COMMONWEALTH OF AUSTRALIA.

DEPARTMENT OF NATIONAL DEVELOPMENT.

BUREAU OF MINERAL RESOURCES
GEOLOGY AND GEOPHYSICS.

RECORDS.

RECORD 1958/73

THE ERUPTIVE TREND OF MANAM VOLCANO

by

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Plate : Rough sketch showing thickness of ejecta Manam (Volcano) Island.

Scale: 1 mile to an inch

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INTRODUCTION

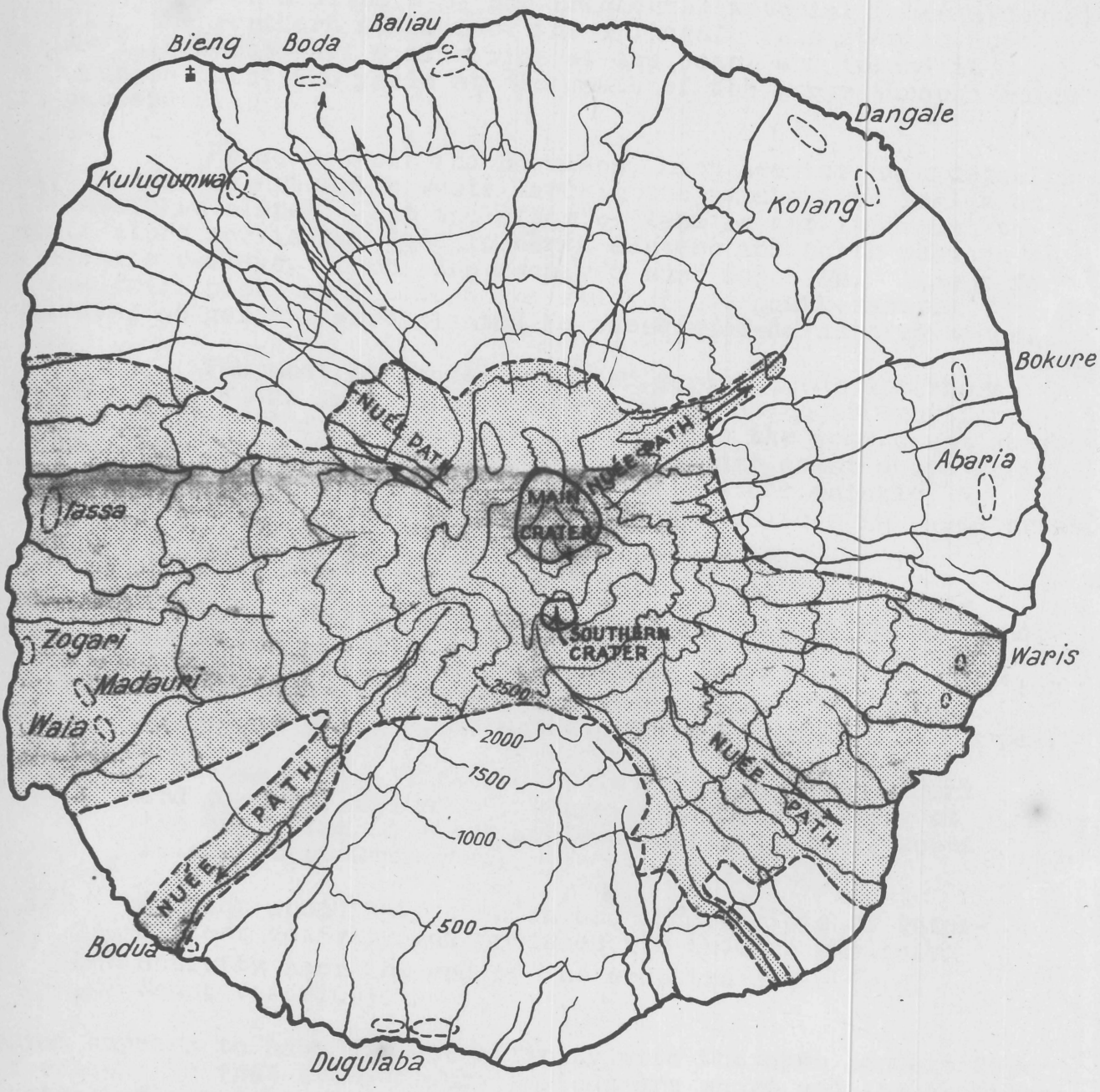
Assurances were given early in the year that there were grounds for believing the intense activity of Manam would wane and that return of the greater part of the population may be possible after the mid-year period. A decline in eruptive activity has indeed taken place. Between March and June emissions sank to a low ebb and the anticipated mid-year increase in activity has produced mild intermittent outbursts in contrast to the powerful eruptions of the first three months of 1958.

The new phase of explosive activity began towards the end of June and, throughout July, eruptive conditions have been similar in many respects to those obtaining in June, July 1957. Although neither this development nor the prevailing seismic activity are reassuring indications of an early end to the eruptive cycle, it is believed that there is insufficient evidence in these factors to justify keeping the bulk of the Manam population on the mainland. It is proposed to review briefly the current extraordinary eruptions and to advance reasons for considering that a decline in eruptive potential is to be expected.

Manam produced major eruptions during each of the four months December 1957 to March 1958. The material ejected by these outbursts wiped out areas of forest, buried extensive areas of garden land, completely destroyed part of one village and severely damaged other settlements. An indication of the severity of the eruptions can be gained from a brief tabular summary of the effects on villages, most of which are situated on, or very near the coast.

Village	Population	Total thickness of ejecta in inches.	Destruction of Houses. Slight	Mod.	Severe.
			< 5%	< 20%	< 50%
East Coast					
Waris	70	c 12			x
Aberia	176	2-3	x		
Bokure	179	2-3	x		
North Coast					
Kolang	184	1-2	x		
Dangale	225	1-2	x		
Baliau	649	3-4		x	
Boda	334	3-4	x		
Kulugumwa	410	4-5	x		
West Coast					
Iassa	404	12		x	
Zogari	326	10-12		x	
Madauri	116	10-12		x	
Waia	213	10-12		x	
Budua	147	2-120+			x
South Coast					
Dugulaba	270	1-2	x		
	3,908				

MANAM ISLAND



Thickness of ejecta 10 inches or more.

SCALE OF MILES

1 0 1 2 3

Bureau of Mineral Resources, Geology & Geophysics. Sept 1958.

PNG.5J-1 GAT IES.

The depth of the ejecta is an estimate of the amount of material which has been deposited in the villages; the deposits increase in thickness inland. The deposits in Budua are unusually heavy due to an avalanche of hot fragmental material (nuée ardente) burying the northern section of the village. This sterile nuée deposit is about half a mile wide at the coast and inland it narrows to about 200 yards at the mouth of the gorge through which it descended.

Between Waris and Dugulaba, much heavier nuée deposits have formed an extensive waste land in the uninhabited region on the southern slopes; but the affected land is not important to agriculture nor is the land in north eastern and north western avalanche valleys, which also received nuée deposits. Except for a few small plots on the Dugulaba side of the south-eastern valleys, no gardens were planted in these nuée-devastated areas.

The most seriously affected garden lands are those which received the great cinder deposits of the major eruptions. A foot or more of fragmental material fell on the west coast above Iassa, Zogari, Waia and Madauri and on the east coast above Waris. Much of it is coarse cinder which may not weather quickly, a property which will temporarily prohibit agriculture in these areas.

THE MODE OF THE VOLCANO AND FUTURE PROSPECTS

In diagnosing the condition of a volcano the vulcanologist tends to lean heavily on the history of earlier eruptions, more particularly eruptions of the volcano concerned. Observation of the eruptive pattern of certain volcanoes led the American vulcanologist, F.A. Perret, to divide them broadly into two types:

(1) a closed conduit type which is normally long dormant and produces its most intense explosive activity at the beginning of a new cycle of activity (e.g. Mount Pelee, Mount Lamington).

(2) An open conduit type which has long periods of intermittent activity and produces its intense explosive activity near the end of the eruptive cycle (e.g. Mount Vesuvius).

Manam appears to have closest affinity with the open conduit type of volcano in that its dormancy periods are short and its eruptions protracted events. At the same time there is little evidence to suggest that past eruptive cycles have ended with a single outburst of major proportions.

The history of Manam's earlier eruptions is imperfectly known and the deductions that can be drawn from the available data are limited. Fisher (1957) lists the following eruptions and observes that the record is incomplete.

November	1877
	1887
	1888
	1889
	1902
	1910
	1917
11th August	1919
March	1921
September, October	1936
15th March	1937
	1946-47

This record clearly indicates that the volcano has remained dormant for only short periods, at least since 1877. That the eruptions have been non-catastrophic is suggested by the lack of any accounts of large scale movements of people or of loss of life. The most intense known eruption occurred in 1919 when arable land was destroyed; the luluai of Iassa has informed me that his village was damaged during this event.

Additional information on the characteristics of earlier eruptions has been made known by members of the Roman Catholic Mission on Manam. Father Boehm observed that explosive activity of the 1936-37 and 1946-47 eruptions was confined essentially to the south-east season, that is, from June to November of these years. He affirmed that the area between Kulugumwa and Iassa was the only one to receive a heavy deposit of fragmental material (nine inches).

The explosive activity apparently went on for long periods and the products of that activity were similar to the ejecta of the current eruption. In 1946-47 lava flows descended the south-eastern flanks and entered the sea in two places, but in 1936-37 the eruption was predominantly explosive.

During the eruption of 1902, Father Aerni has been informed by village people, two natives from Bokure village were killed. No other details on this period are available.

The conclusions drawn from this all too brief history are: -

(1) Frequent explosive and effusive eruptions of relatively low intensity are characteristic of Manam's activity;

(2) Each eruptive cycle is probably a long continued event which may last as long as three years;

(3) The fact that specific months are given for some eruptions suggests that something in the nature of climactic outbursts occur during the course of an eruptive cycle;

(4) These phases of intense activity are most likely to occur around the equinoctial period, that is when the sun is in its zenith position for equatorial latitudes;

(5) The length of dormancy is uncertain and varies from one to fifteen years;

(6) The current eruption is exceptional in the magnitude of its activity. It is the most powerful outburst since 1902 at least.

Three broad concepts have been used, in addition to the instrumental and observational data, in planning the observation work on this volcano and in advising on the probable course of events.

(a) <u>Open conduit type</u>

Identification of the volcano with the open conduit type suggested that the most intense phase of its activity would come late, rather than early, in the new cycle of activity. Experience on a similar basaltic volcano, Ambrym in the New Hebrides, suggested that the climactic phase may take the form of a series of powerful explosive eruptions rather than a single outburst of Plinian magnitude, such as Vesuvius produced in 1906. This conclusion helped to give warning of the events which followed the eruption of December 1957.

(b) Regional stress

Recent studies of tectonic earthquake distributions in the Territory and the New Hebrides have strongly suggested that regional stress conditions can influence volcanic behaviour. It seems that abnormal regional stress can not only trigger off a volcanic eruption but also affect the magnitude of activity. In 1955 attention was drawn to the apparently anomolous condition of Manam in a general increase of seismic activity throughout the Territory. Six dormant volcanic centres had become active but Manam remained quiet. Closer analysis revealed however, that earthquake distributions tended to be specific. It was suggested that a severe eruption of Manam could be expected when earthquake movements in this northern region of New Guinea changed to predominantly coastal and submarine locations. Preliminary analysis of the recent earthquake data (over the last two years) indicates that this prediction is valid for the current eruption. In addition to this general distribution of earthquakes even more specific movements in the Sepik area provide further evidence to suggest that activity of Manam is related to stress conditions in adjacent structural units (Monthly Report, July 1957).

It is concluded then that the present eruption is not a random event but a direct expression of regional crustal instability. An eruption of unusual magnitude has followed unusual regional seismic activity and both phenomena appear related to a common condition of crustal stress. That the magnitude of the eruptive activity reflects the magnitude of the stress condition manifest in the background seismic activity, is suggested with qualifications. Seismic and volcanic events do not lend themselves readily to quantitative treatment and the theory itself needs much closer study before it can be used confidently.

Using the theory broadly, there are reassuring points in the present situation. It is believed that the background regional seismic movements associated with the present eruption do not approach in magnitude the disturbances which occurred in this region towards the end of the last century. During this early period seismic disturbances were so intense that several mainland villages are reported to have been wiped out by tidal waves caused by off-shore shocks, and massive land-slides occurred in the coastal ranges.

Large-scale eruptions followed these extraordinary earthquakes, including the catastrophic destruction of Ritter Island. In the absence of similar signs, early limitation in the magnitude and duration of the current activity of Manam can be expected.

When studying the 1951 eruption of Ambrym volcano in the New Hebrides it was noted that a marked decline in the number of regional earthquakes occurred during the year of greatest activity. This observation was interpreted as supporting evidence for a decline in eruptive potential - an assessment which subsequently proved correct. Although it may be inadvisable to compare conditions in two different structural environments, it seems important to note that there is no clear cut evidence of a downward trend in regional seismicity for the year 1958. Five "major" shocks have had epicentres in this northern region since the beginning of the year. The fact that two of them had inland epicentres cannot be considered as reassuring because they may have been caused by movement in the Sepik depression; a structural unit which is probably related to Manam's location.

(c) Luni-solar influence

It has long been recognized that a relationship exists between volcanic activity and the gravitational forces of the sun and moon. F.A. Perret planned much of his highly successful vulcanological work on the basis of luni-solar dispositions.

Recent studies of eruptions in the Tertiary have emphasised certain aspects of this relationship which seem particularly applicable to volcanic activity in these latitudes and may assist in the present problem. 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 the earth and its satellite around the sun. Neglecting orbital irregularities for the sake of simplicity there are short term periodic maxima at times when the pull of the sun and moon are in opposition and conjunction, that is, at times of the full and new moon. 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 its declination is appropriate for that latitude. The zenith 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 a 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 the lunar phase and declination, and long term or "seasonal" responses connected with the solar declination. For our latitudes, tensional tidal effects will be greatest at the time of the solstices when sun is over the respective northern and southern tropics and the compressional tides will be greatest at the equinoctial periods.

The behaviour of Mount Lamington is a good example of the seasonal tidal effects. The eruption began at a period of high tensional tides during the southern summer when both solar and lunar declinations were high and the early climax came two days before the full moon. The highly explosive phase of this eruption ended at a period of high compressional tides a few days after the sun had passed the zenith for this latitude. It is of interest to note that a new phase of mild activity began in June when tensional forces were again high.

Numerous examples of the seasonal tensional effect have been noted in the activity of other centres. For example, in the first week of June 1955, Bam, Long Island, Langila and Tuluman volcanoes responded to the tensional maxima of that period with explosive outbursts. Other observations have demonstrated the effectiveness of the purely lunar declination in tipping the scales of a delicately balanced volcanic energy system. Four of the five eruptive phases of Langila in 1954 began at times of high lunar declination. 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 in a few days later when the moon moved over to its zenith position for that latitude. This short period lunar effect is comparable on a small scale to the longer period solar effect, which is noted above as the seasonal response.

This body of evidence strongly suggested that Manam's pattern of activity would be related to luni-solar dispositions and as a result it has been possible to anticipate the major phases of activity of the current eruption largely in the light

of this theory. The establishment of the Waris Observation Post was unfortunately delayed a month by the Esa'ala investigation, but its establishment early in June 1957 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 nuées ardentes from the southern crater and freakishly caused greater damage to settlement on the northern side of the island. Warning was given of the possibility of the major activity of the December-January period when once again tensional 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 have begun at each of the subsequent solstices. Marked eruptive responses have also occurred at two of the three equinoctial periods when compressional tidal forces were high.

The expectation that a waning of eruptive potential would take place during the first half of this year has been governed to some extent by luni-solar considerations.

Lamington set a pattern for a volcanic energy system with a large-scale explosive potential in that its phase of highly explosive activity began under tensional and finished with a major outburst under compressional conditions.

In spite of marked difference in volcanic characteristics some evidence suggests that a similar response could be expected from Manam when it reached the critical stage of large scale energy release. As noted earlier in this discussion when the actual month of the year is known for past eruptions it almost invariably turns out to be close to the times of the equinoxes. 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 is most likely to occur under compressional conditions such as those which obtained during last March. Additional evidence for this interpretation is suggested in the observations made by inhabitants who witnessed earlier eruptive periods. They say that eruptive phases began and ended within the south-east season, that is, the activity began under the tensional conditions of the mid-year solstice and ended with the compressional conditions of the following equinoctial period.

Manam's recent phase of highly explosive activity follows a similar guiding luni-solar pattern. Within this framework certain trends become apparent from a close study of the unprecedented eruptions of the last few months. Some of these trends point to a declining potential; the significance of other trends is not so clear.

LOCAL OBSERVATIONS

The recent series of major eruptions beginning in December 1957 have shown a clear trend in their intensity. The initial event was followed by a series of minor outbursts which culminated in a peak intensity when the volcano erupted on 25th January, 1958. The fragmental material thrown out at this time greatly exceeds in volume, that ejected during any other eruption of the series. Yet the duration of this outburst, five hours, was comparatively short. The less powerful eruption in February and the protracted March event which lasted more than twenty-four hours declined in intensity and increased in duration. This trend suggests that pressures in the volcanic system are declining and the conduits have been emptied of their obstructions. The lengthening periods of calm which have followed the January eruption indicates a decline in available energy.

The importance of gas in a volcanic mechanism may be gauged from Perret's unequivocal statement "gas is the active agent and magma is its vehicle". A decline of gas emission in recent months may be, then, a confirmatory indication of a waning trend. The great banner of vapour which extended many miles to the leeward of the volcano during the solstice period shrank between March and June to a light plume which rarely reached beyond the margins of the island. This trend has been reversed with the arrival of the new phase of activity in late June and once again exhalations from the crater have re-established the long leeward banner of vapour and dust.

Sounds from the craters have been broadly related to the volume of emitted vapour, although many individual loud explosions have been heard without visible evidence of a change in emission. Discrete explosive noises were characteristic of the volcano's activity up to March but from the time of the eruption of that month to late June, only prolonged roaring noises were heard and for long periods the vents were quiet. Sharp detonations and clanging metallic explosive noises returned with the current new phase of activity and the sound effects have been very similar in nature to those heard in June of the previous year. Some of the recent noises have been loud enough to disturb people on the mainland.

Lower temperatures during the recent period of calm were indicated by a weak glow and sometimes a complete absence of luminous effects. The brilliant incandescence characteristic of activity earlier in the year has returned with the renewed activity and jets of brightly glowing ejecta have been seen rising above the southern crater.

Perret, when discussing the potential of Mount Pelée in 1930, observed that the presence of incandescent lava in the crater is always indicative of a high eruptive potential. He was referring at that time to an andesitic lava. It is doubtful whether such a generalization can be applied to the basic, more easily fusible lava of Manam. Much of Manam's minor activity has been accompanied by luminous effects and only the periods of unusually bright and persistent incandescence have had special significance.

INSTRUMENTAL DATA

As the nature of seismic movements varies with individual volcanoes assessment of the significance of results from a primary survey presents special difficulties.

At Lamington discrete earthquakes were predominant and a microseismic oscillation was subordinate and confined essentially to phases of highest explosivity. At Manam discrete earthquakes are uncommon and a strong continuous microseismic oscillation has been characteristic of the whole observation period from December to August. Peak amplitudes in this persistent "harmonic tremor" have coincided with the major eruptions. (It is of interest to note that only during the December and January eruptions was seismic movement of the harmonic type great enough to be detected by the low-magnification recorder at Waris. Movement of a lower order accompanied the February and March events).

Recent changes in the relationship between seismic movements and eruptive activity may be significant. Whereas fluctuations in amplitude or intensity indicated the imminence of an eruption during the early observation, after the March eruption similar fluctuations occurred without an eruptive response. It is a noteworthy fact that during the waning stages of the Lamington eruption the relation between seismic movements and eruptive activity becomes similarly ill-defined. Perhaps such a development is symptomatic of waning power. When potential is high and a nice balance exists between the eruptive and restraining forces then 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. In the absence of critically balanced forces these disturbing influences no longer have an immediate effect.

Reference to precedents elsewhere is of little assistance in this issue. Japanese scientists working in this field have noted that the major seismic movements may precede, accompany or follow an eruption - a problematical observation which tends to reduce the importance of the persistent seismic activity which is being recorded at Manam.

Nevertheless it is difficult to accept as "normal" a seismic movement which has persisted for eight months and is easily detectable by low magnification (X 1000) recording eight miles from the craters. The power required to maintain such a movement seems formidable.

The new phase of activity was accompanied by marked fluctuations in seismicity. As the eruptive activity declined early in August, continuous tremor amplitudes fell to lower levels than usual. Continuation of this trend would seem to offer the best confirmation of a decline in eruptive potential.

Tiltmeter readings at Waris have shown movements on the eastern flank of the volcano which are in some respects parallel with seismic movements in that early movements had a special diagnostic significance and later movements have been unrelated to eruptive activity. In August 1957 tilt readings began a slow upward trend which led to abrupt movement and a major eruption in early December. During the December-March period of major eruptions the tilt trend fluctuated but showed a general tendency to level out. Since March some fluctuations without eruptive activity have occurred but generally the readings have maintained a high and essentially static level. The recent new phase of activity was not preceded by marked tilt changes. Throughout July the readings have been exceptionally steady.

Interpretation of tiltmeter results is rendered difficult by the lack of basic data on normal annual movement at Manam. A static tilt may be the sum of a volcanic and a seasonal movement which compensate one another. Thus a slow volcanic movement may remain concealed. Under these circumstances conclusions are limited to the observation that at present there is an absence of abrupt changes in tilt and thus an absence of signs which previously were a prelude to large scale activity.

NUÉES ARDENTES

The nuée ardente, a gas-lubricated avalanche of hot fragmental material which can sweep down the slopes of a volcano at velocities as high as one hundred miles per hour is the most lethal and destructive of all volcanic phenomena. This type of activity is more commonly associated with andesitic and rhyolitic lavas. As far as I am aware a recognized instance of nuées ardentes occurring from a basaltic volcano such as Manam has never been recorded in detail. The presence of this Peléan type activity in Manam's eruptions is therefore of particular scientific interest and of great importance to settlement on the island. The early recognition of the capacity of the volcano to produce this type of activity was probably an important factor in the decision to evacuate the island and thus prevented loss of life.

The early manifestations were small, isolated events which occurred between or during phases of Strombolian activity - the rhythmical jet-like explosions which constituted dominant form of the volcano's activity. The first nuée 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 slopes of the debris apron in the south-eastern valley and set fire to marginal trees. Much more powerful activity of this type occurred in October when a series of nuées from the southern crater devastated areas of forest land and, in one place, entered the sea.

After examining the effects of this eruption it was suggested that the chief danger areas on Manam were those lying in and immediately below the four great valleys which approximately bisect the cone sectors between the cardinal points of the compass. One only of these areas was settled.

Attention was drawn to the vulnerability of Budua village in the event of large scale activity. The four valleys would act as a safeguard to other areas of the island in that they would have channelling effects on the gravity controlled avalanches of the nuée ardente type. Only in the event of an outburst of Plinian magnitude was it conceivable that these topographical features would cease to exercise control over the distribution of the nuées. Such a development did not seem probable.

These generalizations have stood the test of the December-March phase of major eruptions. The most powerful eruption of the series on 25th January expelled nuées into all four valleys. As a result, part of the village of Badua was wiped out and considerable areas of forests in the valley zones were destroyed. In the south-eastern and south-western zones the nuées were sufficiently voluminous and mobile to enter the sea. Voluminous nuées descended from the southern vent during February eruption and, although there was a tendency for the avalanches to override the lower shoulders of the valley wall, they were effectively limited to the valley zone.

It is considered that the generalizations regarding the immunity of most settlements on island to the effects of nuées ardentes still hold good. The site of Budua village should be changed and it is possible that infilling and modification of the summit topography may eventually affect the immunity of Iassa and Dugulaba. Several months ago it was recommended that the island should be photographed to enable a better assessment to be made of this controlling factor in nuée distributions.

CONCLUSION

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

A peak intensity occurred with the eruption of 25th January, 1958. The subsequent major outbursts in February and March have tended to become longer in duration but lower in intensity. The seismic activity associated with these later eruptions have been correspondingly less intense and a notable development was the predominantly effusive nature of the March event. The end of volcanic cycles are sometimes characterised by a predominance of effusive activity. The manam people have a belief to the effect that the activity will die when the lava reaches the sea (as it did in March). Apparently some of Manam's earlier eruptions have ended with an effusive phase.

These observations point towards a downward trend and suggest exhaustion. But this picture needs qualification. The renewed activity of June-July, although relatively mild in intensity, seemed to have more affinity with the vigorous activity of the corresponding period last year rather than to represent the dying end-phase of the cycle. Abundant gas was emitted and the spasms of explosive activity have taken the form of the rhythmical and brightly glowing jets characteristic of the build-up during 1957. This development suggests the existence of a special factor which is 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 is 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 necessarily slow.

Although the time factor seems to be of prime importance in regard to the scale of activity of some volcanoes there is strong evidence to suggest that with others regional stress is the dominant factor governing the magnitude of an eruptive cycle. It is submitted that Manam's current cycle belongs to this latter category. The extraordinary 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 regions adjacent to Manam suggests that unstable stress conditions still obtain. This may account for the nature of the renewed explosive activity but it is not necessarily indicative of a return to activity on a similar scale to that which has occurred during the last twelve months.

The energy available for the eruptive cycle seems to be made up of inherent accumulations which have taken place since the last eruption, plus the energy made available by the application of regional stress. The "conventional" pattern of the energy release with its indication of a climactic phase and subsequent exhaustion suggests that the "accumulated" energy has been used up and thus one contributing factor to the energy system has been eliminated. It follows that residual eruptive energy in Manam is largely dependent on dynamics of regional stress.

There is no way of predicting abnormal stress or the tectonic earthquakes which sometimes accompany this condition. Regional seismic movements are continuing in the area and associated with them has been renewed explosive activity which began in June. The scale of neither manifestation has so far reached proportions which could be considered as indicative of exceptional developments from Manam.

Events in the last century suggest that extraordinary volcanic eruptions in this region were preceded by extraordinary regional seismic disturbances. The magnitude of the current seismic activity is not comparable in scale with these earlier manifestations. It is therefore concluded that although a continuation of activity at Manam seems probable there is no evidence at this stage to suggest it will reach dangerous proportions.

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