On the possible relationship between the Matsushiro earthquake swarm and the inactivity of Asama-yama Volcano (*)

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SUMMARY. — During the famous Matsushiro earthquake swarm more than 700 000 (volcanic) earthquakes were observed. At the same time remarkable contortion of the ground also took place together with other strange geophysical phenomena. In the course of these events, volcano Asama-yama (one of the most active volcanoes of the world) showed a perfect inactivity. This volcano is situated at a distance of about 30 km measured from Matsushiro, that is very near the site of the events. In the paper a causal relationship is suggested between the geophysical phenomena at Matsushiro and the inactivity of Asama-yama. Two alternative possibilites are treated briefly. The hypothetical character of these ideas is strongly emphasized by the author, however both possibilities appear to be physically real and can explain all the important geophysical events observed on the spot.

RIASSUNTO. — Durante il famoso terremoto di Matsushiro furono registrate più di 700.000 microscosse a carattere vulcanico. Contemporaneamente furono notati e una notevole torsione del terreno e altri strani fenomeni geofisici. Nel corso di tali eventi il vulcano Asama-yama (uno dei più attivi del mondo) si mostrò del tutto inattivo; questo vulcano è a circa 30 km da Matsushiro, vicinissimo al luogo dove occorsero gli eventi.

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Nella nota viene proposta una relazione casuale tra i fenomeni geofisici di Matsushiro e l'inattività del vulcano Asama-yama. In breve sono state trattate due possibili alternative.

Il carattere puramente ipotetico di tali idee è messo bene in evidenza dall'Autore: tuttavia entrambe le ipotesi potrebbero avere un reale significato fisico e spiegare, quindi, tutti quegli importanti eventi geofisici osservati in loco.

Introduction

The earthquake swarm of volcanic shocks, that commenced on the 3rd August, 1965 and ended in October, 1967, at the near proximity of Matsushiro (Nagano Prefecture, Honshu, Japan) is really unique in the history of geophysical volcanology, due to the very great number of the shocks. The exceptionally long series of the quakes were accompanied by landslides, the creation or activization of a strike-slip fault, fracturing of the ground, changes in the local geomagnetic and gravity fields, outflow of a remarkable amount of ground-water and last, but not least, crustal deformations.

In the present paper *a new interpretation* of these unprecendented series of events is presented. The basis of this new explanation is an empirical fact: namely the strange *inactivity* of the Asama-yama volcano. We should like, however, to emphasize very strongly the hypothetical character of this solution which — as a matter of fact — comprises two alternative possibilities.

The center of the epicentral area of the swarm is to be found near an extinct volcano, called Minakami-yama, at a distance of about 30 km northwest of Asama-yama, the latter being one of the most active volcanoes of the world. Until the end of the swarm about *seven hundred thousand* stronger and weaker shocks (of volcanic origin) occurred (Kasahara, 1970) (6) and many of them were observed directly by the inhabitants of the affected region. Only very few shocks reached a Richter-magnitude of 5.0 or over it. The total energy, released during the swarm as a whole corresponded approximately to the energy of a single earthquake of a magnitude of $M = 6.3$. Within the series three very active seismic periods can be distinguished. The first climax took place in November, 1965; the second in March and April, 1966; the third in August and September of the same year. The third culmination was associated with landslides and the outflow of a large amount of ground-water (Hagiwara and Iwata, 1968) (2). Generally, however mostly during the first part of the activity, the *hypocentral region* of the felt shocks showed a concentration between the depth of 2 and 8 km with a center at about 5 km. The maximum horizontal extent of the *epicentral region* measured about 34 · 18 km.

The *crustal deformations* were similarly very remarkable and had been *in close association with the seismicity*. Kasahara, 1970 (6), presented an interesting graph on the temporal variation of the cumulative seismic energy, the upheaval of the Minakami-yama region, the exten-

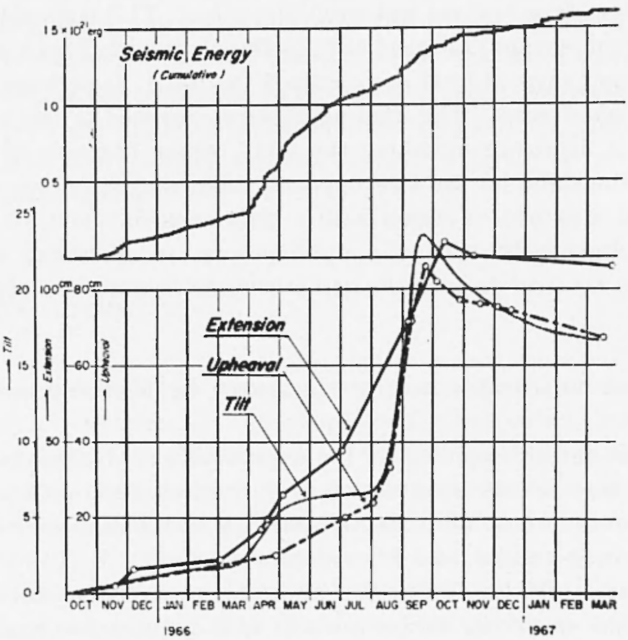

Fig. 1. – Development of various sorts of crustal deformations at the Matsushiro area, compared with seismic energy release (after the Bulletin of the Earthquake Research Institute).

sion of the base-line between village Sorobeku and the extinct volcano, Minakami-yama, as well as the tilt of the ground (Fig. 1). The uplift amounted to about 90 centimeters, the maximum extension was around or somewhat greater than 116 centimeters and the tilt reached almost 25 seconds of arc. The rate of these crustal deformations showed remarkable changes in April, 1966 and in September, the same year, corresponding well to the second and third culminations of the seismic activity. After the September-October period of 1966, the deformations exhibited an abrupt *reversal-process* (Kasahara et al., 1968) (5).

The existence of a *strike-slip fault* of the left-lateral type, between Minakami-yama and Sorobeku is suggested by Kasahara. The length of this (supposedly buried) fault is 7 km and its vertical extent may be 3 km.

The trend of the fault is roughly northwest–southeast. The strike-slip displacement along this fault during the swarm amounted to almost 2 metres. The fault runs across the northern slope of Minakami-yama where *the most prominent upheaval took place.* This appears to be an especially important empirical fact, as this volcano has been considered to be extinct since at least one hundred thousand, or perhaps five hundred thousand years. The local uplift here consisted of two main components: a displacement along the fault, where the rate of upheaval was not the same on the two opposite sides, and a doming-up of the epicentral area over a region with a dimension of about 10 · 10 km.

Simultaneously with the uplift-process in question, significant *changes in the local geomagnetic and gravity fields* were also experienced.

1.1. – The Volcanoes in the proximity of Matsushiro

In the author's opinion for the explanation of all these phenomena it is necessary to call the attention to the curious and by all probability very important fact that *the neighbouring volcanoes, Kusatsu-Shiranesan (catalogue-number: 8.3-12; coordinates: 36°37′ N, 138°33′ E) and Asama-yama (8.3-11; 36°24′ N, 138°32′ E), respectively, showed absolutely no signs of activity during the time of the Matsushiro swarm.*

All the historically known eruptions of Kusatsu-Shiranesan were of phreatic character and steam-explosions took place from the central crater (Kuno, 1962) (7). As the eruptions of this volcano were not true magmatic ones, therefore Kusatsu-Shiranesan is of no interest from our point of view. *The inactivity of Asama-yama is more important.* In other times, namely, this volcano erupted extremely frequently. For instance, the number of known outbursts between 1933 and 1960 was almost two thousands (Kuno, 1962) (7). Characteristical crustal deformations of the order of ± 10 centimeter or even higher were observed many times in association with the activity.

In the precent century the inactive periods of Asama-yama were as follows:

1920: one year. 1923-26: four years. 1933-34: two years. 1943: one year. 1946: one year. 1948: one year. 1956-57: two years. 1960: one year.

As regards the period between 1961 and 1974, in October 1961 explosions occurred 11 times and in November 40 times. After these events a long pausa followed until the 23rd May, 1965, when weak explosions and small ash-falls took place. Between the occurrence of this insignificantly minor "eruption" and the really strong explosive outburst on the 1st February, 1973, the volcano had been in a perfectly calm period again. Disregarding now the events on the 23rd May, 1965, as a matter of fact *the inactive period has lasted more than 11 years*, which, as far as Asama-yama is concerned, is *an unusually long period of quietness.* It must be emphasized very strongly, furthermore, that *the Matsushiro swarm occurred during the period of perfect inactivity of Asama-yama.*

1.2. – The vertical model

In this and the next paragraph the writer expands two ideas by which the explanation of the geophysical phenomena, summarized above, can be given. These are, of course, *working-hypotheses only* and at present not too much evidences are at our disposal in favour of the two models which will be discussed in the followings. These two models will be called *vertical model* and *horizontal one*, respectively. We shall point out some of the difficulties which are still not fully understood, hoping that these unsolved problems will perhaps stimulate other authors to a more detailed investigation of the interesting Matsushiro-events, the real causes of which, in spite of the many investigations carried out up to the present, are not clearly known as yet. The writer feels, however, that his two models are physically real and acceptable and can be used for the explanation of *all* the observed facts.

As it was mentioned earlier the base of the new models is the inactivity of Asama-yama during the period of the Matsushiro swarm. *By some reason the rock-melts could not reach the surface of the Earth through the volcanic conduit and the (top) crater of Asama-yama, but followed another way and moved towards the base of the extinct volcano, Minakami-yama, very near the town of Matsushiro.*

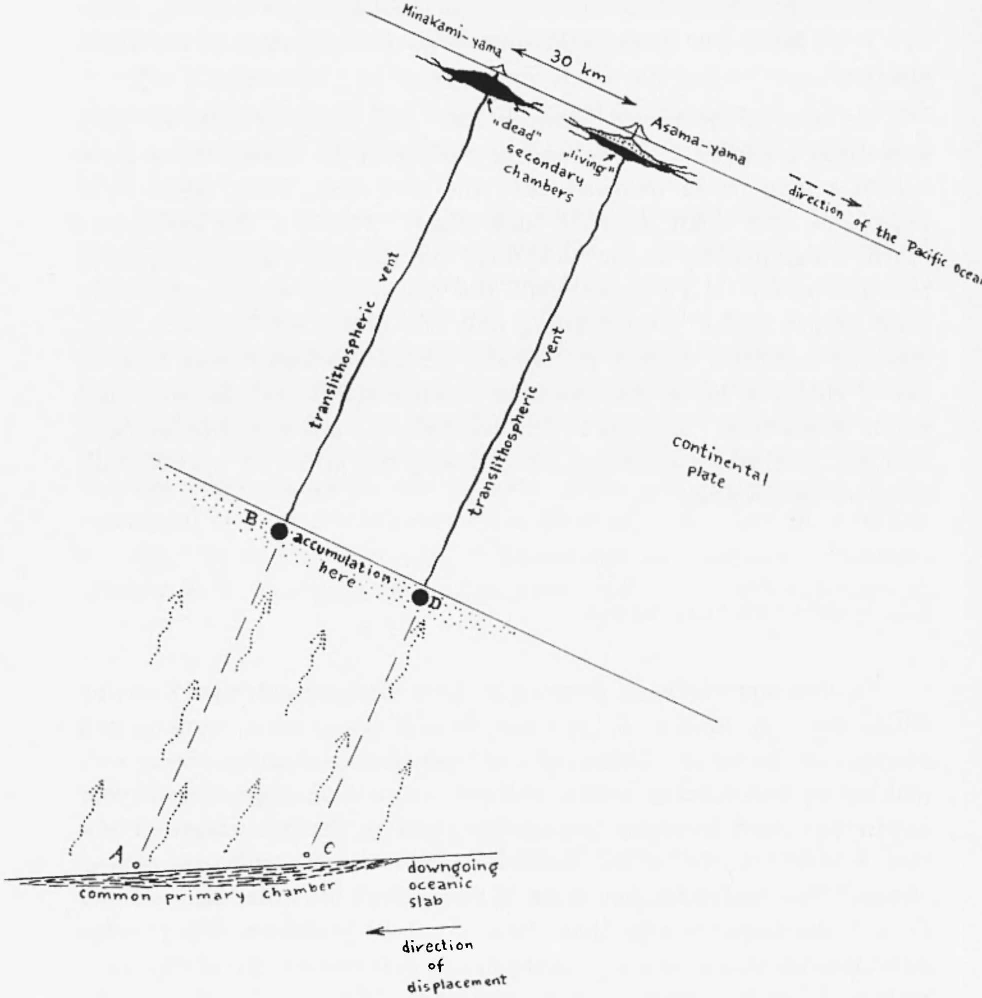

Fig. 2. – The vertical model. For explanation see the text

The subvolcanic structure might be conceived as represen ted by the above picture (Fig. 2).

At a certain depth, by all likelihood and usually greater than 100 km, there is the source of fresh (acidic and transitional) magma. This domain of magma-generation, called *primary magma chamber*, belonging to island arcs and similar structures, can be found either within the downgoing oceanic lithospheric plate, that is in the interior of it (Hatherton-Dickinson model), or along the upper surface of the slab (Toksoz–Minear–Julian–model). From this domain the new magma can reach the *secondary magma chamber* (lying at a very shallow depth just beneath the volcano) through a more or less vertically situated, long conduit, called *translithospheric volcanic vent.*

According to the author's vertical model, the extinct volcano, Minakami-yama has its own, *dead* secondary chamber from which its translithospheric vent passes downward. The volcano Asama-yama has a *living* secondary chamber and also has its own translithospheric vent, as one can see on the enclosed sketch (Fig. 2). It can be supposed, furthermore, that although these vents are separated from one another, *they reach the same, common primary chamber*, developed in the downgoing lithospheric slab's interior or along its upper surface. As the chambei is connected to the downgoing slab which has an oblique position, the chamber itself has also a similar situation, i.e. it is somewhat obliquely oriented. The distance between the two volcanoes, measured along the surface is only some 30 km. In spite of this small distance, the vent of Minakami-yama reaches the common primary chamber at a somewhat *greater* depth, than that of the Asama-yama, since the latter volcano is being situated nearer to the Pacific Ocean and the oceanic lithospheric slab begins to underthrust along the Great Japanese Trench.

Let us now suppose that the translithospheric vent of Asama-yama had been blocked for a certain time by an enormous mass of solidified rock-melt. Therefore the gases, originated in the primary chamber, could not transfer the new magma through this conduit towards the surface and thus the secondary chamber of Asama-yama did not receive fresh, new magma. Its magma-supply was more or less exhausted by the two thousands eruptions between 1933 and November, 1961. Therefore from November, 1961, an inactive period started and it lasted until the 1st February, 1973. On this day or some days or weaks earlier the accumulated gases broke through the solidified obstacle (volcanic *plug*) within the translithospheric vent, and/or the fresh, new magma melted this plug, leading by this process to the occurrence of a new, very strong explosive eruption. Until this event happened, only a relatively few, active magma had been stored within the secondary chamber of Asama-yama and its inherent energy was not enough to produce an eruption on a larger scale. As we know during the long inactive period only a minor outburst took place (on May 23, 1965, preceding some weeks the beginning of the Matsushiro earthquake swarm).

In the period, during which the translithospheric volcanic vent of Asama-yama was closed by the solidified magmatic mass, new magma had been created within the common primary chamber of Asama-yama and Minakami-yama. Since the conduit was blocked towards Asama-yama, the accumulated gases and the new magma were forced to move through an other way towards the surface.

When the translithospheric vent of Asama-yama was not closed by the plug, this vent offered a free way upward for the new magma and gases. In the absence of such an obstacle within the conduit, no unusual accumulation of magma and gases occurred along the lower boundary, of the continental lithospheric plate, that is just above the primary magma chamber. But in the presence of such a plug within the Asama-yama's translithospheric vent, there was only one way for the fresh magma and gases to move upward, namely the old and evidently also closed translithospheric vent of Minakami-yama.

Now the following problem arises: how could break through the new magma and the gases this solidified, old volcanic material which had been stored within the vent of Minakami-yama?

We must take into consideration the fact that those parts of the magma and gases which accumulated around point B (see in Fig. 2) came into being at point A; while the magma and gases accumulated around point **D**, originated at and came from point **C**. But, as the primary magma chamber has an oblique position, **A** is lying at a deeper level than **C**. Therefore at point **A** the temperature and pressure is remarkably higher than at **C**. As a result the thermal energy of the accumulated magmatic mass at point **B** is greater than that of the magma stored transitionally around point **D**. Similarly, the accumulated gases have a greater pressure and a higher inherent energy near point **B** than at **D**.

The accumulation began just after the closing of the translithospheric vent of Asama-yama, that is somewhat after the last eruption of this volcano (November of 1961). The earthquake-swarm, on the other hand, has begun as late as August of 1965. Consequently there was enough time — several years — for the accumulation of very hot gases and magma near **B** and for the accumulations of remarkably less hot gases and magma at **D**. As a result the opening of the two translithospheric vents, partly by melting and partly by bursting through the material within the conduits couldn't happen simultaneously. It happened *earlier* in Minakami-yama's vent because of the greater inherent energy of magma and gases. That is the fresh magma began to rise from the lower edge of the continental lithosphere towards the surface *at first* in Minakami-yama's conduit, causing the unprecedented earthquake-swarm and other geophysical phenomena near the surface, and during this time the Asama-yama was in an inactive stage. *This model is supported by the observational fact according to which the hypocentral depth of the volcanic shocks near Minakami-yama decreased steadily as the time elapsed, showing clearly the effect of an emerging magmatic mass within the conduit.* As the Japanese experts have pointed out on the basis of the observations on the spot, the earthquake-swarm was the direct consequence first of all of the *microfracturing* of the rocks, lying at a shallow depth. This microfracturing was the result of heating, due to the emerging magma.

1.3. – The Horizontal Model

In this model the basic supposition is that the shallow conduit of Asama-yama was temporarily blocked by a consolidated, solid plug, somewhere between the top-crater and the secondary magma chamber. Therefore the fresh magma could not reach the crater. The secondary chamber, however, was *tapped* and the rock-melt, previously stored in this domain, *moved sidewards* through a subterrain outlet of the chamber. This outlet might be a more or less horizontally situated dike-like intrusion along a shear-fault. "Left-lateral shear-faults are common in northern Honshu so that there might be a connection between Asama-yama and Minakami-yama which might have been active already in the past when the latter volcano came into being" (van Bemmelen, personal communication).

If one take into consideration the fact that the distance between the epicentral area of the swarm and the top of Asama-yama is as low as 30 km, such a subterrain, direct connection between this volcano and the swarm-region seems to be possible. Under the point entitled "Discussion" (see at the end of this paper) we shall mention observational facts regarding the possibility of subterrain connections between neighbouring volcanoes. In addition to these the writer wishes to mention some data concerning the probable dimensions of secondary magma chambers as well.

According to certain calculations made by Machado, 1965 [8] and Machado 1965-1966 [9], respectively, the total length of the secondary magma chamber of Etna may be about 100-120 km and its width is some 40 km. Under volcano Agua-de-Pau (Azores) a width of 20 km and a total length of some 60 km were found.

Taking now into account these figures it seems that 30 km is not a too great distance; that is a part of the subvolcanic system, existing beneath Asama-yama, can extend to a domain which is lying just under the extinct volcano Minakami-yama (Fig. 3). A subterrain outlet being 45 km long will be mentioned in the "Discussion".

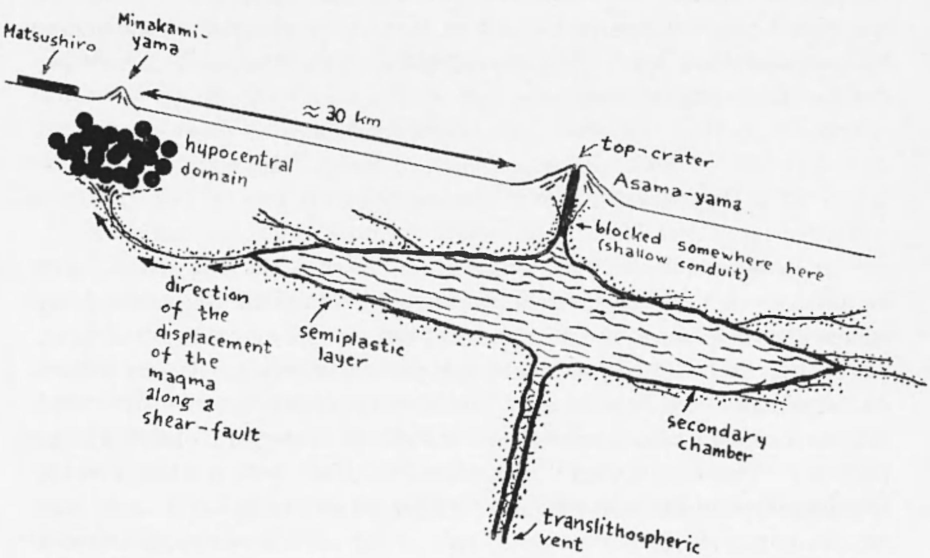

Fig. 3. – The horizontal model. For explanation see the text

It may be noted that according to the opinion of many experts, the secondary magma chambers begin at a depth of 3-6 km only, but their thickness (extension towards the interior of the Earth) is not known. Furthermore, it is reasonable to assume that the secondary chambers are surrounded by a peculiar region also of unknown thickness, in which the rocks are in a semiplastic condition due to the heat of the nearby magma. In this semiplastic layer of the near the environment of the secondary chamber, the material is *not* hard and rigid enough for the accumulation of mechanical stresses.

This region therefore is free from *tectonic* earthquakes. Microfracturing, due to heating, can occur only *outside* of this semiplastic region.

The subterrain situation may be represented in Fig. 3. Let us suppose now that the *shallow conduit* (that connects the secondary chamber with the top-crater of Asama-yama) was blocked somewhere as it is indicated on the drawing. Therefore an inactive period of Asama-yama had to start. Now the magma began to move slowly towards the base of Minakami-yama along one of the left-lateral shear-faults (or through more than one faults as it is indicated in our figure. This displacement happened more or less parallel to the surface of the Earth. The depth may be about 8-9 km under the surface, that is somewhat beneath the hypocentral domain developed under the Minakami-yama volcano (see later).

Here is an important problem. Why has shifted the magma at this depth along a fault instead of breaking through the plug in the shallow conduit of Asama-yama? A possible answer to this question may be that in the latter case the magma had to work against gravity and had to work against the internal strength of the rocks of the plug, simultaneously. But in the case of a sideward displacement (more or less parallel with the surface of the local geoid) no work was needed against the gravity. Furthermore: if the secondary chamber of Asama-yama is long enough, in this case the way through the fault (see on the drawing) is relatively short.

Another problem is as follows: the period of dormancy of Asama-yama was much longer than the duration of the Matsushiro-swarm as a whole. Why? The answer is self-evident and easy. The reason is, namely, that a certain time was needed for the magma to find its possible way sidewards, that is towards beneath the base of Minakami-yama. But as we shall see later, too, this magma never reached the surface. And — on the other hand — a certain time was needed within the secondary chamber of Asama-yama until a remarkable amount of gases accumulated which was necessary to break through the plug in the shallow conduit. As we know, this happened only some days or weaks preceding the powerful explosive eruption of Asama-yama on the 1st February, 1973.

If our hypothesis on the possibility of the *lateral* displacement of magma holds, that is the horizontal model is acceptable, than one can expect, especially if the beginning period of seismic activity is concerned, that *a slow migration of the epicentral area had to occur.* Similarly, as the time elapsed, a slight displacement of the hypocenters towards the surface is also to be expected. Really, we have some evidences that such shifts did occur, and these are in favour of the hypothesis.

Hagiwara and Iwata (1968) (²) pointed out that in the very first stage of the seismic activity small earthquakes were observed *only* at the south-western slope of Minakami-yama in August and September, 1965, while within the Wahako Prefecture, north of Minakami-yama, no earthquakes occurred at this time (Fig. 4, and Fig. 5). In October

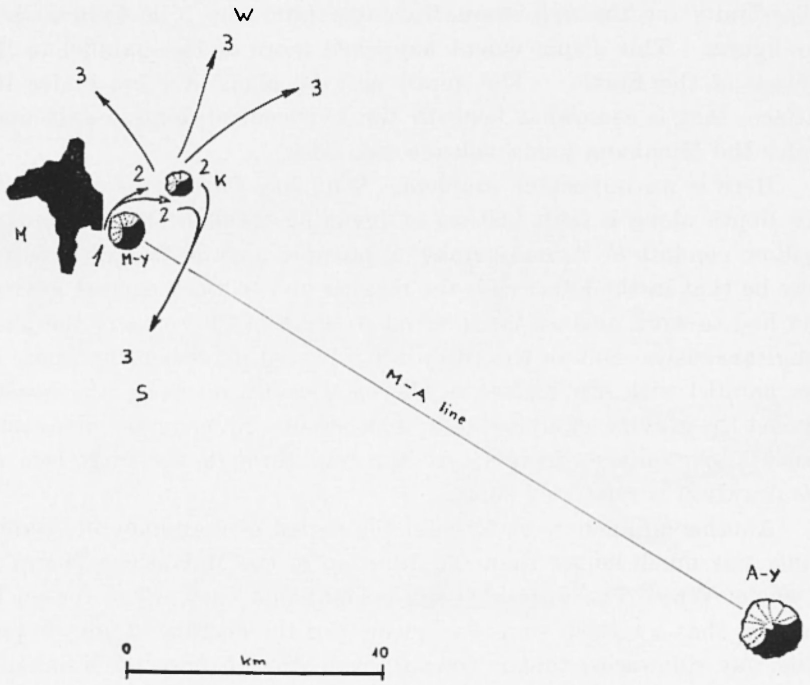

Fig. 4. – Migration of seismic activity. 1) August and September, 1965; 2) October, 1965; 3) March-July and August-September, 1966. M = Matsushiro; M-y = Minakami-yama; K = Kimyosan; A-y = Asama-yama; W = Wahako district; S = Sanada district (After the data of Hagiwara and Iwata, 1968 (²), compiled by the author).

small earthquakes took place around Kimyosan (Mount Kimyo), at about 3 km northeast of Minakami-yama. Kimyosan is situated farther from that line which connects Asama-yama with Matsushiro, than Minakami-yama itself. Hamada and Hagiwara (1966) (³) also noted a westward drift of epicentres during the next year, more precisely speaking in August and September, 1966, and a northeastward one is also known from March-July, 1966. Generally, it can be stated that the center of activity was lying at first just on the Matsushiro —

Asama-yama line near and under Minakami-yama and later on the activity spread from this area towards the neighbouring regions, as it is indicated in Fig. 4. This migration is consistent with the idea that the shocks reflected the distribution and displacement of magma that

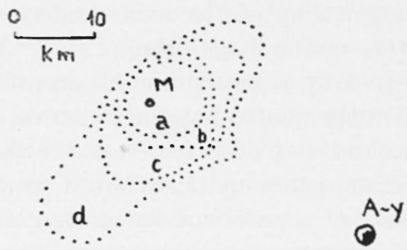

Fig. 5. – Areal distribution of seismicity between August, 1965, and October, 1967 (on the basis of data provided by Hagiwara and Iwata (2)). M = Matsushiro; A-y = Asama-yama; a) August, 1965 - February, 1966; b) March, 1966 - July 1966; c) August, 1966 - December 1966, d) January, 1967 - October, 1967.

arrived from the secondary chamber of Asama-yama. As it was mentioned previously the earthquakes were due first of all to microfracturing in the crustal rocks. Therefore the first shocks occurred not just along the border of the magma chamber, as the rocks there are in a semiplastic condition, but farther, where the rocks were rigid enough to permit the occurrence of microfracturing within themselves. It is noteworthy, moreover, that according to Hamada and Hagiwara (1966) (3) *the hypocentral depths decreased* after the end of July, 1966, and this decrease got even more expressed in the middle of October, the same year (Hamada and Hagiwara, 1967) (4). *These observations on the decreasing tendency of the focal depths are also in excellent accord with the expectations, based on the horizontal model*, as they supported at the same time the vertical model as well.

2. – Concluding remarks

The opinions on the true nature and cause of the Matsushiro-events are not unanimous. For instance, in their first paper on the swarm, Rikitake and his co-workers (1966) (13) pointed out that certain changes in the local geomagnetic field were observed at the epicentral region. Similar variations in the magnetic inclination were experienced at volcano Mihara-yama, during its eruption in the years of 1950 and 1951. The phenomenon at Mihara-yama might have been the result of the demagnetization of the rocks, due to the rise of their temperature and — respectively — due to their new magnetization (remagnetization) during the period of cooling of the rocks under consideration below the *Curie*-temperature of the magnetite.

It was emphasized by Rikitake and his co-workers ([13]) that up to the time of writing of the quoted paper (December, 1965) only a slight upheaval of the ground was observed near the town of Matsushiro, at the foot of Minakami-yama and therefore it seemed as though only the dike-like intrusion of a *small* amount of magma would have been responsible for the creation of the events at Matsushiro, but not a *larger* volume of rock-melts was involved. But now having a knowledge of the results of geodetic measurements, carried out *later*, that is during the *further* progress of the swarm and other events, we are able to state that *crustal deformations on a much larger scale had taken place. Hence, on this basis, the intrusion of a more voluminous magma seems to be very likely.* We can estimate it on an energetical base, as follows:

The number of earthquakes of higher magnitudes in the Matsushiro-area from October 1965 to October 1967 was the following (Hagiwara and Iwata, 1968) ([2]):

$M \sim 3.9$	$M = 4.0–4.9$	$M \geqslant 5.0$	Total
7664	388	9	8061

The total seismic energy released by these 8061 shocks amounts to $1.66 \cdot 10^{21}$ ergs. On the other hand (Kasahara, 1970) ([6]) for the creation of crustal deformations about $17 \cdot 10^{21}$ ergs energy was used ($7 \cdot 10^{21}$ ergs for local and $10 \cdot 10^{21}$ ergs for regional crustal deformations). Hence, the total energy necessary to produce the earthquakes and crustal deformations together amounts to $1.866 \cdot 10^{22}$ ergs. If we take into consideration the medium density of magma as 3.0 gr cm^{-3} and its temperature as 1000°C, we got the result that this value corresponds to the total thermal energy of a magmatic mass with a volume of roughly 500,000 cubic metres. This is a rather remarkable volume, however the whole volume of magma, playing a role in the Matsushiro-events was certainly higher since only a fraction of its inherent energy was used for the creation of the phenomena.

In spite of the larger contortion of the ground, that commenced later (i.e. after the writing of the quoted paper, December 1965), Rikitake and his co-workers have preferred the idea according to which the local anomalous change in the geomagnetic field was attributable to a piezo-magnetic effect (Rikitake et al., 1966, 1967) ([13]), that is *not* to the intrusion of a hot magmatic mass. Kasahara (1970) ([6]) had a similar view.

Here we can mention that some kind of changes in the gravity field were also observed. This support the idea according to which a dense material — probably magma — had penetrated into the rocks beneath Minakami-yama and its environment. The changes in the local geomagnetic and gravity fields can — accordingly — be attributed to the same phenomenon. The view concerning the piezo-magnetic effect can not explain the change in the gravity field, but only that of the magnetic one. Similarly by the supposition of a piezo-magnetic effect we can not account for the crustal deformations and the outpouring of ground-water.

Morimoto and his co-workers are of the opinion (Morimoto et al., 1966) ([12]) that "*From the geological point of view, both volcanism and tectonic movements are probable as the cause of the present earthquakes*" (*op. cit., p. 444*). "*But it is improbable at least that there exists a large shallow magma reservoir of several hundred metres or more in diameter or a growing dike swarm in hypocentral area at a depth of several kilometres beneath the surface. Therefore, if the magma should play an important role in bringing about the present earthquakes*, the head of magma should be deeper than the focal realm ... (Italics mine – *P. H.*). *A fracture system of EW direction is supported in the basement rocks beneath the hypocentral realm. A magma from a deeper source had intruded upwards enlarging these features, resulting in extension of the overlying part of the crust towards NS-direction*" (*p. 445*).

Hagiwara, 1966 ([1]), has also suggested that if an active magma existed and penetrated into beneath the territory of the seismic events, the head of this magmatic mass should be rather deep.

It is evident that *the magma from first to last has remained underneath the hypocentral domain and thus never reached the surface.*

From this point of view *the Matsushiro-swarm as a whole reminds very much to the case of the similarly famous Ito earthquake-swarm* that occurred on the Izu – peninsula in the year of 1930. The shocks at Ito were distributed between the depth of 2 and 7 km with a strong concentration between 5 and 6 km. In this respect the author wish to refer to some sentences, written by Minakami, 1960 ([10]).

"*Many investigators incline to regard the Ito earthquake swarm as a kind of igneous activity in which magma under the ground intruded to a* *certain depth of the earth's crust. They regard the Ito earthquake swarm as an intermediate phenomenon between general earthquake phenomena and volcanic phenomena. If the magma had ascended further, the magma would have been extruded and would have formed a volcano such as Syowa-Sinzan or Paricutin".*

The present writer is convinced that almost the same event occurred at Matsushiro during the unique earthquake swarm. By the supposition of a magma intrusion we can explain all of the phenomena observed on the spot. These are summarized in Table 1

Table 1

Event	Cause
Earthquakes	Microfracturing above the head of the emerging (upgoing) magma
Changes in the local geomagnetic field	Demagnetization of the rocks heated by the upgoing magma, and remagnetization during their cooling process
Changes in the local gravity field	Intrusion of dense material (magma) into the crustal rocks which have a lower density
Deformations of the ground especially at Minakami-yama	Intrusion of magma, similarly to the case of Syowa-Sinzan volcano in 1943, although at Matsushiro the magma never reached the free surface
Inactivity of Asama-yama volcano	During a certain period of time, Asama-yama did not receive fresh magma, but the magma moved towards the base of Minakami-yama as expressed in this paper
Appearance of a great amount of ground-water on the surface	The ground-water was squeezed out by the emerging mass of magma
Landlides and fracturing of the ground	These phenomena were evidently connected to the ground-deformations and the many earthquakes

3. – Discussion

Professor R. W. van Bemmelen (Den Haag, Holland):

The statistical relation between the Matsushiro earthquake swarm and the quietness (dormancy) of Asama-yama is a remarkable basic observation. The interpretation might be *either* a direct relation at shallow level between the subvolcanic chamber of Asama-yama and the extinct volcano Minakami-yama, *or* a deeper relation beneath the crystalline basement complex (say perhaps under the *Conrad* discontinuity) where deep seated faults (shear-faults) allow release of stresses along sidewards stress gradients.

Dr. P. Hedervári: I think that my so called vertical model corresponds to the second possibility, mentioned by Professor van Bemmelen.

Dr. J. H. Latter (Wellington, New Zealand): Your comments on the Matsushiro swarm and the inactivity of Asama sound very convincing. I have not heard this suggestion made before.

Dr. P. Hedervári: Dr. Latter's words refer to the so called horizontal model. The essence of this model is the supposition according to which subterrain connections between neighbouring volcanoes are possible. In our present case the volcanoes in question are Asama-yama and Minakami-yama, respectively, although the latter is considered to be extinct since one or more hundred thousands of years. Regarding the possible existence of such subterrain relations I wish to refer to two volcanoes. The first belongs to the category of those volcanoes the magma of which is basaltic, poor in gases and has a relatively low viscosity. Its explosive index is generally low except some rare cases of phreatic eruptions. The second example — on the contrary — has a magma of rhyolitic composition which is very rich in gases and has a relatively high viscosity. Its explosive index is very high. Thus we have to do with two extreme cases. Asama-yama, which has a Volcanian character with medium gas-content and a medium viscosity, is placed at about half-way between these two extremities.

The first case is the combined Kilauea Iki — Kapoho eruption in Hawaii. According to the Atlas of Volcanic Phenomena (U. S. Geological Survey, authors are J. P. Eaton and R. G. Schmidt, respectively, Sheet 19):

"*The most spectacular eruption of Kilauea Volcano in modern times started at the satellitic crater of Kilauea Iki (Little Kilauea), lying just outside the main caldera, in late 1959. The eruption occurred in 3 stages:*

1st Stage – Summit eruption at Kilauea Iki. *In early October 1959, earthquakes at Kilauea Caldera multiplied as the entire summit region swelled in response to rising magma. At 8:00 p.m., November 14, lava fountains erupted from a rift 1,200 feet long on the south wall of Kilauea Iki, and cascades of lava poured into the crater. On the following day the euption narrowed to a single strong fountain at the west end of the crater. This stage continued intermittently until December 21.*

2nd Stage – Flank eruption at Kapoho. *Following the eruption at Kilauea Iki, seismic tremors continued* as subterranean lava moved outward *beneath the east rift zone. On January 13, 1960, a flank eruption occurred from a fissure half a mile long on the east rift zone near Kapoho Village,* about 28 miles (some 45 km – P. H.) *east of the summit caldera. The eruption soon became restricted to a single powerful fountain that at times attained a height of 1,400 feet or more. Lava from this vent poured eastward to the ocean, forming a fan-shaped flow that covered an area of about 4 square miles. This stage of the eruption ended on February 19, 1960.*

3rd Stage – Collapse of Halemaumau crater. *Four days after the start of the Kapoho eruption, the summit of Kilauea began to sink as lava drained from beneath the caldera and moved into the east rift zone. On February 7 the entire floor of Halemaumau settled about 150 feet, and a small circular area in the center dropped another 200 feet. Two additional secondary pits were formed by local collapse — one on February 9, the other on March 11 — to end the eruption.* (Italics mine – *P. H.*).

In the summary of a paper, written by P. Bordet, G. Marinelli, M. Mittempergher and H. Tazieff, respectively (Contribution a l'étude Volcanologique du Katmai, etc., Mémoires de la Soc. Belg. de Géol., Série in-8°, No. 7, 1963) we can read the following important statement:

The June 1962 activity consisted, first in a strong subcrater-lake fumarolic activity in the Katmai caldera and a powerful gasblast activity on the cumulo-dome of Mt. Trident; it was followed by a violent and short explosive eruption at the Trident dome, and by a dead stop of the Katmai fumarolic activity; it looks to the authors as a confirmation that, remembering the 1912 Katmai - Nova Rupta concomitant eruptions, underground connections do exist under the Katmai District volcanoes. These connections could be regional tectonic faults, *the working of which may, as in 1912, exactly precede, or accompany, the eruption. These characteristics are very exceptional indeed, and should deserve a thorough field analysis, both volcano-tectonical and seismological*". (Italics mine – *P. H.*)

Concerning the Katmai-events of 1912 we may add, after P. L. Ward and T. Matumoto (A Summary of Volcanic and Seismic Activity in Katmai National Monument, Alaska; Bull. Volc., **31**, 1967, p. 12), that: "... *the majority of the activity came from Novarupta, a crater 10 km west of Mt. Katmai... It is through that after this* (volcanic — *P. H.*) *material had been drained out through or near Novarupta, but from under Mt. Katmai, Katmai's summit collapsed*". (Italics mine – *P. H.*)

Taking now into consideration these interesting observations we can really suppose that subterrain connections between neighbouring volcanoes (by the presence of 10-45 kilometres long, regional tectonic faults within the uppermost 10-15 kilometres of the solid crust) may be possible, perhaps in the case of whatever volcanoes, that is *independently from the type* (*character*) *of activity.* By other words the observations concerning the Kilauea Iki – Kapoho event on one hand and the Katmai – Nova Rupta – Mt. Trident events on the other are in favour of my horizontal model.

APPENDIX

According to the results of recent investigations, carried out by the author (see: RGPGV Report No. 6, August, 1976) the Matsushiro earthquake swarm was preceded by three intermediate, furthermore one deep and one shallow shocks, all took place in 1965 near the area considered (data are given originally in J. P. Rothé: The Seismicity of the Earth, 1953-1965, Paris, 1969). The data of the shallow shock are: 1965.04.19., 34.9° N, 138.0° E, $h = 50$ km, $M = 6.3$. That is this was a rather powerful earthquake, that occurred at only 220 km southwest of Asama-yama. By all likelihood *this shock might have had a triggering role* which caused the commencement of the movement of the magma from the secondary chamber of Asama-yama through the subterrain fault or fissure towards and under Minakami-yama, just near Matsushiro, corresponding to the so called horizontal model. In RGPGV Report No. 6. some further examples are treated when tectonic earthquakes of shallow origin triggered volcanic eruptions in the near proximity of the epicenter.

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REFERENCES

(1) HAGIWARA, Y., 1966. – *Natural Radioactivity in the Matsushiro Earthquake Area.* "Bull. Earthq. Res. Inst." "BERI"), **44**, 3.

(2) HAGIWARA, T., IWATA, T., 1968. – *Summary of Seismographic Observation of Matsushiro Swarm Earthquakes.* "BERI", **46**, 3.

(3) HAMADA, K., HAGIWARA, T., 1966. – *High Sensitivity Triparite Observation at Matsushiro Earthquakes.* Part 3., "BERI", **44**, 4.

(4) HAMADA, K. - HAGIWARA, T., 1967. – *High Sensitivity Triparite Observation at Matsushiro Eacthquakes,* Part 4. "BERI", **45**, 1.

(5) KASAHARA, K. et al., 1968. – *Electro-Optical Measurements of Horizontal Strains Accumulating in the Swarm Earthquake Area* – Part 4. "BERI", **46**, 3.

(6) KASAHARA, K., 1970. – *The Source Region of the Matsushiro Swarm Earthquakes.* "BERI", **48**, 4.

(7) KUNO, H., 1962. – *Catalogue of the Active Volcanoes of the World. Part XI:Japan, Taiwan and Marianas.* Napoli.

(8) MACHADO, F., 1965. – *The Messina Earthquake of 1908 and the Magma Chamber of Etna.* "Bulletin Volcanologique", **28**.

(9) MACHADO, F. 1965-1966. – *Anomalias das Intensidades do Terramoto de S. Miguel (Açores) em 1522.* Boletim do Museu e Laboratório Mineralogico..., **10**, 2.

(10) MINAKAMI, T., 1960. – *Fundamental Research for Predicting Volcanic Eruptions* – Part 1. "BERI", **38**, pp. 497-544.

(11) MOGI, K., 1958. – *Relations between the Eruptions of Various Volcanoes and the Deformation of the Ground Surface around them.* "BERI", **36**, pp. 99-134.

(12) MORIMOTO, R. et al., 1966. – *Geological Consideration on the Matsushiro Earthquake Swarm since 1965 in Central Japan.* "BERI", **44**, 1.

(13) RIKITAKE, T. et al., 1966-1967. – *Geomagnetic and Geoelectric Studies of the Matsushiro Earthquake Swarm* – Part 1. "BERI", **44**, 1. Part 4. "BERI", **44**, 4. Part. 5. "BERI", **45**, 2.