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RECORDS.

Records 1958/14

ACTIVITY OF TULUMAN VOLCANO, ST. ANDREW STRAIT ADMIRALTY ISLANDS SEPTEMBER 1955 - MARCH 1957

by

M. A. Reynolds

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CONTENTS

SUMMARY

This report deals with the activity of Tuluman Volcano from September, 1955 until March, 1957, and is a continuation of Report No. 33 (Bureau of Mineral Resources, Geology and Geophysics, Canberra) which covered activity of Cones Nos. 1 to 6 from June, 1953 until August, 1955. The only major eruption during the later period occurred between November, 1956 and February, 1957; it was from a new source called Cone No. 7. Some minor activity was reported between September, 1955 and November, 1956.

The eruption of Cone No. 7 showed strong response to luni-solar influence. It differed from previous eruptions at other centres in that the effusive phase predominated over the explosive phase when the cone was sub-aerial. A large island formed from outpourings of lava from two main vents called Craters A and B. Some submarine flows occurred from vents south and south-west of Crater A before Crater B formed.

The only movements recorded on the shock recorder during the period of observations (28th November - 5th December 1956) were those obtained when the recorder was stationed on the island of Cones 2 and 4; they resulted from explosions at Cone 7 and a mud eruption at Cone 4.

A map of the Tuluman Islands has been prepared from surveys conducted on 3rd and 4th December. Other figures included in this report are photographs and maps of the islands and of the activity until the end of February, 1957. At that time only a small remnant of the original island of Cone 3 and a large composite island of Cones 2, 4 and 7 existed. The latter formed during an uplift between 31st January and 8th February, 1957; the maximum rise of about 15 feet occurred along the southern and western sides of the island of Cones 2 and 4. A breach formed across the island during the same period.

The nomenclature suggested in Report No. 33 is reviewed and periods of activity are attributed to cones as follows:

Cone 1: June-July 1953, October-November 1954, May-June and ?20th September 1955.

Cone 2: November 1953 - February 1954, July 1954, February 1955, June 1955.

Cone 3: ?April 1954, July 1954.

Cone 4: February, July-August, October, November 1955, November-December 1956.

Cone 5: February-March 1955.

Cone 6: (Submarine) March-May 1955.

Cone 7: ? September, ? October 1955, November 1956-January 1957.

The source and trend of activity since May 1955 are reviewed after a short discussion on the probability of gas motivating eruptions of Tuluman Volcano since 1953. Prior to November 1956 eruptions can be divided into 4 periods when activity commenced at Cone 1 and migrated to the south-west; the periods decrease from 14 months in 1953-54 to 3 months in 1955. The eruption from November 1956 to January 1957 showed a similar migration from north-east to south-

west but commenced south-west of Cone 1 and occurred over a shorter distance. This is possibly indicative of decrease in volume of gas in the parent magma body. The uplift in early February 1957 can be explained by assuming magmatic pressures insufficient to breach existing consolidated cones to the surface but enough to cause uplift of overlying deposits allowing magma to expand into the cavity formed and thus attain equilibrium. The idea of diminution in gas volume is supported by the fact that the effusive phase predominated over the explosive phase when Cone 7 became sub-aerial. Also, major eruptions between June 1953 and May 1955 were never more than 5 months apart; the only major eruption since May 1955 occurred after an interval of 18 months.

Some results of microscopic and chemical analyses of rocks from Cones 3, 4, and 5 are included in this report. The rocks are more acid in composition than previously thought. This may have been due to the accumulation of gas between eruptions causing differentiation within the magma column.

I. INTRODUCTION

Best (1954) proposed that the submarine volcano, in the St. Andrew Strait, which became active in June, 1953 and subsequently built islands above sea level should be named Tuluman. The writer (1955b) proposed Tuluman Islands for islands formed by the volcanic activity and numbered the cones in the chronological order of their first activity. Fisher (1957) adopted the name Tuluman Volcano and the numbers applied to the cones by the writer (1955b).

Results of the investigations of eruptions between June 1953 and August 1955 were combined to form Report No. 33 of the Bureau of Mineral Resources, Geology and Geophysics, Canberra. Details of activity from September, 1955 until 11th December, 1956 were included in a preliminary report on the eruption of Cone No. 7 which commenced in November, 1956 (Reynolds, 1957). The information contained in the preliminary report is incorporated in this report together with photographs and maps to give a complete account of events and results of investigations between September, 1955 and March, 1957.

The writer visited the Tuluman Islands area between 28th November and 5th December, 1956, to observe the eruption of Cone No. 7. During this period the remnants of the islands of Cones Nos. 2 and 4 and Cone No. 3 were surveyed using chain and compass. Subsequent inspections were made from aircraft on 12th January and 8th February, 1957. Other details of activity between September, 1955 and March, 1957, were supplied by the officers in charge of the Sub-District Office on Baluan Island, 3 to 4 miles south of Tuluman Volcano.

II. ACTIVITY, SEPTEMBER, 1955 - MARCH, 1957.

1. Activity arranged in chronological order:

1955	September 20	Small vapour clouds were noticed rising intermittently from the vicinity of Cone No. 1.
	September 26-28	Submarine activity from approximately 500 yards east of Cone No. 2.

Figure 1. Activity at Cone 7 during the aerial inspection of 28th November, 1956. The island of Cones 2 and 4 is in the foreground and the small remnant island of Cone 3 is to the upper left. The densely wooded southern tip of Lou Island is in the background. Photograph taken from south.

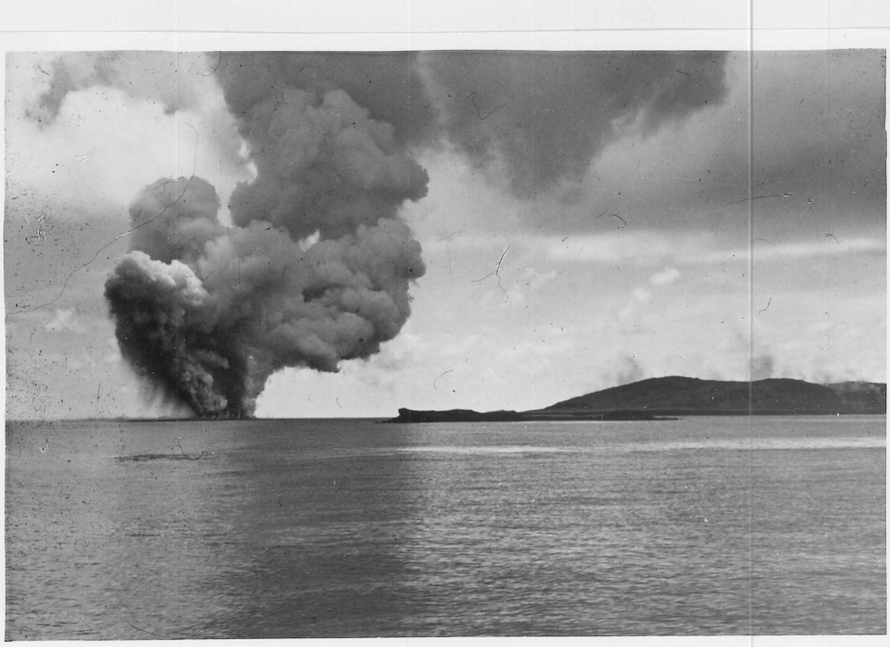


Figure 2. November 29th. "Jet-like ejections of steam and dust accompanied by loud roars...." The jet shown occurred at about 1110 hours from the north-west side of Cone 7. Dust and vapour were forced to about 400 feet above sea level at an angle of about 30° from vertical. Island of Cone 3 silhouetted in right foreground; island of Cones 2 and 4 at back.

	October 3 - 7	Renewed activity; surface manifestations spread over area centred about 300 yards east of Cone 2.
	October 15 - 28	Spasmodic mud eruptions and strong vapour emission from vent near western rim of Cone 4 (record not complete).
	November 7 - 25	Natives reported minor activity from Cone 4.
1956	March 29, 30	Slight increase in vapour; natives reported that while in the vicinity of the volcano they felt shocks similar to submarine explosions of dynamite.
	November 7	Tuluman erupted; time and site of eruption not known.
	November 8	Pilot of aircraft saw slight steam emission from sea north of Cone 2. (site of Cone 7 eruption?).
	November 15	Pilot flow over area again; vapour cloud had increased in volume and rose to height of from 200 to 300 feet above sea level.
	November 27	Vapour clouds rising to 2,000 feet above sea level at intervals of about 5 minutes.
	November 28	Steady emission of steam and gas from a small cone-shaped island which had built up to about 10 feet above sea level. A cumulous cloud had formed above the vapour and extended upwards to a height of about 7,000 feet. The colour of the vapour column up to about 1,000 feet varied from orange to brick red; this colour developed from the main central vent. A subsidiary amount of white vapour was added to the column by steam formed at several places around the outer rim of the island. The island was 300 yards north of the east end of the island of Cones 2 and 4; it was called Cone No. 7. Figure 1 shows the activity on this date.
	November 29	At 0500 hours, while travelling from Lorengau to Momote the District Commissioner of Manus District noticed that the column of vapour rose to an estimated height of 20,000 feet. By 0700 hours, however, a wind had developed from the south-east, and the vapour cloud was cumulous and did not ascend higher than about 5,000 feet. The first explosive activity was witnessed at 0730 hours from north of Lou Island; a separate column of vapour rose vertically from what appeared to be a source just

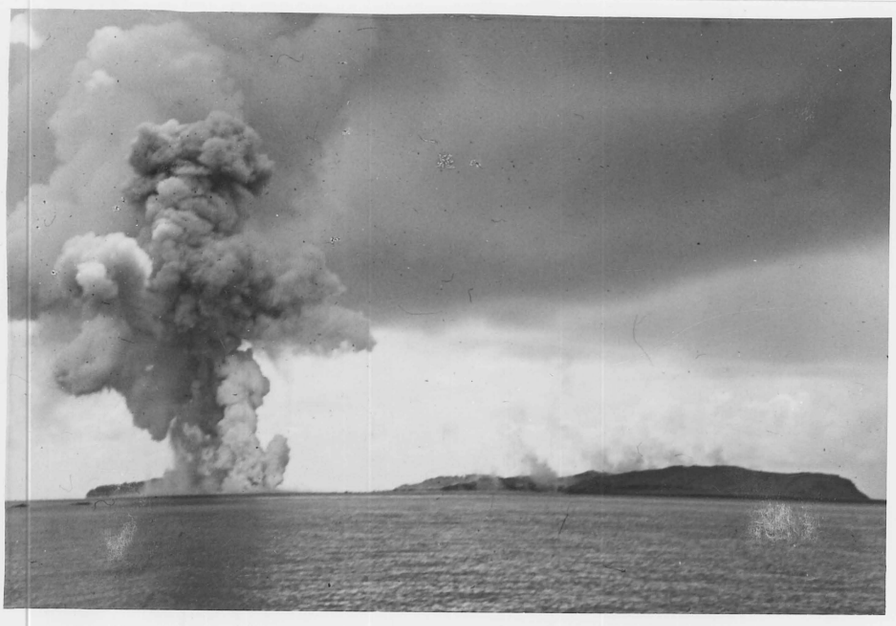


Figure 3. November 29th, 1130 hours. Explosion from Cone 7. Small vapour streams can be seen rising from thermal areas in the central and north-eastern parts of the island of Cones 2 and 4. Photograph taken from north-west.

west of the main cumulous bank. At 0750 hours there was another explosion, followed by frequent spasmodic explosions during the rest of the morning. Jet-like ejections of steam and dust accompanied by loud roars, similar to those noticed during previous eruptions, also occurred at spasmodic intervals. They lasted for periods of up to 10 minutes' duration, and were often directed at angles of as much as 45° to the vertical, thus giving a fountain-like appearance to the ejection. Figure 2 is a photograph of a jet-like ejection. There was a mud eruption from the submarine vent just west of the western margin of Cone 4 at 1033 hours; the ejected material, which appeared to be dark grey to black mud, was forced to a height of about 100 feet above sea-level. Another explosion from Cone 4 occurred at 2100 hours. The frequency of explosions from Cone 7 diminished during the afternoon and night. Explosive activity of Cone 7 is shown in Figure 3. An unusual feature of the activity witnessed at night was that apart from the red glow of the dome, there was an incandescent glow at the surface of the sea. The glow was continuous and remained in the same area near the western margin of the island.

November 30

The main activity of Cone 7 was the continuous emission of orange and white coloured vapour. Submarine activity commenced at a position mid-way between Cones 7 and 2 during the morning, and blocks of lava appeared at the surface at half-hourly intervals. Most of the explosions witnessed during the day were from this source. There was one explosion at 1230 hours from Cone 4. The thermal area south of Baun village on Lou Island was inspected during the afternoon; temperatures and conditions were the same as reported in June and August, 1955. The maximum temperature recorded was 101°C at the western end of the swamp lake.

December 1

There was continuous emission of vapour from Cone 7; the only explosions witnessed were one from Cone 7 at 0955 hours, and from Cone 4 at 0915 and 1210 hours. No further submarine activity occurred.

December 2

No explosive activity was witnessed; there was an apparent increase in volume of vapour during the afternoon but this may have been due to greater

condensation owing to the squall which developed from the south-west at that time.

December 3

Explosive activity at Cone 7 commenced at about 1100 hours and continued intermittently throughout day and night. The most active period was between 1530 and 1730 hours, when there were at least 8 explosions at Cone 7 and one at 1605 hours from Cone 4. Before and after this period explosions occurred at intervals of about one hour. The photographs, Figures 4 and 5, were taken on this date.

December 4

There was continuous vapour emission from Cone 7 and occasional explosions; Cone 4 erupted mud at 1125 and 1205 hours.

December 5

Apart from vapour emission there was no other activity during the morning. After a strong explosion at 1350 hours and other explosions of less intensity during the next hour, it was noticed that a change has occurred in the pattern of activity. The first indication was that the island had built up to an almost perfect inverted cone, the apex of which was about 40 to 50 feet above sea-level.

The basal portion of the cone to a height of about 20 feet was light grey in colour and composed of lava flows and some large blocks ejected during explosions. The two most recent lava flows were on the north-east and north-west sides (noted during a close inspection at 1530 hours). The flow on the north-west side was overhanging a vertical drop to the sea. It was also noticed during the close inspection that a large bomb rolling down the side of the cone had impressed a shallow gutter in the surface of the molten lava; this bomb was at that time perched about 5 feet above sea level at the bottom end of the gutter.

The upper part of the cone was brown to red in colour and appeared to be scoriaceous. Steam and gas were being emitted, often with great force, from vents and fissures in the central part; a large volume of finely comminuted orange-brown material was also emitted from this source.

The next explosion at 1550 hours was more violent than preceding explosions; the upper part of the cone (an estimated volume of 2,000 cubic yards),

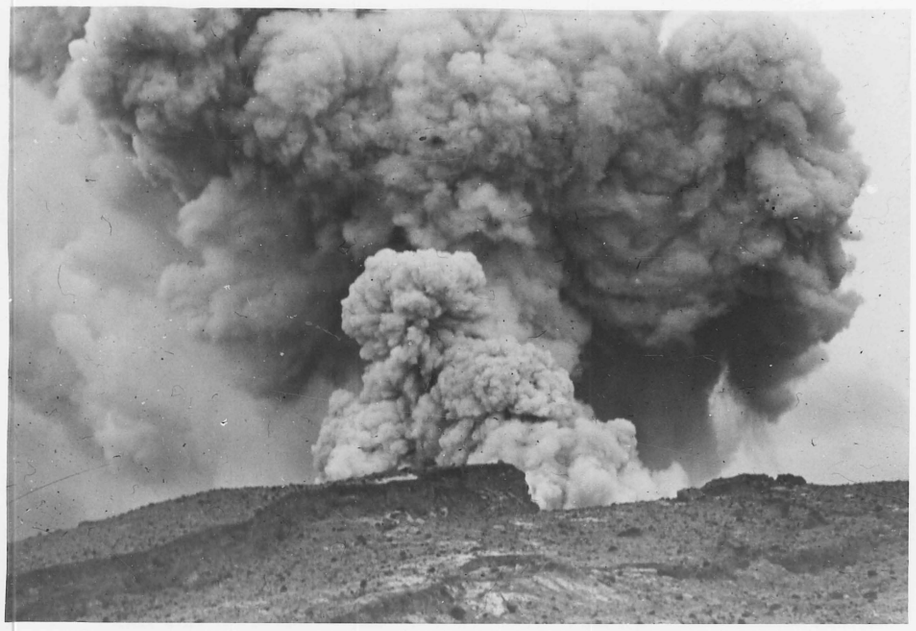


Figure 4. December 3rd, between 1202 and 1207 hours. Dust clouds from explosions of Cone 7 (taken from west side of northern part of island of Cones 2 and 4). These explosions caused displacements of the trace on the shock recorder (see Figure 10).

The map accompanying this report was prepared from chain and compass surveys on December 3rd and 4th; this photograph also shows the two northernmost of the small faults mapped on the island of Cones 2 and 4.

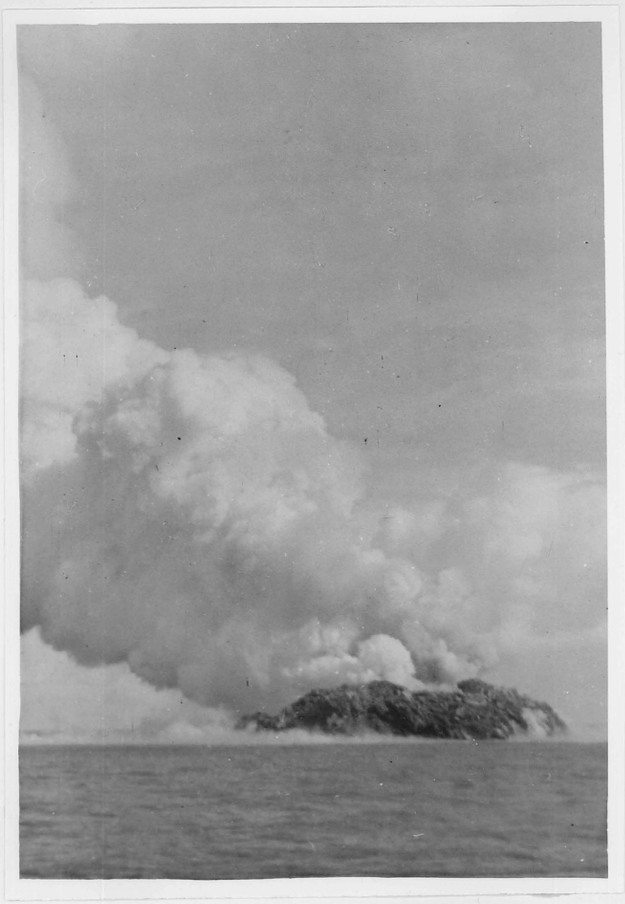
Figure 5. December 3rd, about 1215 hours. Photograph taken from eastern half of northern part of island of Cones 2 and 4 showing summit of Cone 7 and northernmost of fault scarps referred to in Figure 4.

and probably a large volume of underlying material was disintegrated and ejected. The District Commissioner, who had his back turned to the cone at the time of the explosion experienced sharp pain in his ears.

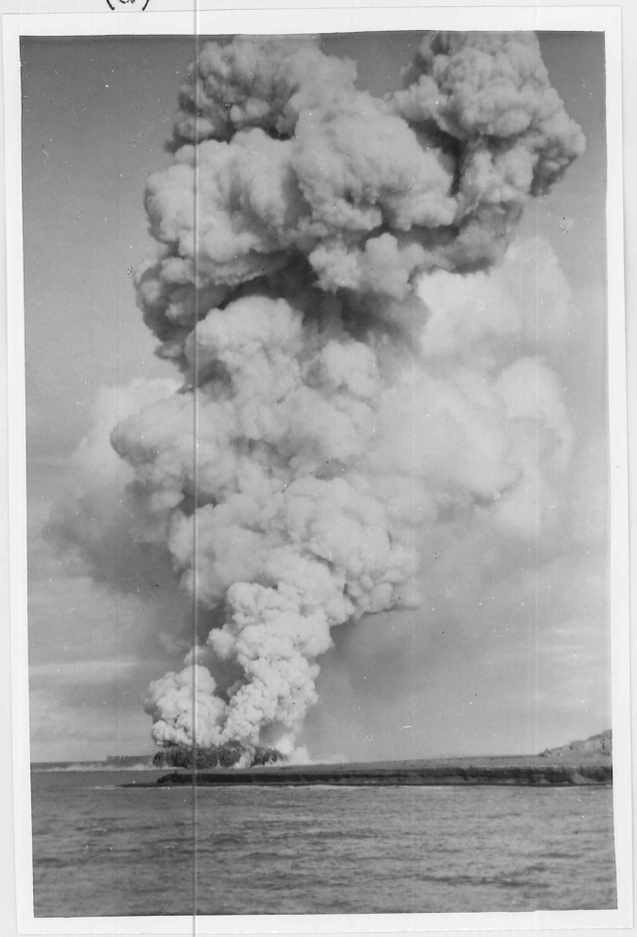
Immediately after the explosion, only the light grey basal portion of the cone remained above sea-level. During the next five minutes red-hot lava in a solid state was forced upwards and reformed the cone as it existed prior to the explosion. The upward movement was accompanied by jet-like emissions of steam, gas and orange-brown dust. The scoriaceous appearance and brown to ochre red colour of the surface formed gradually after upward movement had ceased. The cycle described is illustrated in Figure 6.

The pattern of activity described above continued until midnight, when observations were discontinued. There were explosions at 1614, 1710-15 (4), 1800, 1810 (small), 1850 (small), 1905, 2018, 2125, 2220 (small), 2233, 2300 hours. The lava plug forced up after the 1614 explosion contained large angular accessory blocks which were stained dark green. As the lava cooled the outer edges of the stain appeared to fade to a pale yellow colour. A large crack appeared on the western side of the dome after the 1710-1715 explosions; it extended from the top of the dome (plug) almost down to sea-level and gradually expanded over a period of about 20 minutes. At the same time it was noticed that the lava flows seen at 1530 hours had fractured and slipped down to sea-level and that either the eastern side had been breached and filled by the plug or material from the plug had overflowed the rim of the crater. Because of the apparent solid condition of the plug when it appeared, the fracture and slippage of the lava flows, and the fact that steam being formed at sea-level on the eastern side did not not vary in volume, the first of the two alternative suggestions is more likely correct. The jet-like emission of vapour was seen very well at night, particularly after the 2125 explosion; on this occasion red-hot particles were ejected to over 100 feet above the vent, and the accompanying roar was so loud that conversation was practically impossible within one-half a mile of the island. Generally the jets forced through vents on the top of the dome, causing lava in the vicinity to glow more brightly (the glow changed from

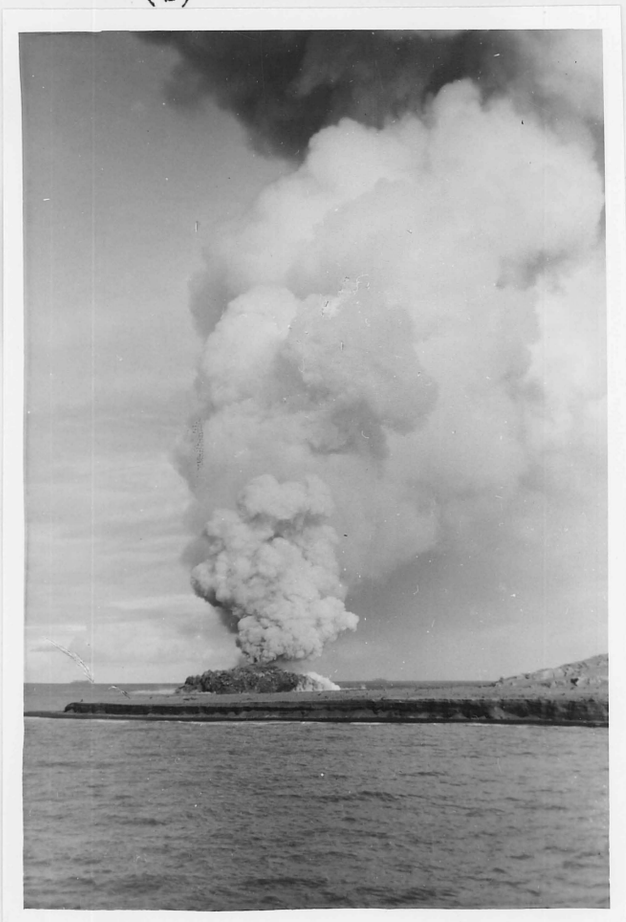
(a)



(b)



(c)



(d)

Figure 6: Cycle of activity on 5th December, 1956.

(a) Plug removed by explosion;
(b) Basal, crater portion of island (close-up photo from north-west);
(c) Upward movement of lava plug accompanied by jet-like emissions of steam, gas and orange-brown dust;
(d) Plug filling crater. (Photos (a), (c) and (d) from west).

Photos by Mr. J.H.Kemsley, Master of Administration Trawler, M.V. "Eros".

red to orange in colour); flame from the vents reached on the average 20 feet above the vent.

During observations from the leeward side of the volcano, it was possible to obtain some indications of the gaseous emanations. The only obvious smell in the vapour was sweet and somewhat nauseating; it was probably similar to the smell of burning tar noticed by Best during his investigations of lava flows on Cone Co. 3 in 1954. A slight smell of sulphur could be detected accompanying this gas.

December 6 — Audible explosions at 0655, 0834, 0844, 0951, 0959, 1055, 1222, 1933, 2012, 2025, 2028 hours. (N.B. Strong wind during afternoon, and no explosions were heard at Baluan Island).

December 7 — Explosions heard at 0003, 1115, 1226, 1737, 1739, 1932 hours; probably some explosions not heard due to wind.

December 8 — One explosion heard at 0828 hours.

December 9 — The wind was not as strong, and explosions were heard at 0555, 0852 and 1631 hours; the volume of red material being emitted increased.

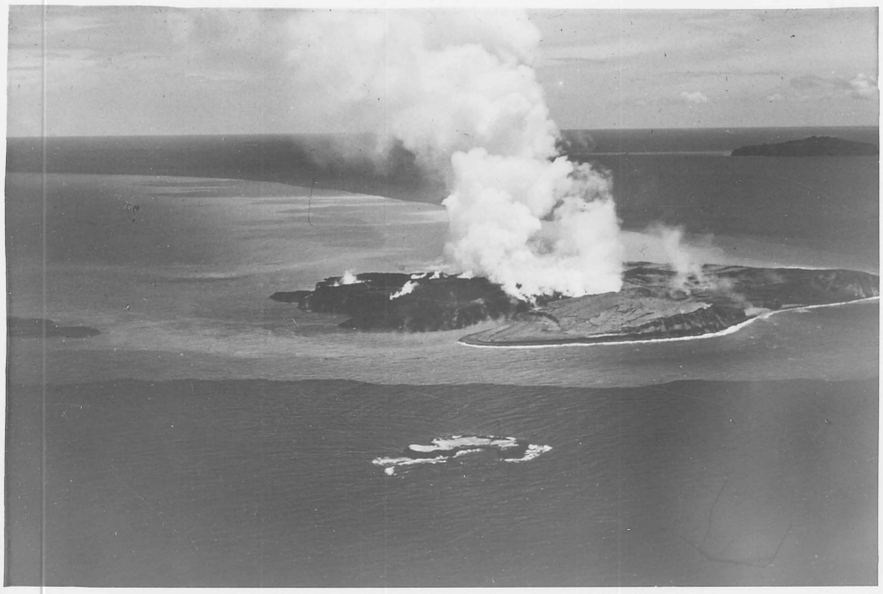
December 10 — Mild explosions at 0900, 1836, 2050 and 2143 hours. Glow from crater seen at Baluan Island for first time in current period of activity.

December 11 — Mild explosion at 1149 hours; decrease in explosive activity and increase in emission of vapour and finely comminuted red material.

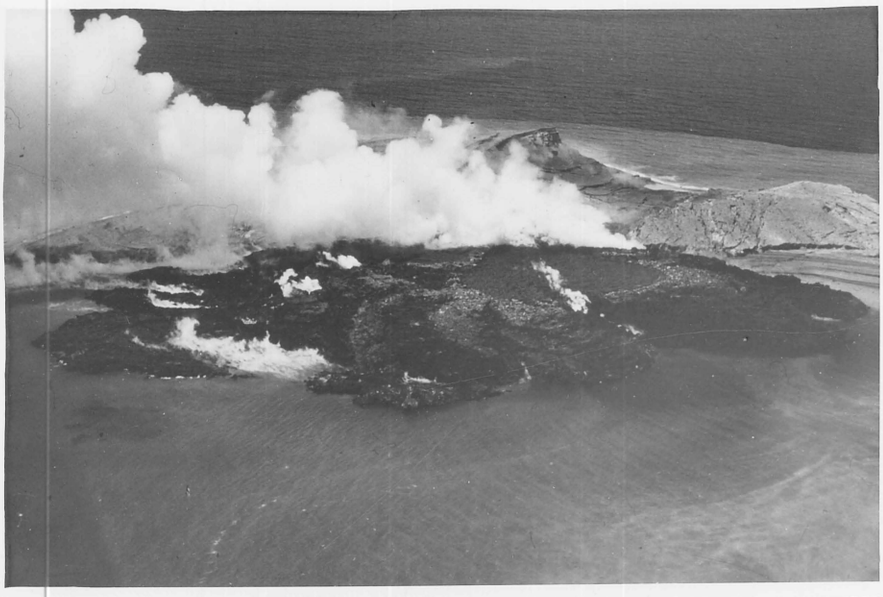
December 20 — Activity did not change between 11th and 20th.

December 21 — Tuluman volcano visited by Assistant District Officer from Baluan Island. Solidified lava flows seen south and south-east of Cone 7; they appeared to have originated below sea level, but observations were hampered by clouds of water vapour rising from the edges of the rock masses.

1957 January 2 — Another inspection conducted. Lava had filled the area between Cone 7 and the northern edge of the eastern end of the island of Cones 2 and 4. It was flowing to the north-west from a new crater, about 12 feet in diameter, just north of the junction of island and lava mass. The average height of the lava island was 20 feet above sea level; the rim of the crater was about



(a) showing lava flows from Crater B, Cone 7, near island of Cones 2 and 4; island of Cone 3 in foreground; photo from north-west;



(b) lava flows photographed from north-north-east.

Figure 7: The Tuluman Islands at the time of the aerial inspection on January 12th, 1957.

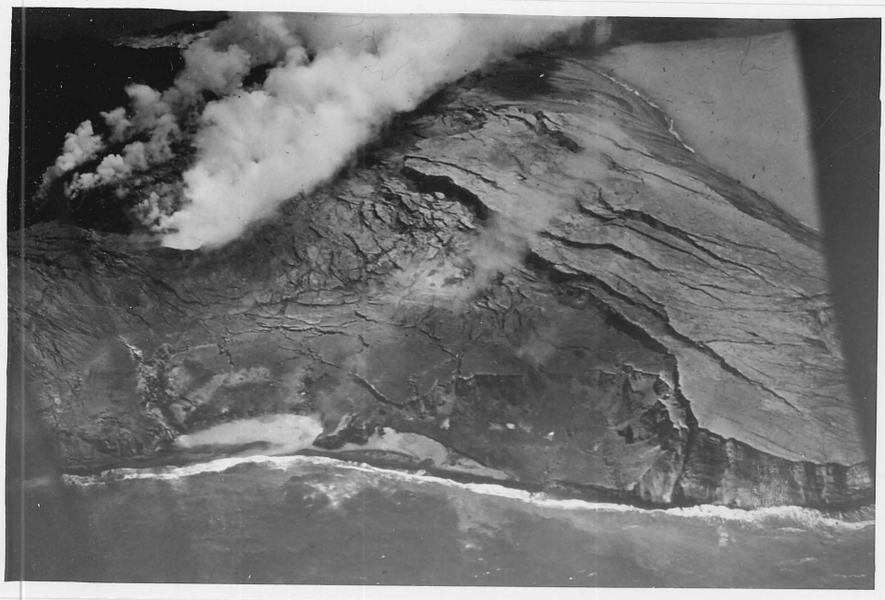


Figure 8: Aerial photograph of island of Cones 2 and 4 from the west on January 12th, 1957.

	50 feet higher. The volume of vapour was not as great as during activity of Cone 7 in early December, 1956; the vapour cloud carried no dust, and smelt like battery acid. There had been spasmodic mild explosions until 30th December, 1956 (source of activity not given). Sea water had entered the original crater of Cone 7 and vapour was drifting from it. The termperature of water between the new island and the remnant island of Cone 3 was 10°F., higher than normal.
January 2 - 9	Observer absent; intermittent explosions, including 3 on 8th, reported by native people.
January 11	Lava flow continued and island built up in parts almost to same height as island of Cones 2 and 4 (about 100 feet above sea level). Height of lava fronts were 20 to 30 feet above sea level. Vapour emission was unchanged.
January 12	Aerial inspection conducted; photographs, Figs. 7 and 8 were taken.
January 14	Small explosion at 1422 hours.
January 21	Explosions at 1800, 1850, 1950, 2100, 2110, 2115 hours.
January 22, 23	Explosions at 0845, 1315, 22nd, and then frequently until about 1500 hours, 23rd.
January 24	(1505 hours). Explosions during preceding 24 hours less frequent.
January 25	Five explosions in afternoon.
January 26	Thirty-six explosions counted during day; stronger than above.
January 28	Explosions ceased.
January 31	Tuluman volcano inspected; average height of lava island had increased to about two-thirds height of island of Cones 2 and 4 (i.e. about 60 feet above sea level), but area was only slightly greater than when last inspected. Vapour output was less. The eastern side of the island of Cones 2 and 4 appeared to have risen 2 or 3 feet, and although the tide was high, waves were breaking offshore to the north-west and south-west of the island.
February 7	No activity, other than fumerolic, witnessed since January 31.
February 8	Photographs taken during the aerial inspection on this day show that the island of Cones 2 and 4 had been breached - see Figure 9.

Figure 9:
The Tuluman Islands at the time of aerial inspection on February 8th, 1957.

(a) from north-north-west;

(b) from west showing breach in island of Cones 2 and 4;

(c) from south-east

February 26	Both islands appeared to have risen, in parts up to 15 feet, during the preceding fortnight.
February 28	Another inspection of the islands showed that the most pronounced rises (15 feet) had occurred on southern and western sides of island of cones 2 and 4; the island was breached in an east-west direction. Gas ebullition was occurring in an area about 20 yards in diameter at the western entrance to the breach, and also in the breach itself. It was noticed that the lava mass was joined to the island of Cones 2 and 4. (A rough sketch showing estimated increases in height and other detail was included in the report from Baluan Island; Figure 13 is a slightly modified copy).
March 13-23	No significant changes seen. "Tuluman examined p.m. 18th - little if any rise since examination late February. Small radial and concentric fissures apparently formed within last fortnight around No. 4 cone. Several rocks near high water mark 18th painted white for future reference".

2. Luni-solar Influence:

From the beginning of November 1956 until early February 1957, activity of Tuluman Volcano appeared to be strongest when both sun and moon were at, or very near, their southernmost declinations; on two occasions sun and moon were in conjunction. The activity at these times was as follows:

(a) minor eruption on 7th November

(b) activity of Cone 7 became stronger on 27th November; strongest explosive periods were on 29th November, 3rd and 5th December

(c) lava seen flowing from new crater 2nd January

(d) the climax of explosive activity which commenced on 21st January occurred on 26th, when intensity was greater, and thirty-six explosions were counted.

The coincidence of these events with periods when strong tidal stresses were operative suggests that response to luni-solar influence was even greater than during previous eruptions of Tuluman Volcano.

3. Remarks.

Important facts that emerge from the study of the activity and above discussion are

(1) the small island formed by the summit of Cone 7 was composed mainly of lava flows;

(2) explosive ejecta consisted of large fragments with very little dust;

(3) during periods of explosive activity, intervals between explosions were longer than during eruptions at other centres in 1954-55;

(4) the effusive phase continued above sea level; lava from a crater noticed on 2nd January, 1957 south of the original crater of Cone 7 formed a large island which was subsequently joined to the island of Cones 2 and 4. With the exception of Cone 5, the effusive phase in previous eruptions continued only until the summit of cones reached sea level; small flows occurred above sea level at Cone 5 possibly "due to a premature upsurge of the magma from the conduit as a result of luni-solar influence", (Reynolds and Best, 1957);

(5) the south-western side of the island of Cones 2 and 4 rose 15 feet between the end of January and 26th February, 1957;

(6) response to luni-Solar influence was very strong.

When these facts were examined at the end of February, two conflicting ideas emerged -

(a) the volume and pressure of gas accumulation for recent activity was less than for previous eruptions and Tuluman Volcano was returning to the dormant state;

(b) because of an uplift of the island, a strong eruption was imminant. (During the six weeks before the strong explosive activity of Cones 2 and 4 in February 1955, the summit of Cone 2 was uplifted 15 feet).

In view of this volcano's past response to tidal forces from luni-solar influence and the fact that strong compressive forces would be acting in those latitudes for mid-March, the writer felt justified in predicting an eruption for mid-March in his February monthly report. Although the nature of recent activity indicated that the eruption might not be as strong as in 1955, the precautions were taken of sending a shock recorder to Baluan Island, and when it was reported that the Manus District trawler M.V. "Eros" was unserviceable, of recommending that another Administration trawler be made available until repairs of the "Eros" were completed.

No further activity of Tuluman Volcano was reported before the writer left New Guinea on April 2nd, 1957, however, and the phenomenon of the uplift of the island of Cones 2 and 4 remains to be explained.

4. Seismic Activity:

As on previous occasions of volcanic activity in this area, no earthquakes were felt preceding or during the eruption. A shock recorder was operated, undamped, from 29th November until 3rd December at the southern end of Lou Island (one mile north of the volcano). It was placed at a height of about 20 feet above sea level on a flat bed of rocks which were set in a coarse-grained pumice deposit. On 3rd December, the recorder was moved to the island of Cone 4 and placed about 400 yards west of Cone 7 and 350 yards north of the active vent of Cone 4; the position is given on the accompanying map.

The only movements shown were those recorded at the times of explosions between 1135 and 1625 hours on 3rd

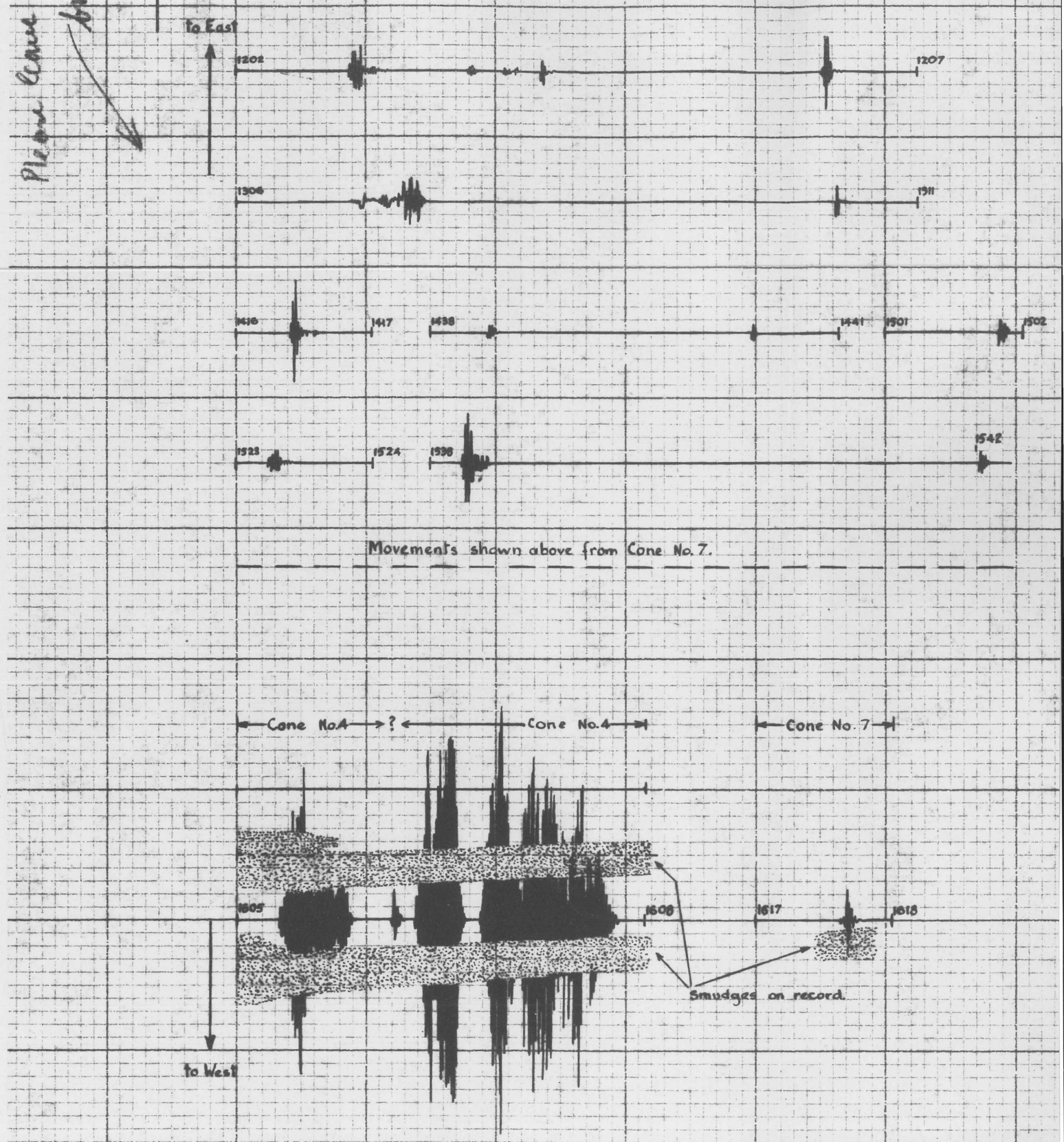


FIGURE 10: Enlargement of movements traced by shock recorder stationed on Cone No. 4 from 1135 to 1625 hours, 3 - 12 - 1956. Magnification X 5 approximately.

December; these were the east-west components of ground vibration. Movements resulting from activity at Cone 7 were of short duration and the maximum displacement was 2 mm. Explosions at 1605 hours at the active vent of Cone 4 caused a series of movements for 2¼ minutes; the maximum amplitude was 8 mm.

Because of the windy conditions and lack of shelter on the island of Cones 2 and 4, the smoked paper record was smudged, and some recorded movements were partly obliterated. The speed of drum rotation (5 to 5½ mm. per minute) is very slow, and trace displacements are jammed together. For this reason, and because the foci of movements were very close, it is impossible to identify accurately changes of period and the commencement of phases. The directions of initial movements are likewise difficult to determine.

Actual movements recorded were reproduced for Figure 10 by sketching the image formed using a binocular microscope and camera lucida attachment - magnification about 20 - and then reducing, by measurement, to give a magnification of about 5.

Since the preparation of the preliminary report (Reynolds, 1957) an alternative explanation has been suggested for the fact that only primary (longitudinal) waves of explosions from Cone 7 appear to have been recorded: transverse waves from Cone 7 explosions would be vibrating in a north-south direction, and would therefore give minimum displacement to the pendulum mass which was oriented to show maximum movements in the east-west plane.

This is more logical than explanations offered in the preliminary report, and the first conclusion reached therein has been modified:

(1) Both longitudinal and transverse waves were probably generated by explosions from Cones 7 and 4, but longitudinal waves were the main cause of trace displacement for explosions from Cone 7; transverse waves from explosions of Cone 4 causedthe large displacements between 1605 and 1608 hours.

Although the shock recorder was oriented to show maximum displacement for transverse waves from Cone 4 explosions, further explanation is needed to account for the comparatively large movements from explosions of only very small intensity compared with Cone 7 outbursts. This is possibly provided by the comparison of explosive activity from each cone.

A. Explosions of Cone 7 were from a crater above sea level, and most energy was dissipated in an upward direction; ground waves would have been dispersed from the summit as follows -

(a) longitudinal waves by both sea water and submarine connections to other land masses

(b) transverse waves by submarine land connections only.

B. Explosions of Cone 4 probably resulted from gas accumulation beneath a shallow submarine vent plugged by volcanic debris. Compared with explosions from Cone 7, a greater proportion of energy from Cone 4 explosions would be dispersed as ground waves because of the resistance offered by water above the vent to an upward outburst. The island of Cone 4 and its submarine extensions embrace this vent and

transverse waves would be transmitted directly to it.

Conclusions (2) and (3) of the preliminary report have also been changed on the basis of the above discussion:

(2) The proportion of energy of explosions dispersed as ground waves from Cone 7 was probably much less than from Cone 4 because of the different environments of the vents.

(3) Ground waves from the vent of Cone 4 passed directly to the shock recorder stationed on that island; longitudinal waves from Cone 7

(a) travelled through solid, liquid, solid media, and

(b) were followed by transverse waves from the solid lava cone to unconsolidated sediments by submarine paths.

III. THE TULUMAN ISLANDS

The map accompanying this report was prepared from a chain and compass survey completed on 3rd December, 1956; the remnant island of Cone 3 was surveyed on 4th December and a large scale map is included as Figure 11 to show structure in greater detail. Figure 12 shows the islands formed as at 25th March, 1955, the positions reported for subsequent minor activity, and the outlines of the islands as at 3rd December, 1956 and 8th February, 1957. A modification of the sketch, prepared by Assistant District Officer W. G. Murdoch, of the island of Cones 2 and 4 and the adjoining lava mass as at 28th February is included as Figure 13.

1. Cone No. 3. Only small remnants of the island mapped in March 1955 remained in December 1956. The unconsolidated portion of the crater rim was almost entirely eroded away and the island was composed of lava covered by a layer of pumice dust one foot thick. The lava marked the eastern side of the crater, and the island was horse-shoe shaped. The island had a width of 20 yards and was about 100 yards long in a north-south direction; the maximum height above sea level was about 10 feet. Determination of the strikes of small folds around the margin of the island indicated that the vent from which lava was extruded in July 1954 was at the eastern end of the crater built up by subsequent explosive activity. The island of Cone 3 is well shown in photographs, Figures 1, 2 and 7a.

The sedimentary deposit of pumice and sand which extended for about 800 yards north of the northern crater rim in March 1955 had been eroded away, except for a small elongated portion of the northern end. This had been left as an island joined by a shallow submarine bar to the north to another small island formed subsequent to March, 1955 by deposition on the reef at the southern end of Lou Island. These islands were mapped and are included in the section "Islands formed as at 3.12.56" in Figure 12; they can also be seen in Figure 1 between the area of brown-stained water north of Cone 3 and the southern tip of Lou Island.

The only activity noticed in the vicinity of these islands was an area of submarine gas ebullition about 100 yards west of the crater; owing to the effervescence,

the sea above the active area appeared green in contrast to the dark blue of the surrounding sea. The temperature of the water above the area was 32°C.

2. Cones Nos. 2 and 4. The western half of this island as mapped in March, 1955 and the island of Cone 5 which joined it to the south had been washed away by December, 1956; the eastern half of the island, formed mainly by Cone 2, was almost the same as in March, 1955. The crater of Cone No. 2 had not altered and was still thermally active at the eastern end. A steep-sided crater into which water had entered by infiltration had formed south-west of Cone No. 2 crater; this was circular in outline and about 70 yards in diameter. It is well shown in Figs. 1 and 9c. No explosive activity has been seen from this crater which was probably formed by subsidence in this area in May-June, 1955. There was also subsidence at that time on the north side of Cone No. 2 and south of the main vent of Cone No. 4. The northern zone which was submarine was still thermally active in December, 1956. The western portions of the crater of Cone No. 4 and of the depressed zone to the south had been removed by erosion and only the steep-sided eastern rim of the subsided zone remained; a small lava peninsula marked the northern side of this rim. The focus of activity of Cone No. 4 shifted to the south after the February, 1955 eruption, and subsequent activity in the form of mud eruptions emanated from the zone of subsidence. During October, 1955 the sea gained access to the crater formed and erosion of the western half of the island proceeded rapidly thereafter. Mud eruptions in November and December, 1956 were from the south crater which was then submarine; submarine gas ebullition occurred in areas from 50 to 100 yards west-north-west and about 200 yards south-west.

On 1st December, temperatures of 102°C were measured in a very active thermal point at the base of the eastern rim of the subsided zone. When visited again two days later, there were fissures through this point, and activity appeared more vigorous with boiling water being ejected to a height of about one foot above the base of the fissures; the maximum temperature, however, was still 102°C. Small landslides around the rim had accompanied the fissuring, and ground in the vicinity of the lava peninsula had become much hotter, according to native police assistants who walked over the area in bare feet during both visits.

Thermal activity in other parts of the island was concentrated along the numerous fissures which had developed. The main fissures and faults shown by Assistant District Officer E.G. Hicks in the sketch which he prepared in August, 1955 still existed. There were also numerous small cracks parallel to the major fractures which extended for distances of up to 200 yards across the island in directions of from north to north-east towards south to south-west. Other fractures were developed around the remnant of the crater rim of Cone No. 4. Small amounts of sulphur had been deposited on the surface of the centre of the island near the eastern rim of Cone No. 4 crater.

The western part of the island of Cones 2 and 4 showed little alteration between 3rd December, 1956 (when it was mapped) and 12th January, 1957 (when Figure 8 was taken). It was further eroded by 12th January, and small lagoons had formed on each side of the small lava peninsula. Figure 8 also shows thermal points, fissures and faults and the area of sulphur deposition near the central sunken portion of the island.

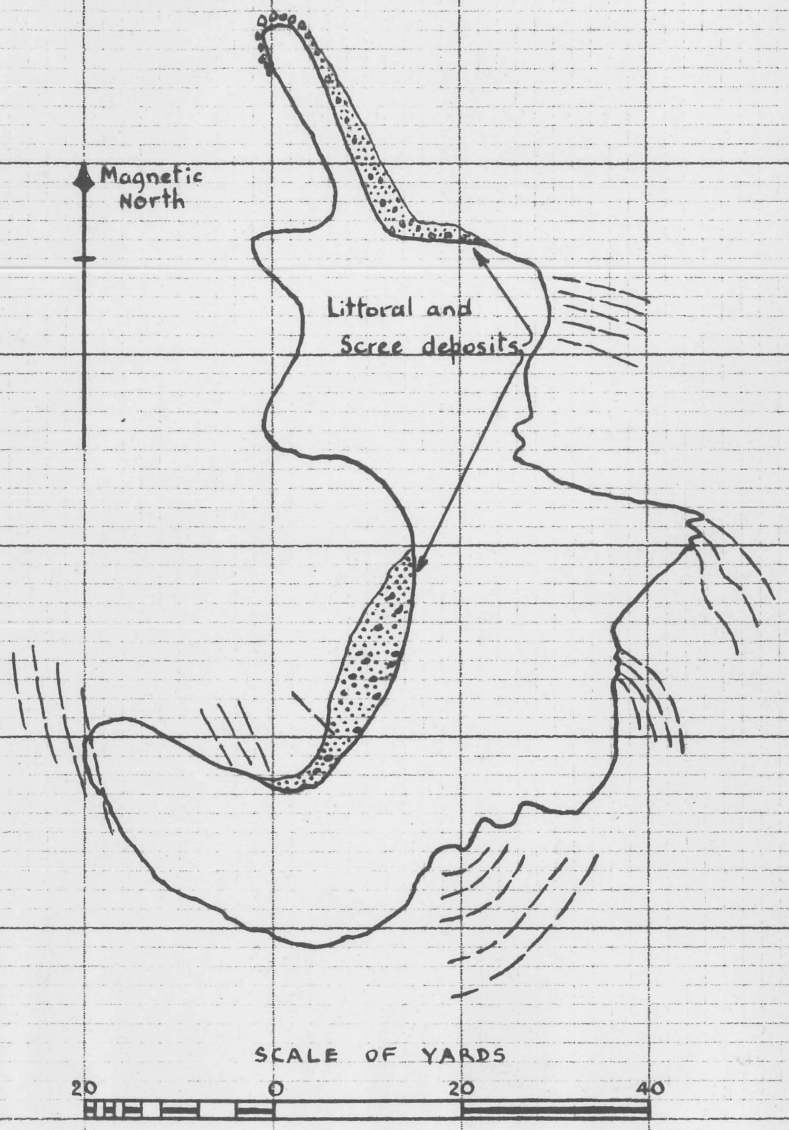
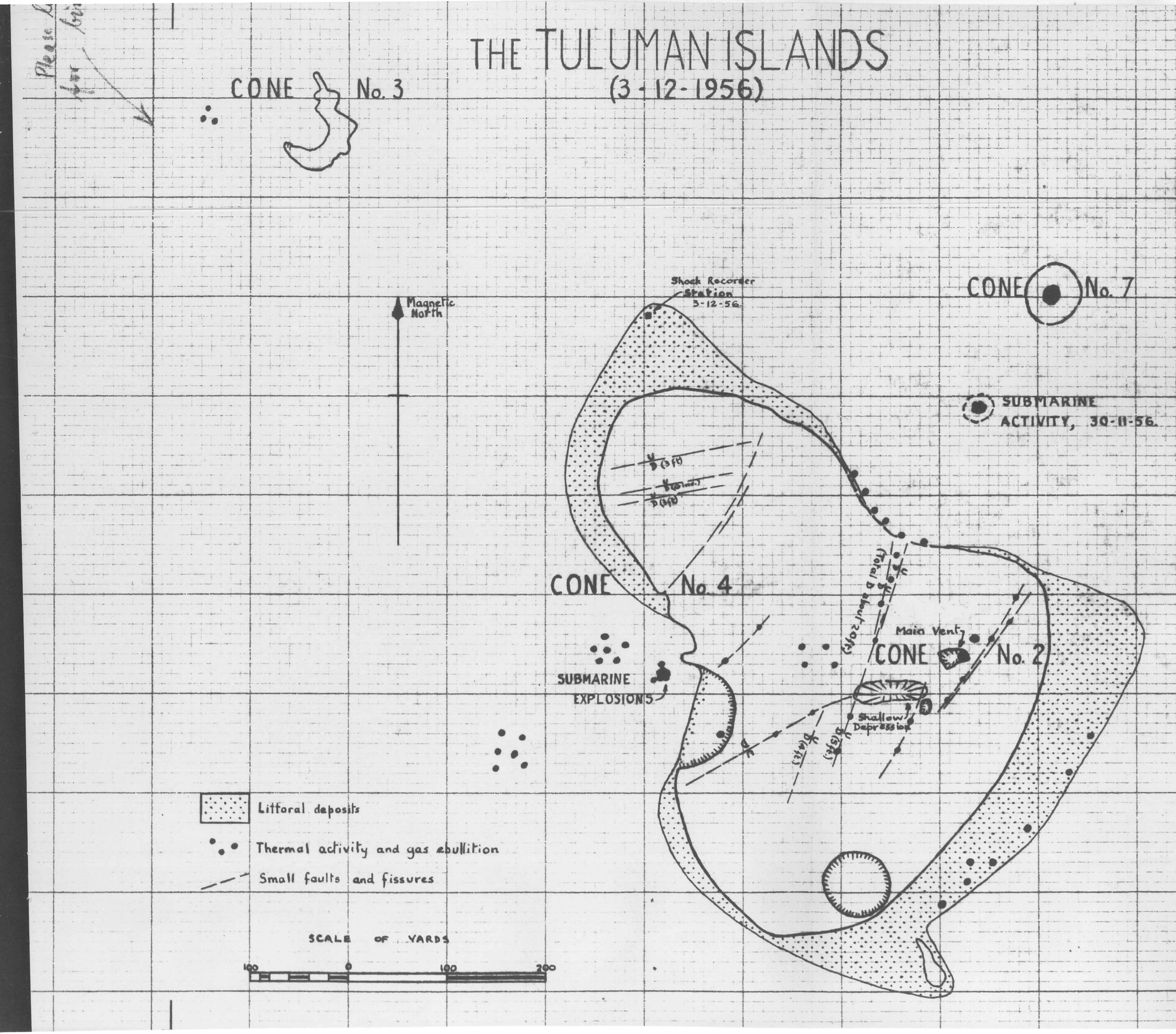


FIGURE 11: Map of Cone No. 3 island showing strike lines of folds and ridges in lava flows exposed at Low Tide level, 4 - 12 - 1956.

THE TULUMAN ISLANDS
(3-12-1956)



3. Cone No. 7. The small island formed by the summit of Cone No. 7 on 27th or 28th November, 1956 was built up by lava flows; it was subsequently obscured by lava flows from the vent to the south in January 1957. The size of the island was greatest (about 50 yards in diameter) in early December; it consisted of a crater whose rim was about 20 feet above sea level, and a central dome which built the island's height to between 40 and 50 feet above sea level.

Submarine lava flows midway between Cones 7 and 2 on 30th November, 1956 and south of Cone 7 (some time between 10th and 21st December) probably originated from apophyses off the main conduit of Cone 7. This migration of focus of activity concluded with lava extrusion and minor explosive activity from a crater about 100 yards north of Cone 2 in January, 1957. The island which formed and joined the island of Cones 2 and 4 is illustrated in Figures 7 and 9; the sketch of the Tuluman Islands as at 8th February, 1957, Figure 12, was prepared from these photographs. The height of the lava island reached about 60 feet by 31st January; the crater rim was apparently about 40 feet higher.

4. Island of Cones Nos. 2, 4 and 7. Although lava flows from the south crater of Cone 7 moved along the north edge of the island of Cone 2 during activity in early January, 1957, the resultant island of Cone 7 did not unite with the island of Cones 2 and 4 until a later upward movement of the cones occurred. A more precise outline of activity between 12th January and 8th February than that given in reports from Baluan Island has been obtained from observations made during aerial inspections. A study of reports received and of Figures 7 and 9 (photographs taken during the aerial inspections) show that the main features of the activity were as follows:

(a) the eastern edge of the northern part of the island of Cones 2 and 4 was joined to the lava flows of Cone 7 between 12th January and 8th February

(b) close inspection of the island of Cones 2, 4 and 7 on 31st January revealed that the eastern part had risen 2 or 3 feet, and there was also evidence that north-western and south-western parts had been slightly uplifted

(c) judging by the extensive littoral deposits exposed around the western part of the island on 8th February, there had been further uplift. (This statement is also based on the fact that strong seas from the north-west, which had previously caused much erosion in this section of the island, were still evident at the time of observations).

(d) the island of Cones 2 and 4 had been breached between 31st January and 8th February.

The observer on Baluan Island reported on 26th February that the island of Cones 2 and 4 and the adjoining lava flows had risen, in parts 15 feet, during the previous fortnight. He visited the island 2 days later and prepared a rough sketch, a modified copy of which is included in this report as Figure 13, showing estimated increases of height above sea level, greatest on southern and western sides, and the breach across the island. The report sent after this visit contained the observer's first reference to the breach. This fact probably indicates that the island had not been closely inspected since January 31st, and that the uplift could have occu occurred unobserved earlier than was estimated in the report of 26th February. On this assumption and the evidence of

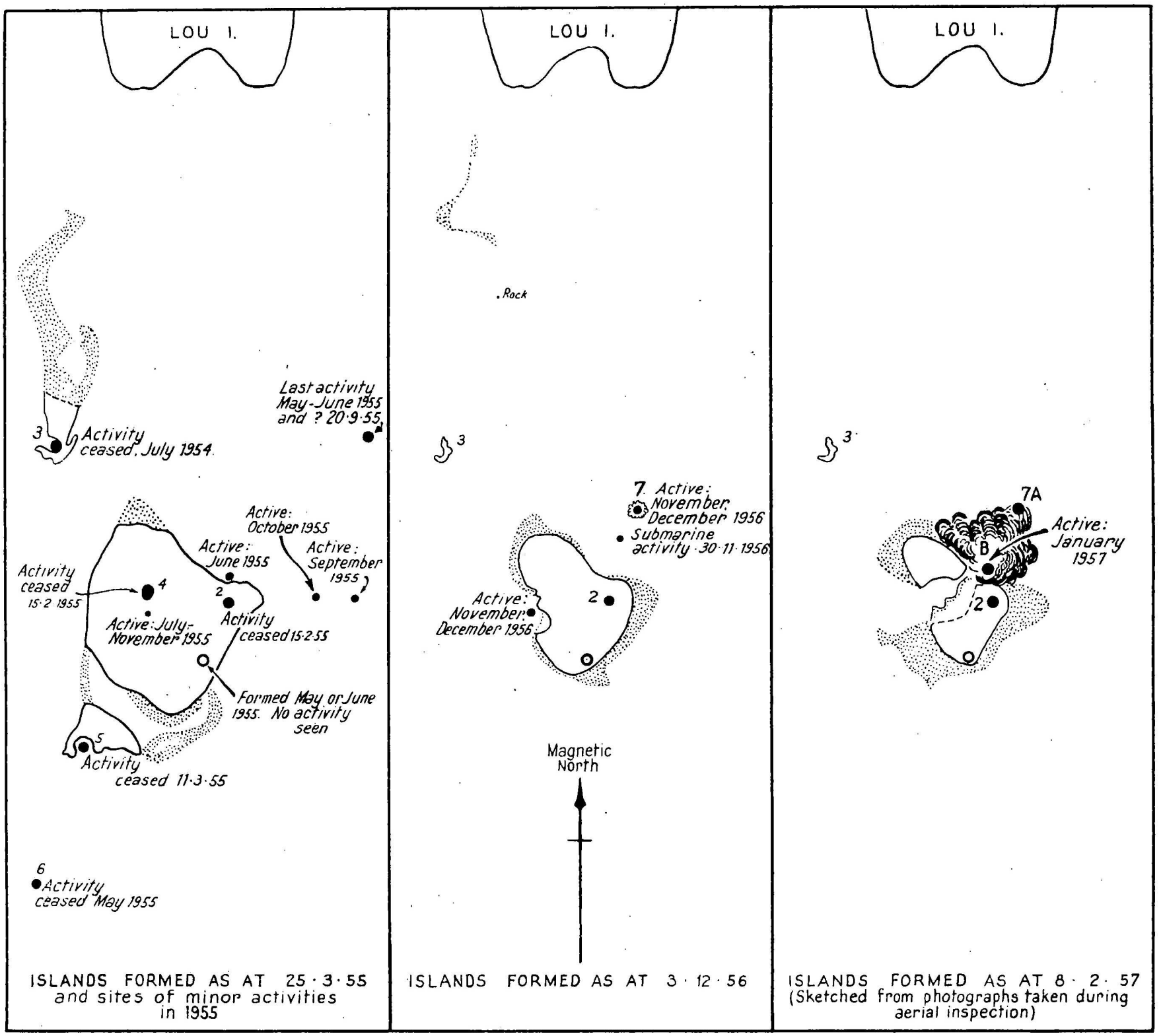


FIGURE 12· *Sketch maps showing further stages in the formation of*
TULUMAN ISLANDS

SCALE OF YARDS
500 0 500 1000 1500

Bureau of Mineral Resources, Geology & Geophysics, Feb, 1958

PNG 15-23 MR KS.

Figure 9, the writer considers that upward movement of the southern and western ends of the island was greatest between the end of January and 8th February, and most likely coincided with the formation of the breach. The apparent merging above sea level of the island of Cones 2 and 4 with lava mass, some time between 12th January and 8th February, also probably resulted from the uplift, and occurred at the same time. (The observer did not report that the island and lava had joined until after his visit on 28th February - they were either not joined above sea level, or the join was not obvious on 31st January).

Figure 13 shows that the breach ("trench") had extended (?) across the lava mass by 28th February. The report, however, only states: "A sea-filled bay running east and west has opened on a line through the side of No. 4 Cone and extending eastwards from it to the rock of No. 7 Cone (lava mass) which now joins the ash of No. 4 Cone. Steam obscuring much of the area from exact observations." Fissures shown in Figure 13 were marked as "cracks parallel to the trench" in the original sketch map. Easterly extension of the breach, therefore, has probably occurred through the active vents shown in Figures 7-9, and may have resulted from withdrawal of magma from beneath the volcano.

IV. REVIEW OF NOMENCLATURE

The system of numbering cones in the chronological order of their first period of activity was used as a means of reference to the numerous active centres of Tuluman Volcano for the period June 1953-May 1955. Its application, however, was difficult because the first activity of most cones was submarine, and accurate positions of the surface manifestations were not often determined. Six cones were finally recognised, and these were formed as follows:

Cone No. 1 (Submarine):

> First active in June 1953. The position given by Mr. Landman, officer in charge of the Sub-District Office, Baluan Island, was "approximately four miles north of Baluan in direction most southerly point Lou Island". This was accepted by Best (1954) and the writer (1955a) as the site of activity in November, 1953 and July, 1954 when two islands, regarded as craters of the one structure, were formed. During the investigation of submarine activity east of these islands in October 1954, local native people told the writer that the focus of activity on this occasion was the same as that in June, 1953. This suggestion was not accepted until subsequently verified by the Agricultural Officer of the Manus District, who had taken rough bearings from Lou Island of activity in both June, 1953 and October, 1954. The writer (1955b) therefore placed the position of Cone No. 1 (submarine) in the position of submarine activity in October, 1954. The latter was determined fairly accurately by taking compass bearings from nearby islands of the surface activity.

Cone No. 2:

> First active November, 1953 - February, 1954 (?). Small lava island formed July 1954. Explosive phase February, 1955. "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" (Cone No. 2), and this

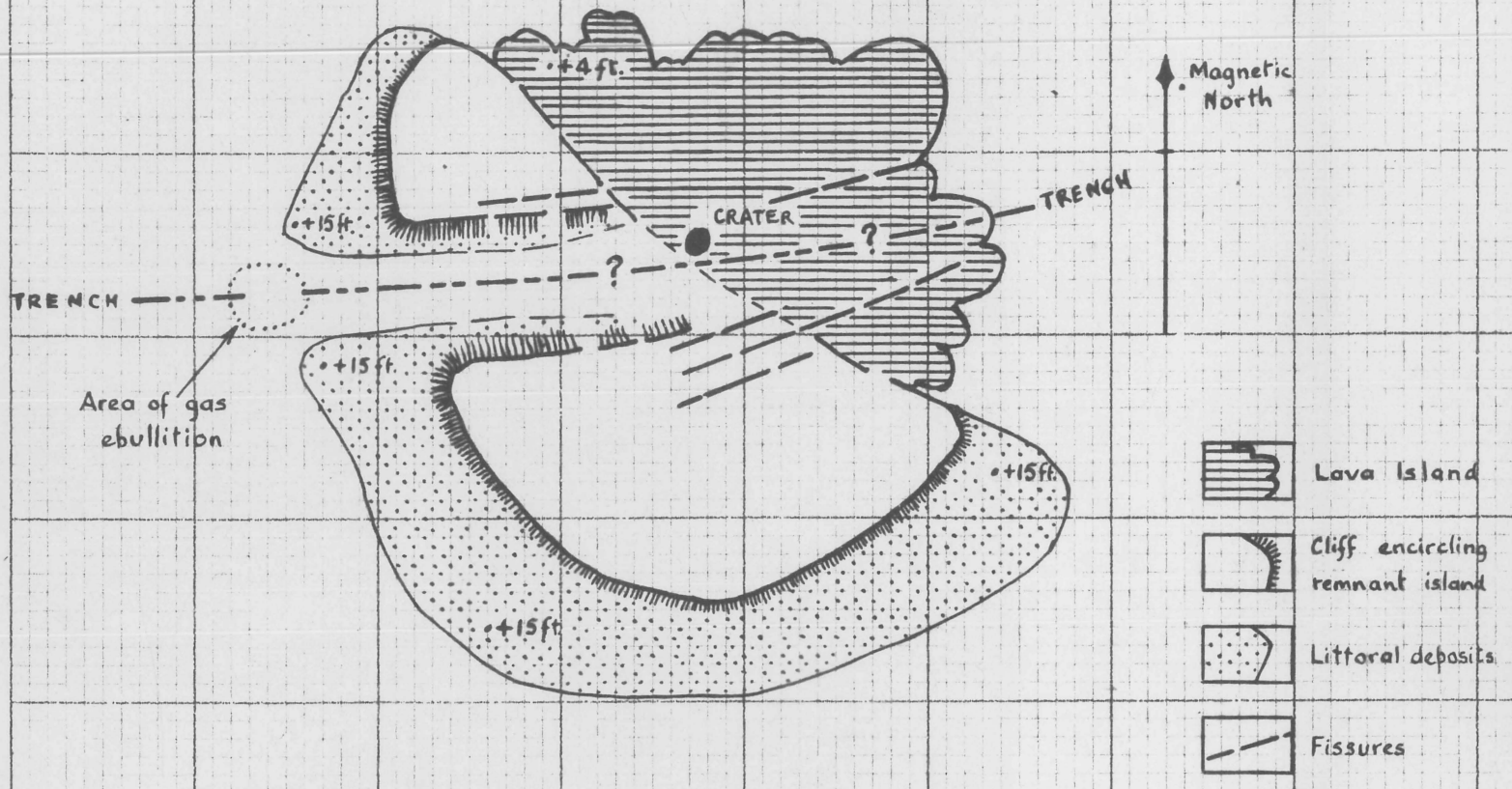


FIGURE 13: MODIFIED SKETCH OF ISLAND OF CONES 2 AND 4 AND LAVA MASS (ORIGINAL PREPARED BY ASSISTANT DISTRICT OFFICER W. MURDOCH, BALUAN ISLAND, 28-2-57).

Scale not given - estimated that 1 inch equals about 180 yards.

island is therefore given precedence (over Cone No. 3 or "West Crater") in the order of numbering." (Reynolds, 1955b).

Cone No. 3:

Explosive phase coincident with lava extrusion at Cone No. 2 in July, 1954. Possibly preceded by submarine vulcanism in April, 1954, but no position was recorded for this activity.

Cone No. 4:

Explosive phase coincident with that of Cone No. 2 in February, 1955 - no preceding submarine activity known.

Cone No. 5:

First active February, 1955; submarine phase commenced at the same time as explosive activity of Cones 2 and 4. Island formed later. Active until March, 1955.

Cone No. 6 (submarine):

Commenced March, 1955 and continued until May, 1955 - did not reach sea level.

After activity at Cone 6 had finished on about 9th May, 1955, there were periods of minor activity from various sources, only some of which could be attributed to cones already numbered. Briefly, these were as follows -

1955	May 16 - June 26	Submarine lava extrusion preceded the appearance of summit of a new cone above sea level. Minor explosions occurred before activity ceased, and island subsided below sea level. The position was estimated by Assistant District Officer E.G.Hicks to be from 100 to 200 yards east-north-east of the eastern tip of the island of Cones 2 and 4, and near the original 1953 eruption.
	June 5 - 26	Spasmodic mud eruptions, Cone 2. An increase in temperatures and extent of activity in Lou Island thermal area also noticed at this time.
	July 21 - Aug. 2	Spasmodic mud eruptions, Cone 4.
	September 20	Small vapour clouds noticed rising intermittently from vicinity Cone 1.
	Sept. 26 - 28	Submarine activity from approximately 500 yards east of Cone 2.
	October 3 - 7	Submarine activity 300 yards east of Cone 2.
	October 15 - 28	Spasmodic mud eruptions, Cone 4.
	November 7 - 25	Minor activity, Cone 4.
1956	March 29, 30	Submarine detonations and increase in vapour from volcano (reported by natives).

More intense activity as from November 1956 is also summarised:

Nov. 8 - Dec. 10	Lava extrusion and explosive activity, Cone 7. Small lava island formed.
Nov. 29 - Dec. 5	Occasional mud eruptions from Cone 4.
Nov. 30	Submarine lava extrusion between Cones 7 and 2.
Dec. 10 and 21 (some time between)	Lava flows occurred from an unknown submarine source south of Cone 7.
1957 January 2 - 11	Sub-aerial lava flows from second crater of Cone 7 (about 100 yards north of crater of Cone 2).
January 2 - 9	Intermittent explosions from second crater.
Jan. 14, 21 - 28	Explosive activity from second crater.
Jan. 31 - Feb. 8	Uplift of southern and western sides of island of Cones 2 and 4 and breach formed through island.

The locations given in reports for activity in 1955 after 9th May are plotted on the map of the islands as at 25th March, 1955, Figure 12. Centres of activity in 1956 and 1957 are shown in the other two sections of Figure 12.

The activity, May 16 - June 26, 1955, was attributed (Reynolds, 1955b) to Cone 1 on the basis of positions given by Mr. Hicks and the fact that the position of Cone 1 had been determined on only the surface manifestation of its previous submarine activity. Since then photographs taken by Mr. G. A. Taylor (Vulcanologist, Rabaul) during an aerial inspection of Tuluman on 20th June, 1955 have become available; they show that the summit of the active cone at that time was very close to the position estimated for Cone 1. Further minor activity occurred near Cone 1 on 20th September, 1955.

Minor activity in the periods September 26-28, October 3-7, 1955, may have originated from the source of the eruption of Cone 7. The appearance of the summit of Cone 7 above sea level in late November, 1956, was not preceded by explosive activity or any manifestation of submarine activity. The summit was therefore either uplifted or built up by lava flows from a source very close to the surface of the sea. This in turn implies that a cone had been formed in this location by submarine activity before November, 1956. In order to relate minor submarine activity in September, October, 1955 with the formation of Cone 7 the following information would be necessary:

(a) depth of point of extrusion of lava
(b) direction and rate of water movement
(c) rate of ascent of lava blocks

This information is not available. However, some evidence for a relationship exists:

(1) A submarine cone existed at the position of Cone 7 before its eruption in November 1956;

(2) the only submarine activity reported which has not been attributed to cones was that in September, October, 1955; further, no major activity occurred between that time and November, 1956 (the submarine detonations in March, 1956 apparently showed no surface manifestation);

(3) the position reported for surface manifestation of submarine activity in October, 1955 was slightly nearer Cone 7's position than that reported for September, 1955 - if lava was from the same source and water movement the same during both periods a growing submarine cone could be suggested.

The review of nomenclature is concluded with a summary of the positions and activities of cones which can be used for future reference :-

1. The position of Cone 1 as shown in existing maps is fairly accurate according to photographs taken during an aerial inspection on 20th June, 1955. Activity occurred in June - July, 1953, October - November, 1954, May - June, 1955 and 20th September, 1955(?).

2. Cones 2 to 5 were built up to form islands and were mapped. Eruptions (including minor activity) occurred as follows:

   Cone 2 - November, 1953 - February, 1954; July, 1954; February, 1955, June 1955;

   Cone 3 - April, 1954 (?), July 1954;

   Cone 4 - February, July-August, October, November, 1955, November-December, 1956;

   Cone 5 - February - March, 1955.

   No separate identification has been given to centres of minor activity on, or adjoining, the island of Cones 2 and 4. These centres have been referred to either Cone 2 or Cone 4 on the basis of their proximity to the craters of those cones.

3. Cone 6 (submarine) was plotted as accurately as possible from its surface manifestations. It was active from March until May, 1955.

4. The position of Cone 7 was mapped in December, 1956. Sources of submarine activity midway between Cones 7 and 2 on 30th November, 1956, and south of Cone 7 (some time between December 10th and 21st) were identified as activity of Cone 7. Migration of focus of activity concluded with lava flows and explosive activity from a crater about 100 yards north of the crater of Cone 2 in January, 1957. The lava mass which was formed and joined to the island of Cones 2 and 4 is tentatively called the island of Cone 7. The original crater (November, December, 1956) and the new crater (January, 1957) are classified A and B respectively. When the islands were last observed by the writer, crater A could not be recognised among the more recent lava flows. Crater B is possibly above the site of mud eruptions in June, 1955 which were referred to Cone 2. (The mud eruptions followed fissuring and subsidence in this area; it was still thermally active in December, 1956 and migration of the focus of activity of Cone 7 into this unstable area would have been comparatively easy).

Activity of Cone 7 - September 26 - 28, October 3 - 7, 1955(?); November, 1956 - January, 1957.

V. REVIEW OF ACTIVITY

The original suggestions on the mechanism of activity were made by the writer (1955b) after examining activity between June, 1953 and May, 1955; a brief summary of the conclusions reached is included in the preliminary report (pp. 1, 2, Records 1957/15), and further conclusions based on subsequent activity were given on pp. 9 and 10. Some of the latter conclusions have been amended in this report.

1. Origin of the magma and source of thermodynamic energy.

The general description of the mechanism of the activity given by the writer (1955b) still appears to be basically correct. No mention, however, is made in the section "Origin of the Magma" that Tuluman Volcano became active at a time when there was general reactivation of volcanoes in the Bismarck Archipelago arc; viz. Bam Island 1954-55, Manam Island 1956-57, Long Island 1953-55, Langila 1954-55; in eastern Papua, Mt. Lamington 1951-52; and at Bagana 1953, in Bougainville. Taylor (1955a) states that this volcanic activity "is explainable on the grounds of widespread regional stress conditions which are manifest in an increase in the frequency of tectonic earthquakes." Such stress conditions have probably resulted in crustal or sub-crustal readjustments which

(a) caused release of pressure in the magmatic chambers of volcanoes and allowed lava, previously in solid state under high pressure, to become fluid,

(b) allowed incursion of abyssal magma into the roots of volcanoes;

(c) opened pre-existing channels allowing abyssal gas to ascent and accumulate in magma bodies;

or, by some other means, caused lava to become mobile. In most cases of recent volcanic activity in the Bismarck Archipelago, gas seems to be the main source of energy. Whether this was released from solution by process (a) of above or supplied from abyssal sources is not known. One fact, however, which probably precludes a process of large magma movement is the fact that recent volcanic activity in the Bismarck Archipelago has not been preceded by volcanic earthquakes.

Examination of the submarine and subaerial phases of vulcanism at Tuluman from 1953 to 1955 showed the important part played by gas in motivating the eruptions. Significant facts were:

(1) the spasmodic, at times periodic, nature of submarine activity,

(2) the development of the explosive phase when cones become subaerial,

(3) the cessation of major activity from subaerial cones after the explosive phase had finished.

(4) renewed activity occurred only at submarine cones.

The facts (3) and (4) were also advanced in evidence that most cones were distinct units.

2. Source of activity since May, 1955.

It was mentioned in the summary and conclusions of Records 1955/95 (Reynolds, 1955b) that if activity between June, 1953 and July, 1955 were divided into three intervals, viz. June, 1953 - September, 1954, October, 1954 - May, 1955, and May, 1955 - July, 1955, a movement of focus to the south-west from Cone 1 occurred in each period. Minor activity from September until November, 1955 also showed this trend if the position for activity on 20th September (near Cone 1) is correct and the eruptions of September 26-28, October 3-7 originated from Cone 7 (submarine); this activity was followed by mud eruptions to the south-west from Cone 4 in October and November.

The focus of activity migrated to the south-west from crater A of Cone 7 during the major eruption, November, 1956 - January, 1957. In this period, however, the activity commenced south-west of Cone 1 and closer to Cone 2. This implies that the parent magma body was not as extensive and that, if gas accumulation caused mobility of the lava as previously suggested, its volume was less than for previous eruptions. Owing to the fact that mud eruptions occurred from Cone 4 during the Cone 7 eruption and that thermal activity on the north side of Cone 2 persisted from May, 1955 until December, 1956, the main source of activity was possibly below Cone 2 or in that vicinity.

A further migration of focus to the south-west in February, 1957, may have been responsible for the uplift of the southern and western sides of the island of Cones 2 and 4. Although subsidiary to the effusive phase, a period of minor explosive activity concluded activity of Cone 7. After the explosive phase, the conduit and its branches would have been sealed by solid lava in the same manner as for other subaerial cones. Attempted migration of the focus of activity to the south-west as more gas accumulated was probably impeded by existing cones with closed conduits. Pressure developed by the gas accumulation was apparently not strong enough to mobilise a large volume of magma and form a new breach. It was, however, possibly great enough to cause uplift of overlying deposits and allow magma to expand into the cavity formed and thus obtain equilibrium.

3. Trend of Vulcanism since May 1955.

The writer (1957) has implied previously that the trend of vulcanism since 10th May, 1955 is toward the dormant state:

(a) the minor activity of Cones 2 and 4 in 1955 was regarded as representing a decadent phase

(b) although activity from Cone 7 in November, December, 1956 was regarded as a major eruption, intensity was less than in other major eruptive periods in 1954-55. The two possible explanations for this were:

" (1) the eruption was triggered prematurely by luni-solar influence, and

(2) owing to the release of large amounts of gas during eruptions since 1953, the energy derived from this source is now almost expired, and activity in the area is declining."

The activity in November, December, 1956 was different from that during previous eruptions in the following respects:-

(1) initial lava flows formed a comparatively steep-sided island

(2) they occurred after the island built up above sea level

(3) during the explosive phase, the intervals between explosions were longer

(4) ejecta were of large dimensions, and there was very little dust

(5) lava plugs (or domes) were forced up into the crater between explosions.

These facts suggest a viscous magma, and that the gas concentration in the magma was less. The activity was probably triggered by luni-solar influence before sufficient gas had accumulated to form a fluid, less viscous magma of the type which was extruded in January, 1957. Although the latter was more fluid, the fact that it flowed above sea level also indicates that the volume of gas was much less than for previous eruptions, and did not develop pressures sufficient for explosive activity and comminution of lava into dust by rapid expansion of the gas.

The main evidence for decline in vulcanism since May, 1955 can be summed up as follows:

(1) major eruptions from subaerial cones in 1954-55 were most strongly explosive; however, after violent explosive activity from Cones 2, 4 and 5 in February and March, 1955, there was a prolonged period of submarine lava extrusion from Cone 6 until about 9th May; in 1956-57 the effusive phase was predominant.

(2) the centres of activity during eruptions between 1953 and 1956 were widely separated; in 1956 the magma body apparently became localised under Cone 2, and activity has been confined to a smaller area.

(3) major eruptions, including those from Cone 1 (submarine), between June, 1953 and May, 1955, were never more than 5 months apart; the only major eruption since May, 1955 commenced in November, 1956, 18 months later.

VI. PETROLOGY

Appendix I contains descriptions of volcanic rocks from Cones 3, 4 and 5 of Tuluman Volcano, from pyroclastic deposits on Lou Island and of a specimen of fumarole deposits from Baluan Island. The specimen from Cone 3 was taken from the lava flow at sea level and that from Cone 4 was from a large bomb on the surface of the island. The first of the Cone 5 rocks described was from ejecta of the last explosive phase in March, 1955; the other was collected from a flow at sea level on the south-west side of the island. Based on their glassy nature and their R.I. of 1.505 all specimens have been classed as rhyolitic.

Two specimens of volcanic glass (Laboratory Nos. 57/39, 40) from Cones 3 and 4 were submitted for chemical analysis; the results of analyses by S. Baker (Bureau of Mineral Resources, Canberra) are listed in Table I hereunder:

TABLE I

	Cone 3	Cone 4
Silicon (SiO_2)	68.67%	67.92%
Aluminium (Al_2O_3)	14.07%	14.16%
Iron (Fe_2O_3)	3.99%	4.80%
Magnesium (MgO)	0.91%	0.65%
Calcium (CaO)	1.85%	1.80%
Sodium (Na_2O)	6.40%	8.34%
Potassium (K_2O)	3.04%	1.17%
Titanium (TiO_2)	0.30%	0.50%
Magnesium (MnO)	0.16%	0.10%
Water (105°C)	0.008%	0.002%
Loss on ignition (800°C)	0.20%	0.35%
	99.60%	99.79%

The norms of these glasses were determined by the method given by Washington (1917). The glass from Cone 3 was determined as Class I (II), Order 4, Rang 1, Sub-Rang 4. Rocks with similar composition listed in this group, with reference numbers, were as follows:

No. 22 Augite Andesite (p.153)
No. 24 Dacite Porphyry (p.153)
No. 30 Biotite Andesite (p.155)
No. 43 Syenite Porphyry (p.157)

The glass from Cone 4 was classified as Class (I) II, Order 4(5), Rang 1, Sub-Rang (4)5. This group contained only two analyses, neither of which was similar to that of the Cone 4 glass. Pyroxene Granitite, No. 26, in the group Class I(II), Order 4", Rang 1(2), Sub-Rang 4(5) had a similar analysis but the norm was different. The main difference in the analyses of glasses from Cones 3 and 4 is the increase in soda at the expense of potash in the glass from Cone 4; this difference resulted in the glass from Cone 4 being classified in a different group to that from Cone 3. Because of the similar mode of occurrence, the glass of Cone 4 might be better regarded as a soda-rich equivalent of the glass of Cone 3. The analysis of dust from Cone 5 given in Reynolds (1955b) shows a similar high silica content (69.41%) but a greater amount of lime (4.86%) than contained in the glasses (1.80 to 1.85%). This suggests that the amount of lime plagioclase in the norm of pumice from Cone 5 would be greater than in the norms of glasses from Cones 3 and 4; the free quartz, however, would be the same or greater in the Cone 5 pumice.

The highly vesiculated, dark-coloured lavas and dense, black glasses formed by Tuluman Volcano were previously considered basic in composition. This was suggested by their appearance and the fact that flows were of the pahoehoe type. Both chemical and microscopic analyses, however, have shown that rocks from this volcano are mainly acid. The samples submitted for analysis were typical of the rocks which occurred on the islands of Cones 3 and 4. Although some were deposited during the explosive phase, they were obviously formed during the effusive phase or, in the case of bread-crust bombs, composed of lava from the same magma zone. This zone was the upper, highly vesiculated portion of the magma column. Gas has been suggested as the source of energy for eruptions of Tuluman Volcano. The rise and accumulation of gas in the magma column between eruptions probably caused pronounced differentiation within the column; this would account for the composition of

the rocks discussed above. There is some evidence that the composition of the magma lower in the column was more basic. The sample from the lava flow on Cone 3 contained a small cognate xenolith of more crystalline rock. Microscopic analysis revealed it to be basaltic andesite with crystals of diopside (see Appendix II).

The only rocks from the old St. Andrew Strait caldera which have been examined by microscope were collected from the thick pumice deposits on Lou Island. A sample from these rocks is classified as trachyte in Appendix I. The lava flows on the parasitic cone which forms Baluan Island have been classified macroscopically as basalts. In view of the results of analyses given, samples of these rocks should be analysed to obtain proper identification. To complete the story of petrology, analyses of samples from the lava island formed by Cone 7 are also necessary. If a reduction in the volume of gas for the eruption of Cone 7 was responsible for the effusive phase predominating over the explosive phase, the magma was probably less differentiated; analysis of samples may, therefore, give a better idea of the composition of the parent magma of Tuluman Volcano.

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APPENDIX I

The following is a report by J. Kerry Lovering on rocks from Tuluman Volcano.

Tuluman Volcano.

Cone No. 3.

The handspecimen is a black pumiceous rock.

The rock consists mainly of fawn-coloured glass which has an R.I. of 1.505. In this glass are microlites of feldspar. Subparallel arrangement of microlites and of elongated vesicles is noted.

The lava is probably rhyolitic in composition.

Cone No. 4. (March 1955).

The handspecimen is very unusual. It consists mainly of very porous rock made up of fine fibres of glassy material. Through this material is a layer with a uniform thickness of one eighth inch, and consisting of black glass. This layer is folded irregularly.

Under the microscope, the fibrous glassy material is seen to consist of numerous microlites in very pale grey glass with an R.I. of 1.505. The numerous vesicles which make up 50 per cent of the volume of the rock, are rounded.

The glass layer consists mainly of microlites tightly packed in a sub-parallel fashion. Glass is interstitial. A few larger microlites are feldspathic and the fine microlites are probably also feldspathic.

The lava is again rhyolitic.

Cone No. 5.

The handspecimen is black and pumiceous.

The rock consists of brown glass with an R.I. of 1.505. The vesicles are rounded.

The lava is rhyolitic according to R.I. of the glass.

Cone No. 5.

The black pumiceous handspecimen has a striking schistose appearance. On one surface the rock appears to have slickensides, in which case the elongation of vesicles is understandable.

The thin section also has elongated vesicles. The rock consists mainly of fawn glass with an R.I. of 1.505. Throughout the glass, incipient crystallisation has resulted in anisotropic blebs. Microlites are also present in the rock.

The lava is rhyolitic.

Baluan Island, Thermal area.

Part of the handspecimen is a white, friable and porous rock with a fan-shaped appearance. At the base of this white rock is a light grey part whose contact with the white has a botryoidal outline; this is followed by a light brown vitreous part.

In thin section the vitreous part is seen to consist entirely of opal with an R.I. slightly less than 1.455. Cracks in the opal are fan-shaped. At the botryoidal edge are accumulations of fine-grained clay. The white part of the rock consists of opal and a little clay.

Lou Island.

This grey, compact and homogeneous specimen is older lava from this region.

A distinct layering of microlites and phenocrysts is noted in thin section. Phenocrysts of oligoclase and magnetite are rare in this rock which consists mainly of feldspathic microlites in a very fine-grained groundmass with interstitial glass. Light-coloured patches in the rock consist of accumulations of feldspathic material with a low R.I. This may be potash feldspar.

The lava is trachytic.

According to curves drawn by George, quoted by Turner, Williams and Gilbert in "Petrography", an R.I. of 1.505 corresponds to 70 per cent SiO_2 in the glass.

Report dated 30th July, 1957.

APPENDIX II

INCLUSION IN LAVA FROM TULUMAN VOLCANO

CONE NO. 3

The inclusion is a black dense and very fine-grained rock. One small crystal embedded in this rock was examined by W.M.B.Roberts by X-Ray techniques and found to be diopside.

A thin section of the rock revealed that it is basaltic andesite. It is composed of microlites of zoned labradorite, granules of diopside which occasionally have rims of pigeonite, and granules of magnetite in a light brown glass whose refractive index is less than Canada balsam, but greater than the glass of the lavas from Tuluman volcano.

J. Kerry Lovering