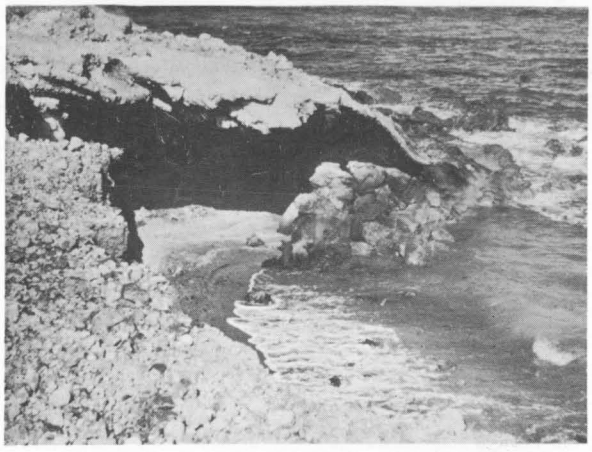


Figure 2.
Lava flow on west side of Cone 3, showing cavern resulting from outflow of molten lava from beneath solidified crust. July, 1954.

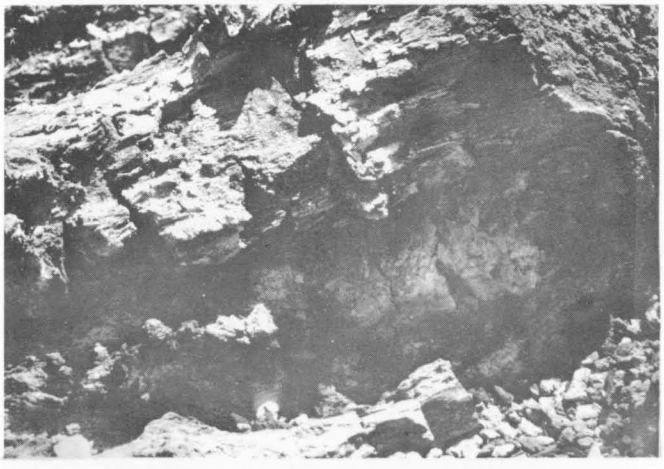


Figure 3.
Lava flow on easternmost island over Cone 2. 3rd November, 1954.

PLATE 16.

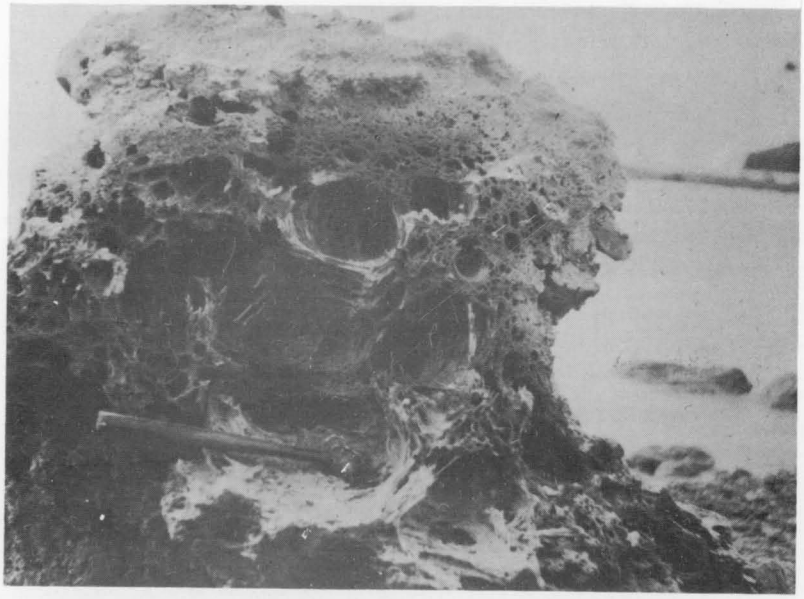


Figure 1.
Vesiculated pumice on Cone 3. July, 1954.

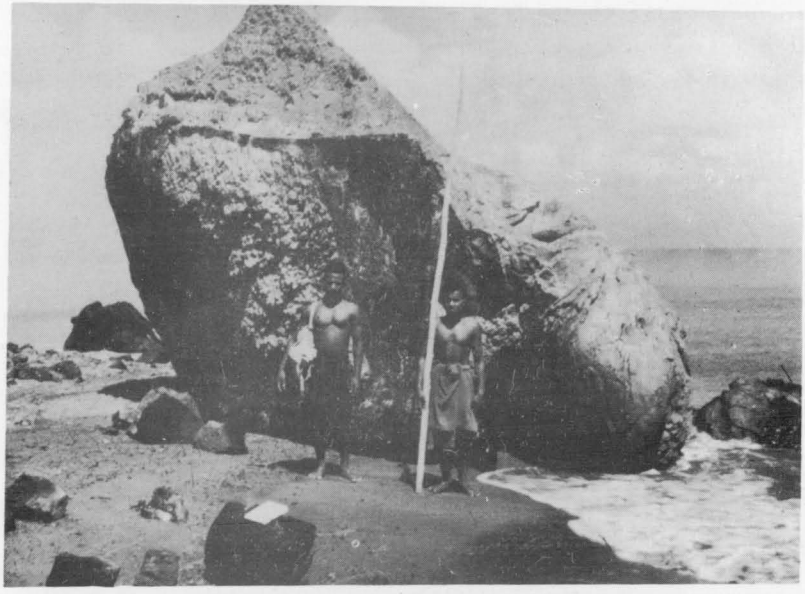


Figure 2.
Bombs that fell on Cone 3 island during activity in July, 1954.

The formation and lithology of the submarine lava flows would be similar to that described above except that owing to the more rapid cooling, there would probably be a greater percentage of glassy material. Also, because of hydrostatic pressure and the quenching of its outer surface, the pumice would be highly charged with gas. When extruded from the submarine vent the pumice masses either floated directly to the sea surface or flaked off from the outer surfaces of the dome as described in the general discussion of submarine activity (Plate 16, figure 1).

Agglomerates Unconsolidated deposits of angular fragments of the rock types described above occur together with smaller ejectamenta in beds overlying the lava flows, or, in Cone 5, interbedded with lava flows.

Dust Deposits These are white to light grey and form massive deposits which with one exception represent the final phase in activity of the cones which have been built up above sea level. In Cone 5, dust deposits marked the end of the first phase of explosive activity from that centre, but the second phase culminated in violent explosions from which only large bombs, mostly of fragmentary material, were deposited around the crater.

Samples of dust deposited on the Pam Islands were collected for analysis to discover the salts responsible for the poisoning of crops in native gardens. Analyses were made by Mr.N.Stravs, industrial chemist of Coconut Products Limited, Rabaul. Water-soluble salts formed only 0.16% of the dust samples tested: the dust collected had probably been almost completely leached by rain. Mr.Stravs, although unable to complete a full quantitative analysis of the dust because of lack of suitable reagents, presented the following figures from the work which he was able to complete:

Silica	69.41%
Calcium Oxide	4.86%
Other oxides	18.61%
Loss on ignition	1.09%
Not determined	6.03%

Bombs and pumice lapilli are interspersed with the Tuluman Islands' dust deposits. The bombs are of two types; large angular blocks of pumice, glass, or the basaltic (?) type of rock; and bombs formed from material ejected in the plastic state, most of which were formed predominantly of pumice with an outer skin of glass which had become bread-crusted during cooling. Some specimens of pumice bombs contained thin bands of black glass which, during the plastic state, had been distorted and folded (Plate 16, figure 2).

Gases and Temperature of Vents

This section deals only with the information obtained during ground surveys of the islands after the eruptive phases had ceased. Only sulphuretted hydrogen and sulphur dioxide could be detected without the aid of chemical reagents during the various visits to the islands. Concentrations were not high, although during a visit to Cone 4 on 16th February, some throat irritation was experienced, possibly from sulphur dioxide.

The yellow, orange, and red colours imparted to the white vapour clouds during eruptions from cones which had built up above sea level are attributed to sublimation products which were apparently being rapidly deposited on the outer lips of active vents and then removed and finely comminuted by steam jets or explosions. The colours of sublimates around fumaroles observed during visits to the island were white, yellow, orange, and red.

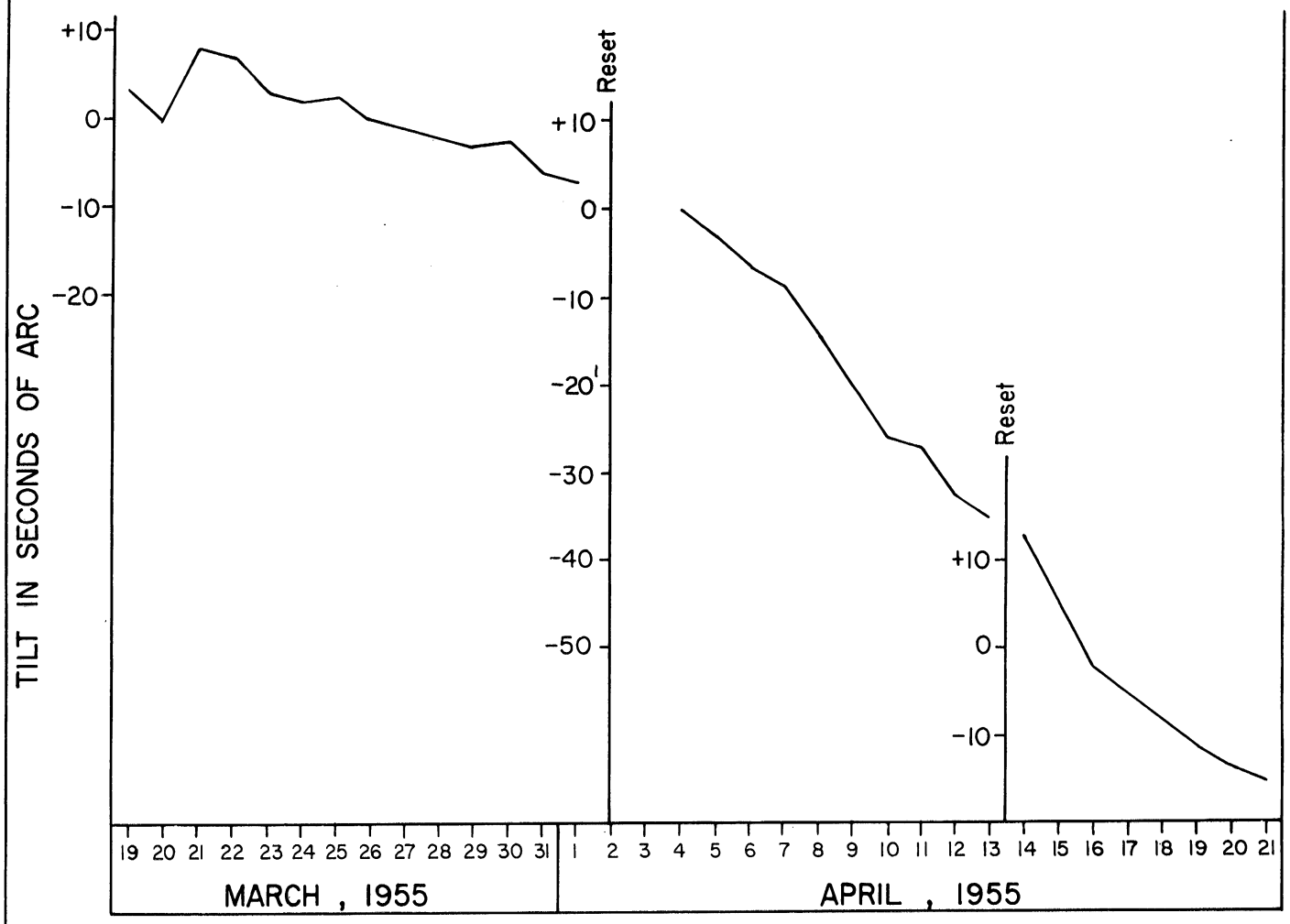
Temperature recording at fumaroles on the Tuluman Islands was begun during March, 1955, at Cone 5 along the peninsula at the south-west side. The first recorded temperature was 74°C. For the next reading the thermometer was lowered into a fissure from which steam and gas escaped under pressure. The thermometer was attached to a long piece of insulated copper wire and inserted about five feet into the fissure. The temperature was so high that the mercury fractured the tube. That is, the temperature was above 400°C.; the heat was probably derived from a recent fracture in an underlying lava flow which had not completely cooled. This was on March 24th, thirteen days after the last eruption from this centre had finished. The area was still noticeably hot when visited again on 31st March.

Seismic Activity and Tilt

Seismic activity was surprisingly slight before and during the period of volcanic activity in the St. Andrew Strait. The nearest inhabitants to the Tuluman Islands are situated at Baun village on Lou Island, the Pam Islands, and Baluan Island , $3\frac{1}{2}$, $2\frac{1}{2}$, and 4 miles respectively from the nearest centre of activity. Indigenes of Pam Mandian Island reported small sea waves, which caused minor damage to canoes, after the initial explosion in June 1953. During ground inspection of newly formed islands in 1954 and 1955 no seismic activity was felt, although when another submarine cone was active the explosion of lava masses at the surface of the sea caused ground movements on these islands, probably through concussion waves transmitted by the sea. The only other reported movements were of buildings and resulted from aerial concussion waves at the time of violent explosions. The slight tremors felt on several occasions at Baluan during the November submarine activity of Cone 2 are attributed to a similar source, since they were not felt on Lou Island, where buildings are protected from such effects. A shock recorder installed on Baluan Island from 23rd October

PLATE 17

TILTMETER READINGS, BALUAN ISLAND
(TAKEN DAILY AT 0800 HOURS)



PNG 15-11

to 6th November 1954 showed no movements on its records which could be attributed to the submarine activity then occurring at Cone 1.

A new store which had been completed by the time the writer returned to Baluan on March 18th was used for housing and setting up a tiltmeter. Before the floor was built, the area was levelled by making a bed of loose scoria, about five inches thick at the northern end, and this was covered with one or two inches of a dry mixture of sand, cement, and basalt gravel. A layer of wet cement less than two inches thick was added to form the floor. The tiltmeter was aligned north-south approximately and readings started at 1500 hours on 18th March. Adjustments were made daily every hour or so between 0600 and 2300 hours, except when the writer was away from Baluan. Owing to the arrival of new supplies the tiltmeter was removed from the store on 1st April, and not replaced until the monthly issue of rations to natives was completed. Because the readings taken in the store indicated an unusually large overall tilt, it was considered that the floor might still be settling. For the last week, therefore, the tiltmeter was aligned north-south on a flat portion of a lava-flow outcrop near the A.D.O's. quarters on Baluan. It was found, however, that tilting in the same direction continued, although differences between readings taken at the same hour each day became less over the last five days. The graph readings taken at 0800 hours daily is shown in Plate 17, and although there are two small gaps in the succession, there is a variation of at least one minute ten seconds of arc over the period 18th March to 21st April 1955. Readings taken hourly to two-hourly each day were also plotted, and although atmospheric temperatures were not taken, it was apparent that the daily graph was closely related to temperature fluctuations.

During the periods of more intense activity of the submarine Cone 6, the graph shows the following trends:

March 20 (evening) - 22 (evening): a small rise and fall in readings;

April 4 - 11: an average daily fall of just over four seconds of arc from the 4th until the 10th;

April 16 - 18: preceded by a fall of fifteen seconds of arc between the 14th and 16th.

In the periods of milder activity between March 22nd and April 1st, the average daily fall in tilt was 1.4 seconds of arc; from 10th until 13th April the average daily fall was three seconds of arc; after the 16th there were daily falls of 3, 3, 3, $2\frac{1}{2}$ and $1\frac{1}{2}$ seconds. It is unfortunate that 8 o'clock readings were not taken on 2nd and 3rd April and that the tiltmeter was reset between 13th and 14th. Comparisons between readings taken at other times, however, show that the steep gradient of the graph in early April commenced on 3rd April, and that between 13th and 14th readings fell substantially.

Many variable factors influence tilt, and the determination of the degree of intensity of activity has been influenced to a certain extent by atmospheric conditions. Nevertheless, this tilting movement may have been related to the submarine activity. The direction of the tilt indicates either a downward movement in the St.Andrew Strait caldera region or an upward movement in the central crater area of Baluan Island.

A small oscillation of the tiltmeter bubble was noticed when a reading was being taken at 1300 hours on 17th April.

Taylor (1955a) has attempted to correlate major tectonic earthquakes and volcanic activity in the Territory of New Guinea. Epicentres of the earthquakes since 1950 between Longitudes 146°E - 149°E, Latitudes 1°S - 4°S are:

21.6.50	3.8°S,	146.4°E (JSA) or 3½°S, 147°E (USCGS) Magnitude 6½
21.11.50	3½°S,	147°E.
25. 6.51	3¼°S,	149°E.
4.11.51	3⅛°S,	146°E. Depth 200 km.
3. 1.53	3° S,	146°E (BCIS) or 3°S, 149°E (Wellington)
23. 4.53	4° S,	149°E
Early 1954,	3°S,	148°E (shown on map prepared by Taylor to accompany his report, but no details available at Rabaul of epicentres determined between January and June 1954).

Between 1940 and 1945 no epicentres were recorded for this area; in 1945 two earthquakes occurred, one being of Magnitude 7. Other earthquakes in this area before 1950 were in 1946 (2) and 1948 (1). No tremors, other than those in November 1953, which have already been discussed, have been reported from Baluan Island and Lorengau in monthly Vulcanological Returns which have been forwarded to the Observatory, Rabaul, since November 1953.

It is not possible with the information available to suggest a relationship between tectonic earthquakes and volcanic activity in the St. Andrew Strait. The final remarks of Taylor (1955) on this area are significant:

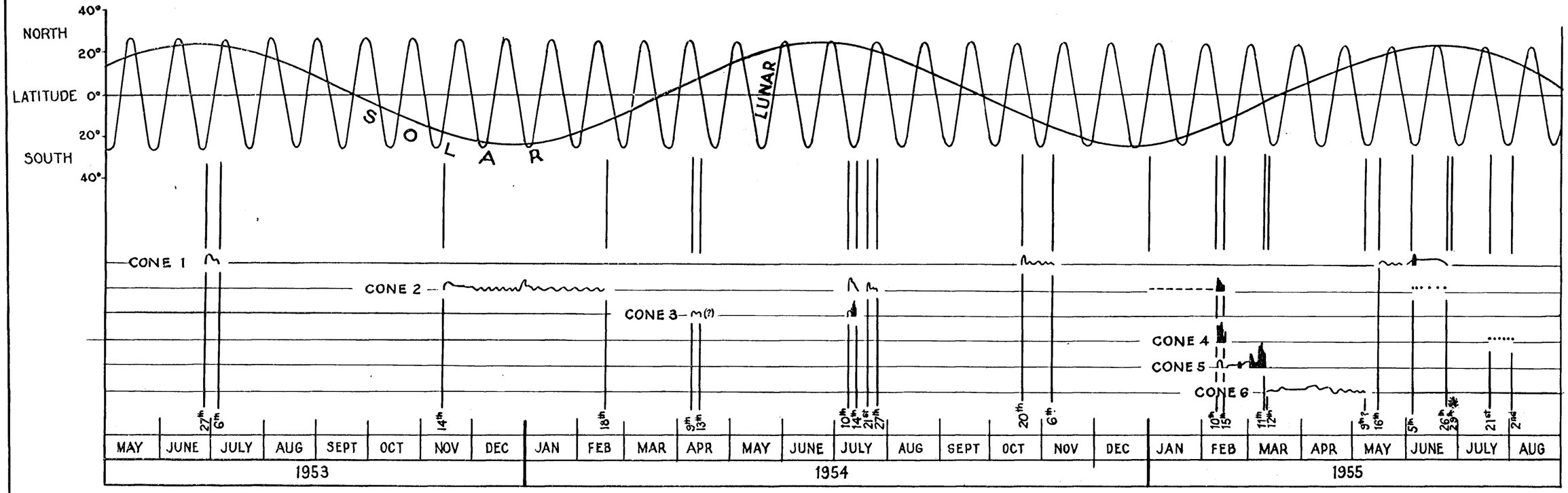
> "the earthquakes in this area tend to be shallower in focus and are therefore less likely to be recorded on world stations. Hence more detailed seismic work should reveal a much clearer picture. If a gravity survey were carried out in this area it would give us a very useful picture of structural conditions".

Other Phenomena

During investigations in February 1955 small spirals of white vapour clouds, sometimes darkened by dust, were observed to ascend from hot masses of lava floating on the surface of the sea to the dust and vapour clouds over the area. The lava was derived from the submarine activity of Cone 5 and dust clouds resulted from the explosive activity of Cone 4.

PLATE 18

LUNI-SOLAR DISPOSITIONS & THEIR RELATIONSHIP TO VOLCANIC ACTIVITY



~ Lava extrusion ▮ Island (explosive) activity ~ Intermittant activity ----- Pre-eruption uplift ····· Mud eruptions (spasmodic) * Sudden, short increase in thermal activity, Lou Island.

PNG 15-12 HES

This effect was noted by Perret (1950) at Sakurashima in 1914. He suggests that there may be an electrical connexion between the "spiracles" and the low-lying overhead cloud mass "after the manner of waterspouts". Such a connexion would account for the upward movement of the spiral and its dispersion when it nears the overhead cloud. The maximum height to which these spirals ascended was about 1,000 feet above sea level.

Luni-Solar Influences

Research has been carried out during the last four years by officers of the vulcanological section to discover whether the luni-solar influences can be correlated with volcanic activity in the Territory of Papua and New Guinea. These studies have been based on eruptions at Mt. Lamington, Mt.Langila, Long Island,and Bam Island. The activity in the St.Andrew Strait offers an excellent opportunity for the continuance of this study since here the magmatic reservoir from which eruptions have emanated is apparently closer to the surface than that of other volcanoes, and good descriptive accounts are available for most of the active phase.

The discussion is based on Plate 18, which shows declinations of the moon and sun and the periods of activity represented by arbitrary curves in which greatest vertical displacement indicates greatest intensity. The activity of May-July 1955 is included in the diagram in order that this discussion will contain all the detail available. To avoid complication in the diagram the times of syzygy, perigee, and apogee are not shown. From the figure the following features will be noticed:

(a) The first period of activity began immediately after the sun and moon had reached zenith positions at the Tropics of Cancer and Capricorn respectively and were in the position of opposition.

(b) Activity from 14th November 1953 until 18th February 1954 shows two interesting characteristics -

  (i) Lava was first extruded less than forty-eight hours before the moon reached the zenith in the latitude of the volcano and at a time when the moon was close to the perigee position of the lunar orbit.

  (ii) When intensity increased at the end of December the sun and moon were close to the Tropic of Capricorn, the sun having just passed the position of maximum southerly declination. At the same time, the moon was at the Last Quarter and in the apogee position.

(c) Details of the activity in April 1954 are insufficient to state whether or not there is any correspondence with periods of maximum luni-solar influence.

(d) Cones first appeared above sea level in July 1954, when the sun had passed its most northerly zenith position and was only two degrees south of the Tropic of Cancer, and when the moon was at its southern-

most declination (the period was between First Quarter and Full Moon, and the moon was close to its position of apogee). The renewed lava extrusion from Cone 2 on 21st July did not correspond with luni-solar maxima.

(e) Submarine activity at Cone 1 recommenced in October 1954 at a time when there were no strong luni-solar influences. The initial activity lasted for 36 hours, after which the volcano was quiescent for 24 hours. At 1500 hours on the 22nd, intermittent activity was renewed at a time when the moon was passing from the Equator to the zenith of the St.Andrew Strait only $2\frac{1}{2}^{\circ}$ to the south.

(f) During the most intensive period of activity, which began in February 1955, eruptions took place from four cones. Some facts associated with this activity are:

(i) The first manifestation of the impending eruptions was during January and early February. Although no specific dates were available, the summit of Cone 2 was noticed to have risen from the surface of the sea some fifteen feet higher than at the end of 1954 before explosive activity began. When uplift started in early January the sun was in the zenith of the Tropic of Capricorn and the moon at its northernmost position of declination. The moon at the time was in the perigee position of the lunar orbit and in opposition to the sun.

(ii) Activity of Cones 2, 4 and 5 began within twenty-four hours after the moon had passed the zenith in the latitude of the volcanoes, its movement at the time being to the south.

(iii) Cone 4 was most active during the evening of 13th February and a period of less intense activity with no explosive activity followed between 0900 hours and 2120 hours on 15th. At the latter time a brief period of intense explosive activity began. This marked the final outburst from this source, and no explosions were noted after 0700 hours on 16th. The moon was near its southernmost declination, in the Last Quarter and at apogee.

(iv) The initial activity of Cone 5 ceased after about fifty hours and no more lava was extruded until about 0600 hours on 16th February, when the moon was at its southernmost declination. An island first appeared during the evening of 23rd, when the moon was moving northwards over the zenith in the latitude of St.Andrew Strait. The island had disappeared by 25th and activity was again submarine. As the moon moved toward the Tropic of Cancer there were more violent explosions; this phase of activity culminated at midnight on 4th March when the moon was again moving south from its northernmost zenith. The most violent phase began $2\frac{1}{2}$ days later, when both the sun and moon, which were in opposition, were very close to the zenith in the latitude of Tuluman.

(f) (v) The cessation of activity at Cone 5 at 1700 hours on 11th March was followed within twenty-four hours by submarine lava extrusion from Cone 6. The more intense periods of activity were when the moon was at or near the zenith in the latitude of the eruption centre.

(g) Cone 1 (submarine) was the source of the next activity, which started on 16th May 1955, when the moon was again at the zenith corresponding to the eruption centre. In early June the moon and sun were in opposition and their zenith positions were at or very near the Tropics of Capricorn and Cancer respectively, and for the first time an island appeared above Cone 1. There was a brief period of explosive activity between 7th and 8th June, during the period of luni-solar maximum. Also at this time there were mud explosions and strong vapour emission from a new vent on Cone 2.

The emission of voluminous vapour clouds from Cone 1 continued until 18th June; from that date activity declined until the island disappeared on 26th June. On 26th June the moon was in quadrature to the sun and the position of its zenith was that of Cone 1.

(h) It was expected during June that if volcanic potential still existed, there would be further activity in the St.Andrew Strait at the time of the luni-solar maximum at the end of June or early July, which would have been of the same strength as that in early June. The only activity, however, was a sudden brief increase in the vapour emission from the thermal area on Lou Island at 1700 hours on 29th June.

(i) Mud eruptions began on 22nd July from a new vent in Cone 4, about twenty-four hours before the moon reached the zenith of the St.Andrew Strait. These continued intermittently until 2nd August.

Taylor (1955) in his report on Bam Island, has stated: "on 5th June the sun and moon were occupying zenith positions close to the Tropics of Cancer and Capricorn respectively and they were in opposition. These conditions produce a maximum tensional pull on structures close to equatorial latitudes". Identical conditions have applied three times during the periods of volcanic activity in the St.Andrew Strait and on each occasion there has been a strong response in the volcanic activity (27th June 1953; 10th-15th July, 1954; 3rd-8th June, 1955). When the sun occupied the position of the Tropic of Capricorn at the end of December, 1953, activity increased when the zenith position of the moon, which was in quadrature, was at the same latitude. On the second occasion when the sun was at this zenith, December 1954 - January 1955, the preliminary manifestation of volcanic activity from Cone 2 began at about the time when the moon was at the zenith of the Tropic of Cancer and was in opposition to the sun.

Only on one occasion during periods of volcanic activity were the sun and moon in zenith positions above the St.Andrew Strait. At this time, March 1955, they were in opposition, and as this was a period of unusually violent activity, it is suggested that the relationship between luni-solar maximum influence and volcanic activity was strongest on this occasion.

Periods of compression such as that of March 1955 would also have occurred when the moon was in its zenith position for the latitude of the volcanic activity, but to a lesser degree. During all periods of eruption, the moon was in this position on twenty-four occasions apart from March 1955, and there were initial or stronger eruptions at or within forty-eight hours of those times on ten or eleven occasions. On at least three other occasions, however, the relationship appeared to be negative rather than of no consequence, a typical example being 26th June, 1955, when the island above Cone 1 disappeared and activity from this source ceased. Study of positions of syzygy and quadrature reveals that they cannot be related to the anomalies.

The influence of the moon in the perigee position of the lunar orbit would obviously be greater, but this is apparently of such minor significance that the effects were not obvious during the analysis of the luni-solar maxima.

It has been frequently stressed that luni-solar maxima influences will only act when volcanic potential exists in any area, and then only as a trigger mechanism. From this study it is also obvious that stresses produced by a potentially active magmatic reservoir may be relieved by certain combinations of forces. So many variables are involved, however, that a complete discussion is beyond the scope of this report. The results of this analysis, therefore, are based on the conditions that have existed in the Tuluman Islands area, and their main value will be for use in diagnosis of future events in that area or in other areas in the Territory where similar conditions have applied.

Activity, May - July, 1955

From details supplied by Mr. E.G. Hicks of Baluan Patrol Post in signals and recent correspondence, it has been possible to prepare a most comprehensive report of activity for this period.

Activity at Cone 6 (submarine) continued intermittently until approximately 9th May, but the exact date could not be ascertained by Mr. Hicks, who was absent on patrol at the time.

Activity was renewed from the vicinity of Cone 1 (submarine) at 2000 hours on 16th May. There were explosions, associated rumbling, and the usual surface manifestations of submarine activity. The intensity decreased on 20th May, and from that date until 2nd June, Cone No.1 was only intermittently active. On 2nd June a strong increase in the vapour output from the

surface area indicated that there was a more prolific lava outflow from the submarine vent. The strong activity continued on the following day and there was a continuous glow from the surface during the night. No explosions, however, were heard, and floating pumice masses were no longer apparent. By the morning of 6th June the lava dome had been built up above sea level, and at 1530 hours on that day there was a brief period of explosive activity. The red glow at the surface which had been noticed consistently during the preceding nights was not seen that evening, and immediately after the explosions the red tinge which had been a feature of the vapour cloud since 3rd June had disappeared. On 7th June voluminous vapour cloud hung above the dome, the brick-red colour had returned to the cloud (this effect is attributed to fine dispersion of sublimination products by steam jets), and the red glow from the dome was again visible at night. There was no apparent change in the activity from 7th until 20th June, when a slight decrease was reported. Explosive activity was notably absent during this period. From 20th June the activity decreased until 26th June, when it ceased and the summit of the lava dome disappeared below sea level. The position of the activity was estimated by Mr.Hicks to be one to two hundred yards east-north-east of the eastern tip of the island of Cones 2 and 4, and near the original 1953 eruption.

Three large depressions have developed on the island of Cones 2 and 4 since it was first surveyed in March 1955. The first of these areas to be noticed was that on the north coast of Cone 2, where a thermally active region has developed, possibly as a result of subsidence. Spasmodic mud eruptions took place at this locality during the activity of Cone 1 (16th May - 26th June) and ejected material was thrown to heights of from 15 to 20 feet. Much vapour was emitted from this area until at least 26th July.

Of the other two depressions, that on the south-east was due to subsidence between parallel fractures or faults which extend from the vicinity of the main crater of Cone 2 to the south-eastern crater rim of Cone 4. There was no explosive or thermal activity from this centre. The other region of block subsidence is along the inner margin of the crater rim of Cone 4 and is apparently just south of the main vent. From the outer rim of this depression to the base was estimated to be 80 - 100 feet, and on 2nd August, when it was inspected by Mr. Hicks, there was "boiling mud" at this depth. The first activity from this source was witnessed by the native councillor Paliau, who reported that he had seen what appeared to be a dense cloud of grey-black smoke or vapour issuing from there at midnight on 21st July. A signal received on 30th July from Cadet Patrol Officer Burnett, who was stationed at Baluan during Mr.Hicks' absence, reported that there had been three explosions from this source on 27th July, and that natives had witnessed eight other explosions since 22nd July. Material ejected during these mud eruptions apparently never rose more than one hundred feet above the vent,

and no accompanying noise was heard from Baluan. The last of the spasmodic activity was witnessed by Mr.Hicks, who states in a letter dated 7th August, 1955: ".....just as I was about to go ashore at the West end of the large East Tuluman Island (Cones 2 and 4) at about 9.30 a.m. on the 2nd inst., there was an explosion which threw up quite a lot of mud, some blackish dust (?) and great clouds of steam". Most of the original surface of the island was buried under mud deposits "and the whole island now has a 'streamlined' appearance - like a huge snow- or sand-drift ...."

It is perhaps significant that the first period of eruptions occurred when there was a strong luni-solar maximum, and the second when there was a strong period of compression, when the moon was near the zenith in the latitude of the Tuluman Islands, in conjunction with the sun and just past the perigee position of the lunar orbit. An upsurge of gas-vesiculated lava into the main conduit channel of Cones 2 and 4, which is by now probably connected to the surface by other subsidiary channels and fissures, would result in the uninhibited escape of gas through such side vents. Owing to the rapid escape of gas, the lava would congeal in the main conduit or in the branching fissures as dykes. The large volumes of steam escaping at the surface would convert the volcanic dust, through which the vent opens and which would collapse into the vent, into a viscous mud which, through alteration by heat, might become bentonitic.

Theoretically, these mud eruptions represent a decadent phase of volcanic activity from this centre.

A slight tremor was felt by Mr.Tonkin at the north side of Lou Island "on or about the night of the 24th July". This was not felt by the Baun village natives who reside nearer the Tuluman Islands. Owing to the uncertainty of the time and date of this tremor, the nature of its origin cannot be specified, but it does not appear to be of significance as far as volcanic activity is concerned.

Later Activity

From August 1955 until May 1956 the following reports of further activity were received.

On 20th September and intermittently between 26th and 28th September, and also between 1930 hours on 3rd October and 1430 hours on 7th October - submarine eruptions near Cone 1.

On October 15th, 16th and 23rd October, and from 7th to 25th November - small steam explosions from the vent on the west side of Cone 4.

THERMAL AREAS ON SURROUNDING ISLANDS
(See Plate 1).

Baluan Island There have been no reports of increased activity from thermal areas on Baluan island since they were last inspected in November 1954.

Lou Island The thermal area about half a mile south of Baun village on the eastern coast of Lou Island was visited by Best in July 1953. The maximum temperature recorded was 58°C., in a circular area, forty yards in diameter and denuded of vegetation, about two hundred yards inland from the beach. The maximum temperature in the adjoining swamp area to the north-east was 42°C.

The area was visited again in February 1955 after reports had been received that activity had increased during October 1954. The maximum temperature in the denuded area was 100°C., and temperature had increased around the margin of the swamp lake. Gas ebullition had also increased, according to local natives, and this, together with the greater heat, had killed vegetation in the immediate vicinity.

A signal received from Patrol Officer Pearse, who was stationed at Baluan for a short period, stated that natives had reported a sudden increase in the vapour emission from the thermal area on Lou Island, which occurred at 1700 hours on 29th June, and lasted for less than half an hour. Mr.Tonkin of the S.D.A. Mission station on Lou Island, who had previously accompanied Mr.Hicks and the writer on a visit to the thermal area, reported that the following changes occurred during June/July 1955:-

(a) There were more hot springs;
(b) Springs which had been hot previously were now much hotter.
(c) A wide area of sea off-shore from Baun village had developed hot springs and ebullition points;
(d) The springs area appeared to have subsided slightly.

Mr.Hicks visited the area again on 2nd August and verified Mr. Tonkin's report, although he did not at the time personally observe gas ebullition from the sea. He also observed that there were no fissures or faults in the zone of subsidence, that water in parts of the swamp lake was boiling, and that more trees and scrub in the swamp area appeared to have died. Normally such increases in activity of a thermal area would be taken to indicate an impending eruption from a volcanic source in the vicinity. The most logical source in this instance would be Cone 1 of the Tuluman Islands. Three pertinent facts associated with the increases, however, suggest that they have resulted from volcanic activity rather than that they indicate the approach of an eruption.

(a) The first increase occurred during volcanic activity in October 1954 from Cone 1 (submarine).

(b) The second increase occurred during and after a renewal of activity at Cone 1 at a time when the lava dome was quite near to the surface of the sea.

(c) There was an apparent response from the thermal area to the period of luni-solar maximum influence which existed from the end of June until early July 1955. At this time strong tractive forces would be operating on the earth's surface in equatorial latitudes. At the corresponding time of the lunar month preceding this activity, similar luni-solar conditions applied, and there were responses from the then active Cone 1, and mud eruptions from Cone 2, which have already been discussed.

On the evidence available, therefore, it is suggested that the Lou Island thermal area is intimately associated with Cone 1 of the Tuluman Islands through subterranean fissures and that such fissures offered an easier avenue of escape for magmatic gases and vapours during the release of stress above the area by luni-solar influences in late June 1955 than the already sealed conduit of Cone 1.

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