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AN EXPERIMENT IN VOLCANIC PREDICTION

by

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CONTENTS

SUMMARY

Manam Island, a basaltic volcano situated off the north coast of New Guinea, began a new cycle of activity in December 1956. Intermittent periods of explosive and effusive activity led up to a climactic release of unprecedented magnitude. Although the activity was predominantly of the Strombolian type heavy Pelean clouds were produced during the course of the eruption; some damage to settlement occurred. The inhabitants were removed from the island six weeks before the most powerful eruption.

Prognosis and diagnosis was based on an inference that the volcano's eruptive pattern would follow the open-conduit mode; that stresses from luni-solar gravitational forces and from regional tectonic movement would influence volcanic behaviour. These theoretical concepts were combined with close observational work, tilt and seismic measurements.

The volcano conformed with the open-conduit mode in that its most powerful outbursts came towards the end of the eruptive cycle. All the more important phases of eruptive activity began close to times of minimum or maximum solar declination. During the year preceding the climactic eruptions tectonic earthquakes in the adjacent northern region of New Guinea originated from epicentres which were predominantly coastal and submarine. A similar distribution had been noted to be a prelude to former eruptive cycles. In 1957 some of the earthquake epicentres in the Sepik area, west of Manam, were very close to those which preceded the 1936-37 eruptive cycle. Local seismic movements of volcanic origin were essentially confined to continuous tremor. Fluctuation in the amplitude of these continuous waves preceded some of the eruptions of the climactic series which lasted from December 1957 to March 1958. Tilt measurements indicated a slow build up of pressure beneath the crater area for several months before the climactic phase of release. The first of these eruptions was immediately preceded by an abrupt change of tilt.

A build up in visible manifestations occurred during the two months before the large scale eruptions. Explosive activity intensified, the volume of vapour increased and periods of calm were shorter. The "ashless" Strombolian explosions were replaced by dark-grey convolute jets heavily laden with fragmental material. Brighter luminous effects and the ejection of an uncommon, lightweight, highly gas-diluted scoria preceded the culminating eruption of January 25th.

Early in the eruptive cycle nuees ardentes were produced as small isolated events which closely resembled in appearance the normal collapse of unstable material from the flanks of the cone. These were, however, identified as Pelean in character and attention was drawn to potentially dangerous areas which lay below the four large valleys dissecting the cone. An evacuated village situated in one of these areas was subsequently destroyed in part by a nuee from the eruption of January 25th.

In making an assessment of the eruptive potential of the volcano, in August 1958, the close conformity of the eruptive cycle with the open-conduit mode suggested that the powerful eruptions of early 1958 should mark the end of the cycle. The occurrence of the final eruption of this series

in March close to an equinoctial period gave additional support to this idea; for it seemed that earlier eruptions had ended at such periods and important phases of other volcanic eruptions have ended at times of high compressional tides.

On the theory that time and regional stress are the two main factors governing the magnitude of a volcanic eruption Manam's behaviour was explainable. The occurrence of more numerous earthquakes in the New Guinea region during the years immediately preceding the eruptive cycle suggested that special crustal stress conditions combined with a periodicity of normal duration to produce an eruption of exceptional magnitude. When the volcano ran through a gamut of eruptive activity which conformed with an established mode for its type, it was believed that the volcano had exhausted its immediately available energies. It was suggested that activity in the immediate future would be governed by regional stress developments. Tectonic shocks were continuing in the region and these seemed to provide an explanation for the vigorous post climax activity of June-July 1958. The magnitude and frequency of these disturbances did not suggest an early return to activity which would reach proportions dangerous to the inhabitants of Manam. Reoccupation of the island was recommended.

Manam (lat. 4°S long. 145°E) is an island volcano situated near the western end of the Melanesian volcanic group. It is ten miles from the New Guinea coast and about 500 miles west of Rabaul. The island is inhabited by a few European missionaries and by nearly four thousand native people whose settlements are situated near the coast and within three miles of the crater area.

The volcano has a symmetrical cone rising to a height of about 5,900 feet above sea level: the area of the island is approximately 32 square miles. The cone is of the strato type and consists predominantly of fragmental material which is buttressed by numerous flows and dykes of basaltic lava. The most prominant topographical features are four great radial valleys, or chasms, which descend from the summit area and dissect the cone in azimuths between the cardinal points of the compass. Ejecta from the two summit craters has built up aprons of debris in the heads of the valleys. These aprons have reached such large proportions in the north-western and south-eastern valleys that, in these sectors, they have the appearance of a terminal cone. A southern crater is situated near the head of the south-eastern valley: it is a comparatively small vent which, when seen from the air in 1958, appeared no more than a small depression in the top of the sloping fragmental apron. A main or northern crater is almost U shaped in plan; it resembles a semicircular amphitheatre perched above and opening into the north-eastern valley. The width across the rims is very approximately 1500 feet.

Manam is the most active volcano in the Territory of Papua-New Guinea but the history of earlier eruptions is vague and incomplete. Little is known of the nature or magnitude of earlier outbursts. Fisher (1957) has listed the following eruptions:-

November	1877
	1887
	1888
	1889
	1902
	1910
	1917
11 August	1919
March	1921
Sept-Oct.	1936
15 March	1937
	1946-47

Most of these eruptions are reported to have been explosive, with lava effusion as a minor or major concomitant. Lava flows in 1919 and 1947 were voluminous enough to enter the sea. Destruction of arable land is reported only for the eruption of 1919. Native stories report deaths during the eruption of 1902, but no other casualties are known to the local people. No early record refers to a need for movement of the population from the island during eruptions.

Thus the limited history of the volcano gives an incomplete picture suggesting a mode of relatively mild, intermittent, explosive and effusive, eruptive cycles which are separated by periods of dormancy ranging from one to fifteen years. It is proposed to outline briefly the pattern and nature of the current activity and then to discuss the predictions which had some influence on the Administration's evacuation of the island and thus may have saved loss of life.

THE CURRENT ERUPTIVE CYCLE.

The current cycle of Manam's activity began in late December 1956 after a period of dormancy lasting approximately nine years. During 1957 and early 1958 periods of intermittent explosive and effusive activity led up slowly to a climactic phase of release more powerful than anything known before. The climax was followed by less frequent spasms of explosive activity similar to those which had occurred in the preceding year.

The cycle began with a rhythmical type of Strombolian activity which projected jets of incandescent lava high above the southern crater. At the same time lava flows descended to the base of the debris apron occupying the head of the south-eastern valley. Avalanches were seen descending the flanks of this structure; they were identified as normal collapses of cone material (Reynolds, 1957). This phase of activity lasted about six weeks; the volcano then became quiet.

In April and May 1957 uneasiness of volcanic conditions was manifested by explosive noises from the craters, by small earthquakes, and by some falls of fine ash. In June a more intense phase of explosive activity began and continued intermittently for most of July. Brilliant showers of incandescent lava were thrown above the southern vent and short, viscous lava flows descended about 1000 feet down the flank of the debris apron in the south-eastern valley. After mid-July the activity reached a new peak of intensity, and the focus changed from the southern to the main crater. The Volcano became calm towards the end of July.

During August and September milder spasms of activity deposited light falls of ash over the island. On 18th October intense eruptive spasms produced nuees ardentes voluminous enough to enter the sea below an uninhabited area of the southern slopes. Heavy ash falls from this eruption caused eight houses to collapse in Baliau village on the northern coast. Some native gardens on the northern and north-western slopes were severely damaged and much of the forest was stripped of its branches. Subsequent mudflows buried gardens between Kulugumwa and Iassa and destroyed native bridges on the north-western side of the island.

The level of activity remained high after this eruption. Very frequent spasms of explosive activity from the summit vents distributed ash over most of the island, and for the first time scoria fragments, up to an inch across, fell on the marginal settlements. Vigorous gas emission formed a column of dust and vapour which rose 10,000 feet above the summit before it was swept away, in a long leeward banner, by the prevailing winds. On 17th November a lava flow descended 4000 feet below the southern vent.

This increased activity culminated in a series of powerful outbursts on 6th, 7th and 8th December. The volcano had begun to rumble continuously on 4th December, and the sounds were louder than any heard before. Two days later villages on the eastern coast received a heavy fall of ash and scoria blocks. The largest blocks were 2 X 3 inches, and some of them broke through the roofs of houses in the villages of Aberia and Bokure. More powerful activity occurred the next day, when a number of large nuees ardentes descended the south-eastern valley. Dust and scoriae fell on the northern and western sectors of the island.

The eruption reached a peak on Sunday 8th December. At 10 a.m. the early morning rumbling and ash emission changed to spasms of roaring and to the voluminous ejection of ash and scoriae. For the greater part of the afternoon the northern and western flanks were blacked out by heavy falls of dust and lapilli. The ash rain reached its greatest intensity at Iassa, where the forest was stripped of its branches, gardens were buried beneath three inches of ash and some houses collapsed. Heavy nuees descending from the southern vent destroyed areas of forest and entered the sea below the south-eastern valley.

On 10th December the Administration began evacuating the population of the island to the mainland. The movement of people was completed by the 13th December.

Explosive activity of a reduced intensity went on during the evacuation; the volcano became quiet after 14th December. On Christmas day further outbursts produced nuees which reached the sea near Waris village on the north-eastern flank. Towards the end of the December noisy explosive activity was resumed with a heavy low-pitched booming which caused buildings on the island to rattle and shake. The summit cloud one again became luminous at night.

The January activity consisted of a series of powerful eruptions which led up to a culminating outburst of unprecedented magnitude. Early in the month vigorous spasms of ash and gas release were followed, on the 10th, by a powerful outburst which ejected nuees from the main crater and poured a heavy lava flow down the north-eastern flank. An eruption of greater magnitude followed four days later, when more voluminous lava outpourings from the main crater reached a point within half a mile of the sea. Vigorous ash and scoria ejection followed this eruption and then, for a few days before the culminating outbursts of the 25th, crater activity almost ceased.

At 0605 hours on the 25th January the inactive southern crater started silently to emit ash and vapour. An hour and a half later the main crater became active. At 0800 hours nuees ardentes were expelled onto the south-eastern slopes, and within a few minutes the roar of a full-scale eruption could be heard all over the island. A towering column of vapour and ash rose to more than 30,000 feet and was carried towards the west by the high altitude winds. For the next five hours the column was fed by incessant explosions roaring and rumbling from the summit vents.

Activity fluctuated but was always on a gigantic scale. Near midday the emission reached a new peak of intensity. The main crater began roaring like an enormous blow lamp and huge blocks were ejected as far as the forest margins on the northern slopes. So great was the pressure of this emission that a phenomenon resumbling flashing arcs was seen for more than half an hour; barometric readings on the island were impossible.

Heavy nuees ardentes were expelled during the course of this eruption. These gravity-controlled avalanches of hot fragmental material came down the four great valleys dissecting the cone. The nuees from the southern crater were voluminous enough to enter the sea below the south-eastern and south-western valleys. Part of the evacuated village of Budua was completely destroyed and new areas of forest were annihilated.

Falls of lapilli and scoria blocks did extensive damage to arable land. Much of the western side of the island received deposits of coarse ejecta, which, on the coast, were not less than five inches in depth. A considerable proportion of this deposit was thickened to a depth of not less than twelve inches by the eruption in February.

The February event, on the 3rd, took place in poor visibility, with heavy rain falling on parts of the island. The peak period of this outburst occurred between 0430 and 0730 hours, when loud roaring was heard from the cloud-concealed summit. Voluminous quantities of fragmental and molten material were discharged and powerful nuees swept down the south-eastern slopes: the nuees on this occasion overrode the lower flanks of the south-eastern valley and destroyed additional areas of forest.

The March eruption ended a period of comparative calm. It began at 1415 hours on the 4th and was the most sustained event on record: it lasted for more than 24 hours. The types of eruptive phenomena were similar to those of the previous major outbursts, but, on this occasion, effusive activity seemed predominant.

Some nuees descended the south-eastern valley during the initial stages of the eruption. They were blocky avalanches, less mobile than previous ones. Although they came down close to the coast, none of them entered the sea. The scoriae and lapilli falls were distributed over the eastern slopes and a narrow zone of country was severly affected. Thicknesses of up to six inches on the coastal area were recorded.

The dominant effusive activity took the form of a heavy lava flow which descended quickly to the foot of the debris apron at the head of the south-western valley. Here on gentler slopes, it fanned out into a broad advancing front about half a mile wide. For a time it moved down as a broad lava field and then more mobile tongues broke away from the main body. On 6th March one of these flows entered the sea, the first such entry during the current cycle of activity.

The volcano's activity was greatly reduced after this eruption. The long banner of vapour which drifted from the summit during most of the previous period was reduced to a thin cloud which rarely passed over the margins of the island. Except for very mild explosive activity at the end of April and light dust emission during May the volcano remained quiet until the end of June.

The late June recrudescense introduced a new phase of activity which had many characteristics of the same period of the previous year. Heavy gas emission was accompanied by rhythmical explosions which projected jets of brightly incandescent lava above the southern crater.

Noises were a conspicuous feature of the activity. They ranged from barely audible rumbling to deep-booming and bomb-like explosions which caused air and ground vibrations. The sounds were loudest towards the end of the active phase, late in July, when they could be heard at many places on the mainland.

Ash was emitted for most of the following month and explosions were resumed during the last few days of August and the first week of September. Subsequent activity of the volcano has followed a fluctuating pattern with spasms of increased vapour and dust emission and periodic explosive outbursts. These eruptive spasms have been of comparatively low intensity.

PROGNOSIS AND RECOMMENDATIONS.

In 1955 it was suggested that when evidence of certain local regional stress conditions was forthcoming Manam would become active again and that the next eruption would be severe. The establishment of a permanent vulcanological station on the island was recommended.

After the new cycle of activity began in December 1956 it was believed that the volcano would build up slowly to a climactic stage of release. In April 1957 special concern was expressed to the Administration regarding future developments at Manam. Plans to establish an Observation Post on the island were made in anticipation of a new phase of activity in June.

In June 1957 attention was drawn to the fact that although the eruptive activity was predominantly of the normal explosive type one observation showed that the volcano was capable of producing nuees ardentes.

Early in November it was pointed out to the Administration that the volcano was building up to a phase of climactic release. It was suggested that this culminating phase would occur in December-January 1957-58 or June-July 1958.

The October eruption had indicated clearly the capacity of the volcano to produce powerful nuees ardentes. It was suggested that the areas situated below the four great valleys which dissect the upper cone of Manam were the most vulnerable to lethal effects. At the same time it seemed that these valleys offered the main safeguard to the island settlements in that they would contain the gravity-controlled nuees ardentes. It did not seem probable that the volcano with its present pattern of activity would produce nuees powerful enough to override the obstacles constituted by the valley walls.

At the conclusion of the November observations warning was given that the potential of the volcano was rising slowly.

The Administration sought advice on the probable course of events following the eruption of 8th December. The opinion was expressed that the outburst did not constitute a climax and that more powerful activity was to come. The immediate movement of the Budua village people was recommended.

At this point the Administration moved the whole population of the island to the mainland, the evacuation being completed by the 13th December.

After the major eruptions of January and February the question of the return of the people to Manam arose. It was suggested that a further eruption might occur in March and the most likely period for its occurrence would be during the first week of that month.

It was also suggested that renewed explosive activity would occur in June and that it would be as well to observe the scale of this activity before recommending the return of the inhabitants.

At the end of July 1958 an assessment of the factors governing the eruption led to the conclusion that further major eruptions were unlikely. Reoccupation of the island was recommended.

DIAGNOSIS.

The problem of diagnosing Manam's potentialities was based upon ideas which showed promise when applied to other eruptions studied in the Territory of Papua - New Guinea and in the New Hebrides. Stated in its broadest terms, the approach was dependent upon an appreciation of the importance of external forces on a volcanic energy system, combined with the recognition of an inherent mode in the volcano's behaviour. These factors were supplemented by both instrumental data and a close study of the course and nature of the eruptive activity.

The Mode.

Although incomplete, Manam's earlier history did suggest that frequent and effusive eruptions of relatively low intensity and sometimes of protracted duration were characteristic of the volcano's activity. The fact that specific months were given for some eruptions suggested that something in the nature of climactic outbursts had occurred in the course of individual eruptive cycles. These observations, in combination with the fact that the volcano produced a basaltic lava, indicated affinities with the

Vesuvian mode and with Perret's classical open conduit system (1924). It was therefore expected that the new cycle of activity would build up slowly to a culminating point of climactic release. Experience of Ambrym volcano in the New Hebrides (Taylor, 1952) suggested that the climactic phase might take the form of a series of paroxysmal eruptions rather than a single outburst of Plinian magnitude. This observation helped to give warning of the Manam outbursts subsequent to December 1957.

Regional Stress.

A theory that regional stress, as manifest in the occurrence of tectonic earthquakes, may influence volcanic behaviour was applied to Manam. This idea was derived from a study of the New Hebrides volcano Ambrym which produced an eruption of exceptional magnitude in 1950-51 after a normal short-period dormancy (Taylor, 1952). In the year immediately preceding the eruption the number of regional eathquakes increased markedly and most of them occurred west of the linear island group in a zone containing an adjacent island deep. During the actual eruption, which lasted almost a year, the number of tectonic earthquakes in the New Hebrides region decreased and the epicentres were distributed predominantly in the plane of the island chain itself (Taylor, 1956). It was submitted that these tectonic movements were indicative of a regional stress condition which influenced the behaviour of the volcano.

A preliminary analysis, made in 1955, of the occurrence of earthquakes in the Territory of New Guinea suggested that the number of shocks had begun to increase in 1949 and shocks continued to be more numerous in the succeeding years. Along with this increase came reactivation of long dormant volcano centres such as Mount Lamington, Mount Langila, Tuluman and Long Island. Manam volcano, which has the name of being the most active volcano in the Territory, remained anomolously quiet. After examining the distribution of earthquake epicentres in former years it was suggested that a severe eruption from Manam could be expected when earthquake distributions in the northern region of New Guinea moved to epicentres of predominantly coastal and submarine origin. This distribution did in fact take place in 1957, the year leading up to the climactic outbursts. One strong 1957 earthquake in the Sepik area west of Manam originated from an epicentre very close to that of a notable shock which occurred a year before the severe eruption of 1936.

It was concluded that the current eruption was related to a general condition of regional crustal instability. An eruption of unusual magnitude had followed an increase in the number of regional earthquakes. Both phenomena appeared to be related to a common condition of crustal stress, but the suggestion that the magnitude of the eruptive activity reflected the magnitude of the stress condition manifest in the background seismic activity was made with qualifications. Seismic and volcanic events do not lend themselves readily to quantitative treatment, and the theory needs much closer study.

Applying the theory broadly, one could see reassuring points in the situation in August 1958. It was believed that the background regional seismic movements associated with the current eruption did not approach in magnitude the disturbances which occurred in this northern region o_ New Guinea towards the end of the last century, when seismic disturbances were so great that several mainland villages were reported to have been wiped out by tidal waves caused by submarine earthquakes, and massive landslides occurred in the coastal ranges (Miklouho-Maclay, 1885). Large-scale eruptions, including the catastrophic eruption of Ritter Island, followed these extraordinary earthquakes. The less intense regional disturbances associated with the current cycle of eruptive activity gave grounds for expecting an early decline in activity rather than further extraordinary outbursts.

In the New Hebrides in 1951, the year of Ambrym's large-scale eruptions, the number of regional shocks decreased. Admitting the inadvisability of comparing conditions in two different structural environonments, it seemed important to note that there was no clear evidence of a downward trend in regional seismicity for northern New Guinea in the year 1958. Shocks were more numerous from inland epicentres, a distribution associated with earlier periods of dormancy, but at the same time some of the earthquakes were associated with tectonic movement in the Sepik area, which could be interpreted as a contrary indication of a return to dormancy.

Luni-Solar Influence.

F.A. Perret (1950) records many instances suggesting a relationship between volcanic activity and the gravitational forces of the sun and moon.

Study of eruptions in New Guinea has given strong support to this conception and has emphasised certain aspects of the relationship which seem particulary applicable to volcanic activity in these latitudes. The luni-solar tidal force is made up of a number of periodic components which are governed basically by the rotation of the earth, the orbit of the moon around the earth, and the annual movement of both around the sun. Neglecting orbital irregularities for the sake of simplicity, there are short-term maxima at the syzygies. Long-term maxima are associated with the apparent passage of the sun back and forth across the equator. The pulling body exerts its maximum tidal force for any particular latitude in the tropic zone when it is directly overhead, that is, when the declination is appropriate for that latitude. The zenithe position produces a compressional tide in the crust, for, if the pulling body is at an angle to the location, there will be a lateral component in the pulling force which will produce tensional effect. Thus the characteristics of the luni-solar phase tide will depend essentially on the declination of the respective bodies. We may therefore expect to find in volcanic behaviour evidence of short-term responses connected with lunar phase and declination, and long term or "seasonal" responses connected with solar declination. For New Guinea latitudes tensional tidal effects will be greatest at the times of the solstices, when the sun is over the respective northern and southern tropics, and the compressional tides will be greatest near the equinoctial periods.

The Mount Lamington eruption (Taylor, 1958) began during the southern summer at a period of tensional tides when both solar and lunar declinations were high; the early climax came two days before the full moon. The intense explosive phase of this eruption ended at a period of high compressional tides soon after the sun had passed the zenith for this latitude. A new phase of activity began in June when tensional forces were again high.

The activity of other centres also provided examples of the seasonal tensional effect. In the first week of June 1955, Bam, Long Island, Langila, and Tuluman volcanoes responded with explosive outbursts to the tesional maxima of that period (Taylor, 1955). Four of the five eruptive phases of Langila in 1954 began at times of high lunar declination (Taylor et alia, 1957). The new phase of explosive activity of Long Island Volcano, which began on 5th June 1955 at the time of maximum lunar declination, climaxed and blew itself out a few days later when the moon moved to its zenith position for that latitude. This short-period lunar effect is comparable on a small scale to the longer-period solar effect.

This body of evidence suggested that Manam's pattern of activity would be related to luni-solar dispositions, and as a result it has been possible to forecast the major phases of the eruption largely in the light of this theory. The establishment of an Observation Post was delayed by other commitments and the project was not realized until early June 1957. However, this enabled a close study of the expected new phase of activity, which arrived with the tensional conditions of the mid-year solstice period. An equinoctial response followed in October, when an eruption produced heavy nuees ardentes from the southern crater and paradoxically caused greater damage to settlement on the northern side of the island. Warning was given of the possibility of major activity of the December-January period, when once again tesional conditions of the summer solstice would be favourable for a new phase of activity. The warning was repeated for March when again the volcano responded to the compressional tides of the equinoctial period with a major eruption, and the anticipated new phase of activity duly arrived in June.

Thus the broad pattern of Manam's activity appears closely related to the chief long-period component of the luni-solar tractive force, namely the component whose characteristics are governed by the seasonal changes in solar declination. The eruptive cycle began in December 1956 during the tensional conditions of a solstice period and new phases of activity began close to each of the subsequent solstices. Marked eruptive responses also occurred at two of the three equinoctial periods when compressional tidal forces were high.

The expectation and forecast that eruptive potential would wane during the first half of 1958 was governed to some extent by luni-solar considerations. Lamington set a pattern for a volcanic energy system with a large-scale eruptive potential in that its phase of highly explosive activity began under tensional and finished with a major outburst under compressional conditions. Despite marked differences in mode and volcanic characteristics some evidence suggested that a similar response could be expected from Manam when it reached the critical stage of large-scale energy release. When the actual month of the year was known for past eruptions the solstices were excluded; in three instances out of five these events occurred close to the times of the equinoxes and the other two events were unspecific. It was suggested that this distribution could be interpreted to mean that given a critical build-up of potential, exhaustion of the greater part of the volcano's explosive energy was most likely to occur under compressional conditions such as those which had obtained during

March 1958. Support for this interpretation was suggested by observations made by inhabitants who witnessed earlier eruptions. They claimed that eruptive phases began and ended within the south-east season (May to November), again suggesting a tensional beginning and a compressional end to important eruptive periods.

Before leaving luni-solar considerations it is probably of interest to note an additional instance suggesting influence of the solar component of the tidal force. The phase of catastrophic eruptions at Mount Pelee in 1902 lasted for four months. It began in May and ended in August, the two months of the year when solar declination was in a zenith position for those latitudes.

Local Observations.

It is not easy to appreciate the significance of visible volcanic manifestations, particularly in relation to the primary survey of a volcano with little local precedent for guidance. Nevertheless observations did constitute a helpful index to potential.

The climax period in early 1958 was preceded by three months of increased activity. Although deceptive periods of calm intervened between the more powerful spasms of eruptive activity, the scale of the total output exceeded in magnitude the earlier events of 1957. Voluminous gas emission was a prominent feature of the pre-climax period even in the absence of explosive activity. Total gas emission decreased to small proportions only after the March eruption, and this development was regarded as evidence of a waning potential. Sudden diminution of gas emission during the climactic period was sometimes the prelude to a great eruption. This certainly occurred before the January and March eruptions and it has been observed as a feature of eruptions at other volcanoes (Taylor, 1958).

In November 1957 an interesting change was observed in the texture of the clouds from the rhythmical jet-like explosions which constituted the dominant form of the volcano's activity. In June 1957 these spear-headed projections had risen and expanded into clear showers of luminous fragments and the associated fume was quite translucent. In November, however, the columns changed into turbulent masses of opaque ash cloud and only the marginal fragments were visibly luminous. This was believed to be due to secondary disintegration of the discharged fragments and the development was identified as evidence that the gas charge in the conduit lava was increasing.

Sounds from the craters were broadly related to the volume of the emission cloud, although many individual loud explosions were heard without visible evidence of a change of emission. Sometimes new phases of rhythmical explosive activity were initiated by extremely loud explosive noises which reverberated like rolling thunder. Deepseated booming explosive noises of a very low pitch preceded the January climax by several weeks, but similar less pronounced noises at a later stage of the eruption were not followed by a major increase in activity. For several days immediately before this eruption a continuous rumbling from the main crater was heard. This noise was so low-pitched as to be near the lower limit of the audible range. Similar low-pitched noises have preceded major volcanic events at Vesuvius (Perret, 1924) and Hawaii (Macdonald, 1957).

The most common noises at Manam were discrete explosive sounds associated with intermittent jets. They were characteristic of the volcano's activity up to early April 1958, but from that time until late June prolonged roaring noises were common and for long periods the vents were quiet. Sharp detonations and clanging, metallic explosive noises returned with the new phase of activity in June-July. Crater noises since then have become less and less frequent.

A lead to temperature conditions in the conduit lava was given by luminous effects at night and by the nature of the ejecta. Particularly brilliant incandescence was noted in the eruptive activity which preceded the January climax and the scoriaceous lapilli thrown out during this period were glassy and iridescent and more gas-dilated than previous material. Perret (1935), when discussing the potential of Mont Pelee in 1930, observed that the prescence of incandescent lava in the crater is always indicative of a high eruptive potential. He was referring at that time to an andesitic lava, and it did not seem relevent to apply such a generalization to the more basaltic, more readily fusible, lava of Manam. Much of Manam's minor activity was accompanied by incandescence, and therefore no particular significance was attached to the brilliant luminous condition of the lava during June-July period of 1958.

Instrumental Data.

During most of the 1957 observations instrumental data at Manam were limited to readings from a low magnification (x10) earthquake recorder and a single-component bubble-type tiltmeter. In mid-December 1957 a portable Willmore seismograph was set up on the northern side of the island and continuous recording was maintained until August 1958. The interpretation of the results was problematic.

At Lamington, discrete earthquakes were predominant and a miscroseismic oscillation was subordinate, being confined essentially to the phase of highest explosivity. At Manam discrete earthquakes were uncommon and a strong continuous miscroseismic movement was characteristic of the whole observation period from December to August. Peak amplitudes in this persistent "harmonic tremor" coincided with the major eruptions. Only during the December and January eruptions was seismic movement of the harmonic type great enough to be detected by the low magnification mechanical recorder.

During the first few months of recording with the Willmore, the imminence of an eruption was indicated by fluctuations in amplitude or seismic intensity. After the March 1958 eruption, fluctuations occurred without an eruptive response. As a similar lack of correlation between seismic and eruptive activity had occurred during the waning stages of the Lamington eruption this development was suggested to be possible symptomatic of waning potential. When potential is high and a nice balance exists between the eruptive and restraining forces all that is required to trigger the system into eruption is a movement at depth or, as has been demonstrated, a change in an external force of luni- solar origin. When the forces are no longer critically balanced these disturbing influences have no immediate effect.

Tiltmeter readings on the eastern flank of the volcano were, in one respect, comparable with seismic trends; the early movements had a diagnostic significance and later movements seemed unrelated to eruptive activity. In August

1957 tilt readings began a slow upward trend leading to abrupt movement and the powerful eruption early in December. During the December-March period of major eruption the tilt trend fluctuated and showed a general tendency to level out. After March some fluctuations without eruptive activity occurred but generally the readings maintained a high essentially static level. Marked changes in tilt were not associated with the mid-year activity of 1958 and minor subsequent movements appeared to bear no important relation to eruptive activity.

The interpretation of both tilt and seismic data was handicapped by lack of basic data on the normal movements associated with quiet volcanic conditions.

Nuees Ardentes.

Reference to the production of nuees ardentes from basaltic volcanoes is rare. Lacroix (1904) records an instance in his monograph on Mont Pelee, and Hantke (1951) notes that glowing clouds had been observed during a previous eruption of Manam. Special attention was therefore paid to this aspect of the observations.

Early manifestations were small isolated events which occurred between or during phases of "Strombolian" activity. It was easy to mistake them for normal avalanches of fragmental material from the cone (Reynolds, 1957). The first nuee to be identified occurred in June 1957. It was produced by a "soft" explosion from the southern crater, and an avalanche of hot fragmental material swept down the slopes and set fire to trees on the margin of the south-eastern valley. The dust and vapour cloud rising from this avalanche was diffuse; it lacked the closely convolute appearance which identifies the nuee of elevated temperature and high gas content. The cloud resembled in appearance the low-grade nuees which descended from the flanks of the dome at a late stage of the Lamington eruption (Taylor, 1958).

Manam's October (1957) eruption produced more powerful nuees which were mobile and voluminous enough to reach the sea. Considerable forest areas below the south-eastern valley were destroyed. This eruption removed any doubts concerning the capacity of the volcano to produce large-scale nuees ardentes. It was necessary to assess the probability of even more powerful nuees and their possible danger to settlement on the island.

Experience at Lamington had shown the importance of major topographical obstacles in influencing the distribution of nuees. Here only the paroxysmal eruptions of exceptional magnitude had produced nuees powerful enough to override major topographical features. Manam had no protracted period of dormancy nor did the nature of the regional earthquakes suggest a background for an outburst of Plinian magnitude.

In addition to these factors the predominant mode of the volcano seemed to have more affinity with Vesuvius than with the types of volcanoes which characteristically produced Pelean clouds. It was concluded that the four valleys dissecting the cone of Manam would confine the nuees, and only on the south-western slopes was settlement in a vulnerable position.

Conclusions.

From a mild beginning in December 1956 Manam's current eruptive cycle built up with intermittent spasms of explosive and effusive activity to a phase of major eruptions whose magnitude appeared to be without precedent in the short and incompletely known history of the island. This gradual build-up to very powerful eruptions resembled the classical open-conduit pattern in which the climax occurs near the end of an eruptive cycle.

The peak intensity was reached with the eruption of 25th January 1958. The subsequent major outbursts in February and March were weaker and lasted longer; and the seismic activity associated with these was correspondingly less pronounced. A notable development was the predominatly effusive nature of the March event. The Manam people had a belief that the activity would end when the lava reached the sea, which it did in March. It would seem that some of Manam's earlier cycles also ended with an effusive phase.

Study of the eruptive pattern in relation to luni-solar forces suggested that the highly explosive phase might end at an equinoctial period when compressional tides were high. The limited history and the observations of local inhabitants tended to confirm this view.

Considerable evidence thus pointed towards a downward trend and suggested exhaustion. But this conclusion needed qualification. The renewed activity of June-July, although mild in comparison with preceding eruptions, seemed to have affinity with the vigorous activity of the corresponding period of 1957 rather than to represent the dying end-phase of the cycle.

Abundant gas was emitted and the spasms of explosive activity took the form of the rhythmical and brightly glowing jets which characterized the build-up period of the previous year. This development suggested the possible existence of a special factor which was overriding the "normal" pattern of the volcanic cycle.

Perret's classical closed conduit and open conduit patterns with their most intense activity at the beginning and end of their respective cycles presupposes volcanic energy systems to be isolated units in which the cooling history of a magma was the key to the motivating power. An insistence in such a conception on the importance of the time factor is understandable, for the accumulation of gaseous energies under such circumstances is probably slow.

Although the time factor seemed to be of prime importance in regard to the scale of activity of some volcanoes there was strong evidence to suggest that with others regional stress was the dominant factor governing the magnitude of an eruptive cycle. It is submitted that Manam's current cycle belonged to this latter category. The unusual magnitude of the eruption is believed to be due to unusual regional stress which superimposed its influence on the normal periodicity factors governing the volcano's activity.

A persistence of tectonic earthquakes in the region adjacent to Manam suggested that unstable stress conditions still obtained. This may have accounted for the nature of the renewed explosive activity, but it did not necessarily indicate a return to activity on a scale similar to that which had occurred during the previous twelve months.

It is suggested that the energy available for the eruptive cycle was probably derived from inherent accumulations which had taken place since the last cycle, plus energy made available by the application of abnormal regional stress. The apparently "conventional" pattern of the energy release with its build up to a phase of climactic release and the signs of subsequent exhaustion suggested that the "accumulated" energy had been used up and thus one prime contributing factor to the energy system had been eliminated. It followed that the residual eruptive energy in Manam was largely dependent on the dynamics of regional stress.

Regional seismic movements were continuing in the area, and associated with them was the renewed explosive activity which began in June. The scale of neither manifestation reached proportions which could be considered as indicative of exceptional developments from Manam. There was no suggestion that the regional seismic disturbances were comparable in magnitude with those of the last century, when eruptions of exceptional magnitude and duration occurred.

It was therefore concluded that although a continuation of activity seemed probable there was no present evidence to suggest that it would reach dangerous proportions.

REFERENCES.

Best, J.G., 1953 - Report of investiation of volcanic activity Manam Island T.N.G. April 1953 Bur. Miner. Aust. Rec. 1953/68 (unpublished)

1956 - Investigations of recent volcanic activity in the Territory of New Guinea. Proc. 8th Pan Pacific Sci Congr. Manila 1953 Vol. Il (Geology and Geophysics; Meteorology) p.150

Fisher, N.H., 1957 - Catalogue of the Active Volcanoes of the World including Solfatara Fields, Pt. V:Melanesia Int. Volc. Ass., Napoli.

Hantke, G., 1951 - Ubersicht uber die vulkanische Tatigkeit. 1941 - 1947 Bull. Volc. Ser.ll Tome XI.

Lacroix, A., 1904 - La Montagen Pelee et ses eruptions. Paris Masson.

Miklouho-Maclay, N.de 1885 - On volcanic activity on the island near the north east coast of New Guinea. Proc. Linn. Soc. N.S.W. 9,4,963-967

Macdonald,G.A.,Eaton,J.P. 1957 - Hawaiian volcanoes during 1954. U.S. Geol.Survey Bull. 1061-B

Perret, F.A. 1924 - The Vesuvius eruption of 1906. Publ. Carneg. Intn. Wash.,339

1935 - The Eruption of Mount Pelee 1929-1932. Ibid., 458

1950 - Volcanological observatins. Ibid., 549

Reynolds, M.A., 1957 - Eruption of Manam volcano, Territory of New Guinea, December, 1956 - February 1957. Bur. Miner. Resour. Aust Rec.1957/43 (unpublished)

Taylor, G.A., 1952 - Report on volcanic activity on Ambrym Island. Bur.Miner.Resour.Aust. Rec.1952/4 (unpublished)

1955 - Review of volcanic activity in the Territory of Papua-New Guinea, the Solomon and New Hebrides Islands. 1951-53. Bull.Volc.Ser.ll Tome XVI

1955b- Report on Bam Island volcano and an inspection of Kadovar and Blup Blup. Bur.Miner.Resour.Aust. Rec.1955/73(unpublished)

Taylor, G.A., 1956 - Tectonic earthquakes and recent volcanic activity. Bur.Miner.Resour.Aust. Rec.1956/123 (unpublished)

1957 - Vulcanological Report - July. Adm. Terr. Papua and New Guinea. (unpublished)

1958 - The 1951 eruption of Mount Lamington, Papua. Bur.Miner.Resour.Aust. Bull.38

1958a- Notes on the current eruption of Manam. Bur.Miner.Resour.Aust. Rec.1958/67

1958b- The eruptive trend of Manam Volcano. Bur.Miner.Resour. Aust.Rec.1958/73

Taylor,G.A.,Best,J.G.,Reynolds,M.A.,1957 - Eruptive activity and associated phenomena, Mt. Langila, New Britain. Bur.Miner.Resour.Aust.Rep. 26

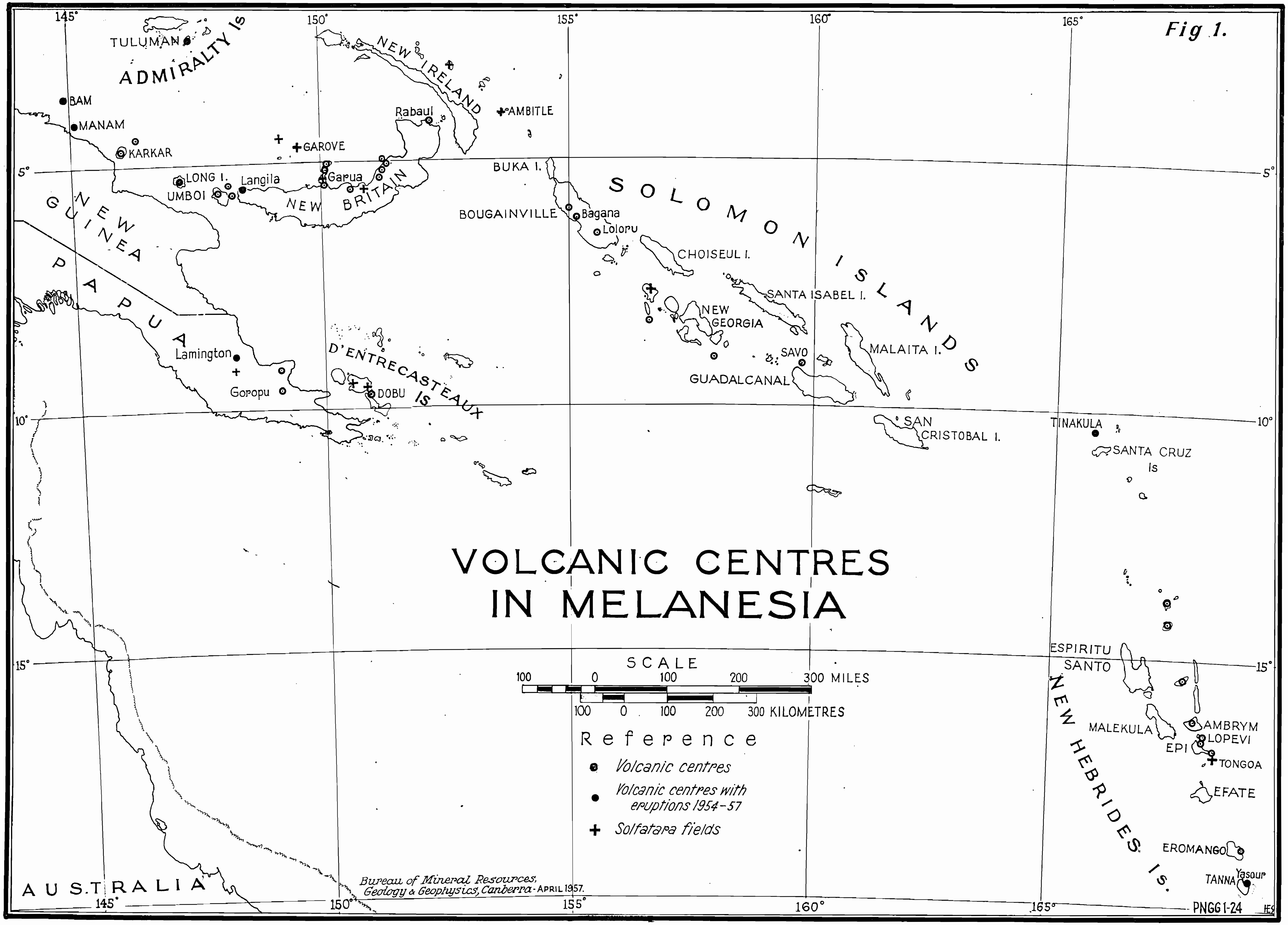
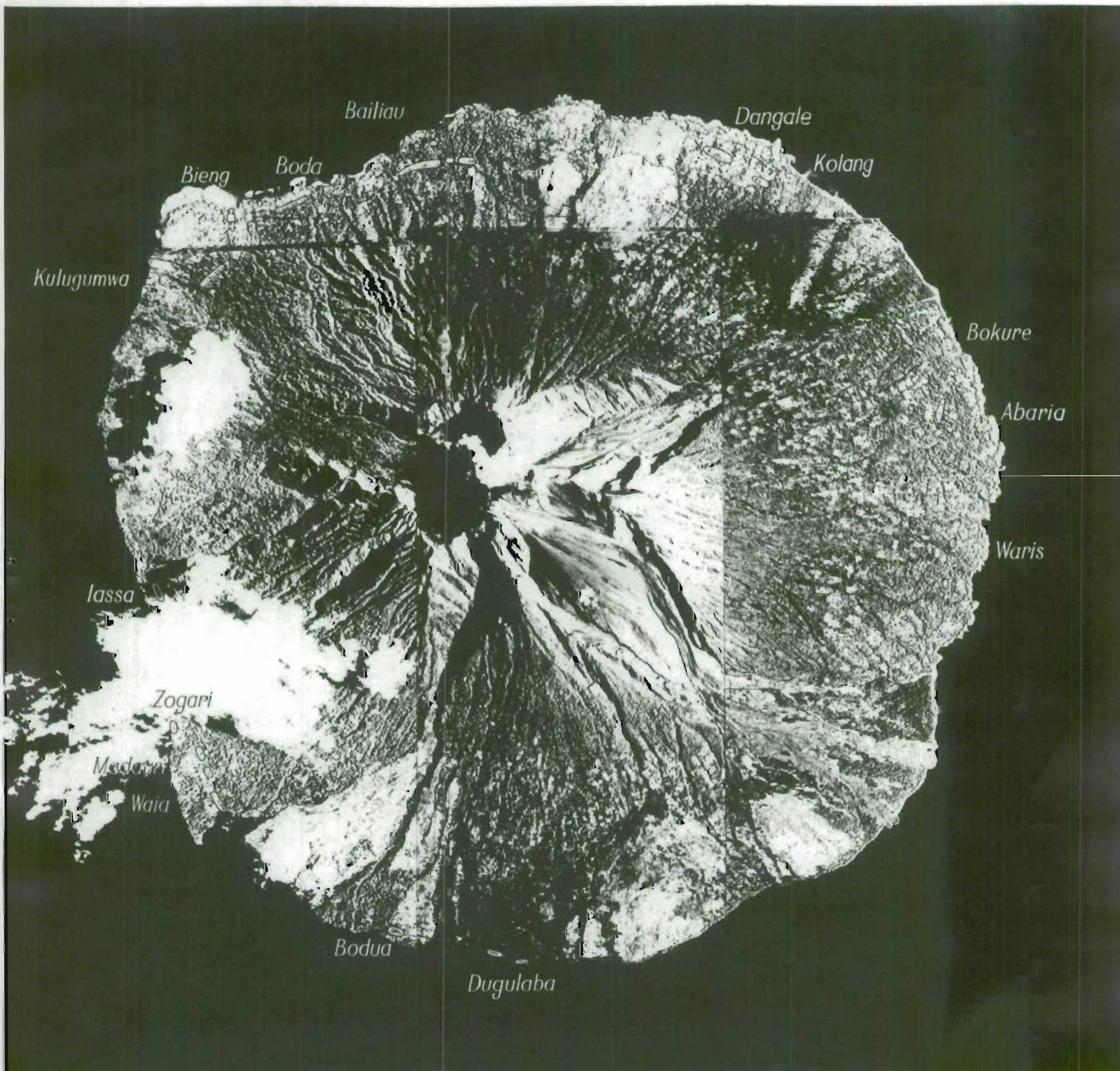


Fig 1.
VOLCANIC CENTRES IN MELANESIA
145°
150°
155°
160°
165°
5°
10°
15°
TULUMAN
ADMIRALTY IS
BAM
MANAM
KARKAR
NEW IRELAND
Rabaul
AMBITLE
GAROVE
LONG I.
UMBOI
Langila
Garua
NEW BRITAIN
BUKA I.
BOUGAINVILLE
Bagana
Loloru
SOLOMON ISLANDS
CHOISEUL I.
SANTA ISABEL I.
NEW GEORGIA
MALAITA I.
SAVO
GUADALCANAL
SAN CRISTOBAL I.
NEW GUINEA
PAPUA
Lamington
Goropu
D'ENTRECASTEAUX IS
DOBU
TINAKULA
SANTA CRUZ Is
ESPIRITU SANTO
NEW HEBRIDES IS.
MALEKULA
AMBRYM
LOPEVI
EPI
TONGOA
EFATE
EROMANGO
TANNA
Yasour
AUSTRALIA
SCALE
100 0 100 200 300 MILES
100 0 100 200 300 KILOMETRES
Reference
Volcanic centres
Volcanic centres with eruptions 1954-57
Solfatara fields
Bureau of Mineral Resources, Geology & Geophysics, Canberra - APRIL 1957.
PNGG 1-24

PHOTO INDEX MANAM ISLAND

NEW GUINEA



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