System of Volcanic activity

P. HÉDERVÁRI (*)

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SUMMARY. — A new system (classification) of volcanic activity is presented for the fast determination of certain important data on the basis of the observed characteristics of phenomena in the case of a given eruption. The main purpose of the present paper beside this is to show the extremely wide variety of the mechanism of volcanic activity.

The system is based on the gas-content of fresh lava on one hand and on the viscosity of it on the other. The classification is basically similar to the system published by Professor R. W. van Bemmelen. The new system — however — differs from the original one of van Bemmelen since the present author took into account some subtypes and transitions among the classical types. On the other hand the author introduced some further types into his new system, for instant the "Alphonsus" type, the "Rift-valley" type, etc. Altogether 28 more or less different types are distinguishable. The sum of the subtypes is not included.

RIASSUNTO. — Viene esposto un nuovo sistema (classificazione) di attività vulcanica per l'accurata determinazione di certi importanti dati, tenendo conto delle caratteristiche dei fenomeni osservati nel caso di alcune eruzioni. Oltre a ciò, lo scopo principale della presente nota è quello di far vedere quanto estremamente vasta sia la varietà del meccanismo dell'attività vulcanica.

Il sistema si basa sia sul contenuto di gas della lava fresca sia sulla sua viscosità.

La classificazione è fondamentalmente simile al sistema studiato e pubblicato dal Prof. R. W. van Bemmelen. Il nuovo sistema, tuttavia, differisce da quello originale di van Bemmelen perché nel presente lavoro l'autore prende in considerazione — fra i tipi classici — alcuni sottotipi e tran-

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(*) Dr. rer. nat., F.R.A.S., Vice-President of International Association of Planetology (IUGS-UNESCO); President of International Lunar Society: Budapest (Ungheria).

sizioni. D'altra parte l'autore introduce nel suo nuovo sistema, ulteriori tipi, quali l'« Alphonsus », il « Rift-valley » etc. Complessivamente è possibile distinguere circa 28 tipi diversi, ai quali va aggiunto l'insieme dei sottotipi già citati.

Introduction.

In the volcanology there is a classical system of the volcanic activity, the short history and the base of which were described almost in all of the volcanological textbooks. We may refer here only to four of them: Bullard [3], Cotton [4], Rittmann [17] and Tazieff [19].

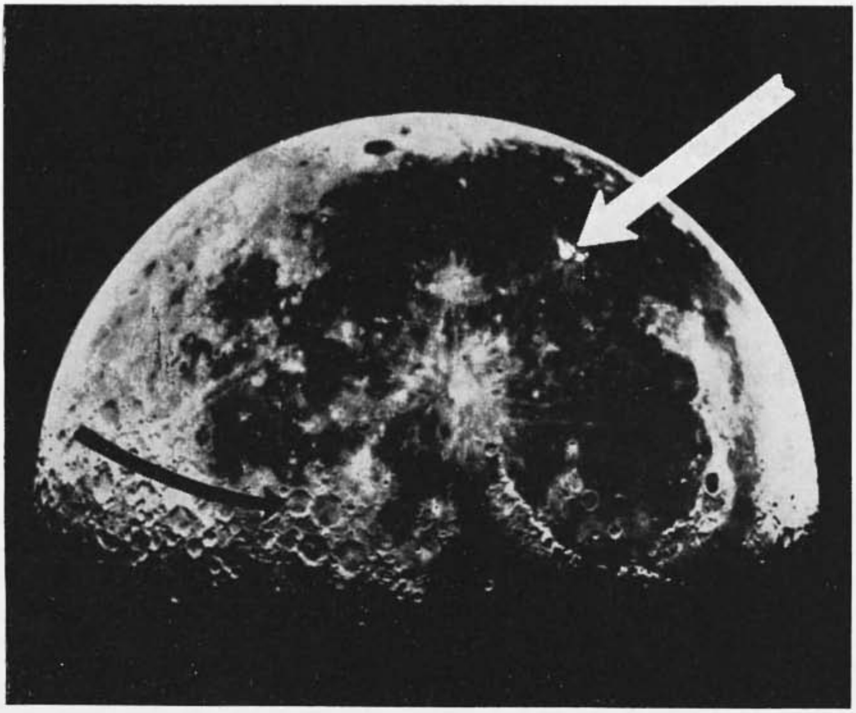

Photo 1 – The site of the two most active areas of the lunar surface. Black arrow: Alphonsus, white arrow: Aristarchus.

In two brilliant papers, van Bemmelen [1,2] has presented a classification on *entirely physical base*, namely on the basis of *viscosity* and *gas-content* of fresh lava. This excellent system consists of all the most important fundamental types (classes) of eruptions, but without the possible transitional- and subtypes.

In the present paper the author is trying to enlarge the system of van Bemmelen and thus to include the important transitional- and subtypes into the new classification. It is possible now, owing to the valuable new results of the recent theoretical and field investigations, carried out by volcanologists over different parts of the world.

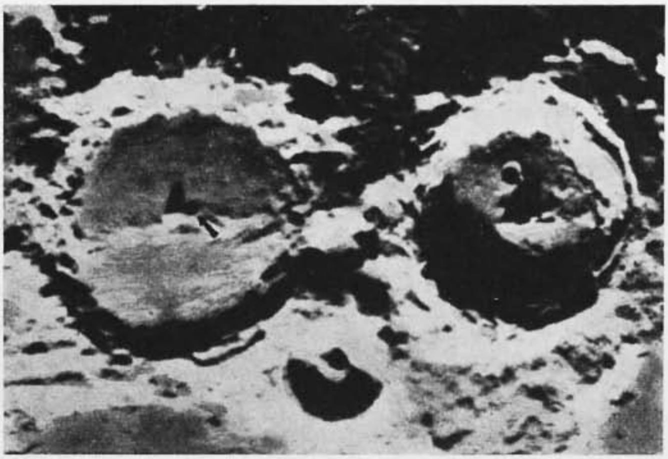

Photo 2 – The Alphonsus. The small arrow shows the site of the new reddish spot, observed by Wilkins.

Needless to say that this new system is more complicated than that of the original one of van Bemmelen. Its main purpose is twofold. *Practically:* in spite of the difficulties arising by the complicated form of the new system, the author hopes very much that this classification may be useful for the experts, as a work-help table for the fast, approximate determination of many data, taking into account the main characteristics of the observed factors in the case of a given eruption. However, to use the system in the practice really is not too easy, since the system is somewhat too elaborated and in many cases it goes into the thiniest details as well. The question, whether the respective system really is useful in the practice or not, will be answered in the future by those experts who will try to apply it. It is possible that some alterations, especially simplifications will be required.

Concerning this point it must be emphasized that *there are neither "absolute cathegories" nor "pure types". Every volcano is a unique* *"individuality" and the character of eruptions may change between two successive cycles of activity of the same volcano, the more, it may change during one cycle of eruptions.* As Professor van Bemmelen had the kindness to call the author's attention: "On the top of every volcanic cycle the activity is unique in its own way, apart from some general characteristic trends" (personal communication). These general characteristics are given in van Bemmelen's original system. During one cycle of activity, or during more cycles which follow each-other in the case of the same volcano, several types of activity might be shown successively. Accordingly, *the theoretical purpose of the present paper is to show the great variousness, the manifoldness of the external volcanic phenomena.*

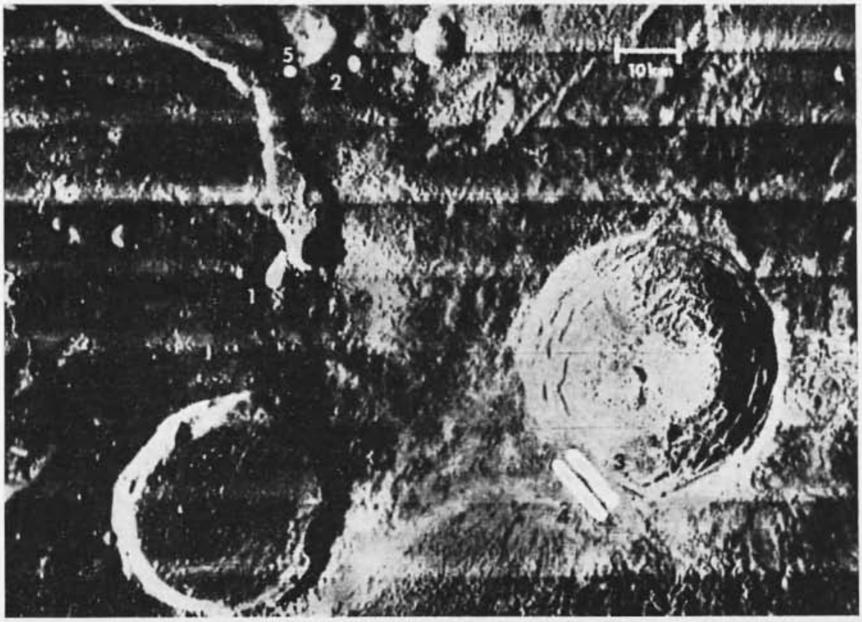

Photo 3 – The site of five reddish patch near to Aristarchus.

To make distinctions among the different kinds of volcanic activity often is rather difficult, especially in the case when the place of a volcano inside the system is very near to the place of an other one. They have many common features, while other characteristics of them may be different. It is not possible to set sharply a limit between the respective types. For example: according to Professor van Bemmelen (also personal communication) *the most important* aspects, determining the classification in the case of types 25 (Vesuv-II) and 26 (Santorin) were the high explosivity, self-induction and the terminal *Perret*-phase; while the other aspects, which represent rather differences than similarities between them, had only a *secondary role*. Such secondary factors were as follows:

The Vesuv in 79, A. D., — as well as the Merapi in 1006, A. D., — were destroyed by gravity slides, producing the somma walls, but not caldera's, while in the case of the so called Minoan eruption of Santorin a mighty caldera originated by the collapse of the roof of the magma reservoir. The eruption of Vesuv in 1906 A. D. destroyed only the top part of the volcanic cone.

* * *

To use the elaborated new system — in spite of its rather complicated form — the knowledge of *only two data*, which are at the same time the base of van Bemmelen's system as well, is indispensable. However these two data are basic and of capital importance. The respective data are as follows:

a) *The viscosity (or the silica content) of the fresh lava.*

b) *The gas-content of it.*

VAN BEMMELEN'S SYSTEM.

It is a table in which the different eruptions are classified as the function of the gas-content of the erupted magma on one hand and of the viscosity of it on the other (Table I).

Table I.

Viscosity	Gas-content		
	Low	Medium	High
Low (basic composition)	Lava sheets (A)	Strombolian (D)	(Ytrian) (G)
Medium (intermediate composition)	Lava tongues (B)	Vulcanian (E)	Plinian (H)
High (acid composition)	Lava plugs and domes (C)	Peléean (nuées ardentes) (F)	Ignimbritic (J)

Van Bemmelen has mentioned that the so called Ytrian type (G) represents an exceptional case, namely the high gas-content was the consequence of the sudden melting of an ice-sheet, under which a fissure-eruption had taken place. Also according to him the types A,

Photo 4 – Electrical phenomena during the eruption of Vesuv in 1944

B and C are non-explosive, but extrusive ones. The types D, E and F are characterised by short explosive eruptions. Lastly, types G, H and I are characterised by great quantity of erupted magma and explosions of extreme violence. In types H and I the magma is transforming into tephra still in the depth, during the rising-process of the rock-melts. While in type H the eruption belches out the magma through a volcanic crater, in case of type I the magma reaches the surface generally throughout fissures. In case of type H the paroxysm takes place during the so called *Perret*-phase (gas-phase, see later), at the end of Plinian activity, during or after that a gravity slide (Vesuv, 79 A.D.) or a total collapse (Krakatoa, 1883) of the volcanic structure may occur. Also according to van Bemmelen, the Bronze Age ("Minoan") eruption of Santorin (between 1500 and 1400, B.C.) belonged to types H and I.

AUXILIARY TABLES.

Owing to certain difficulties in the printing-technique, it is not possible to publish the author's new system as a table but only as a drawing (see Fig. I). It is necessary to supplement the respective drawing with some auxiliary tables, which contain some important features of the fundamental types (classes). The drawing (Fig. I) and these auxiliary tables *must be used simultaneously* (that is *together*). As a result of such a procedure we can obtain many further informative data regarding the volcano which is under consideration — on the basis of its position in the new system.

The first auxiliary table is represented in Table II.

Table II.

Viscosity	Gas-content		
	Low	Medium	High
Very low (ultra-basic)	Ultrabasic Class (J)		
Low (basic)	Lava Sheet Class (A)	Strombolian Class (D)	
Medium (inter-mediate)	Lava Tongue Class (B)	Vulcanian Class (E)	Plinian Class (H)
High (acid)	Lava Dome Class (C)	Peléean Class (F)	Ignimbritic Class (I)

Comparing Table II with Table I, we can state the fact that some classes of the former (types A, B, C, D, E, F, H and I) are to be found in the latter, too. But type G (Ytrian-type) now is absent, since it is only an exceptional case but not a real fundamental type. Its high gas-content — namely — was the direct consequence of a subglacial eruption. In the Nature the low viscosity and high gas-content don't exist together. Therefore we may regard the respective phenomenon, manifested itself in the case of the Ytri-eruption only as a pseudovolcanic one.

On the other hand we introduced a new class, namely the ultra-basic one (J) — corresponding to Bullard's suggestion (3) regarding the

Table III

Viscosity	Low gas-content
Very low	*ULTRABASIC CLASS.* Lava volcanoes. *Explosivity:* extrusive, non-explosive, E (explosion-index of Rittmann [17]) $\leqslant 5$. *Kind of eruption:* on area and linear, predominantly slow lawa-flows, sometimes and in some places however submarine eruptions are possible. *Seismicity:* in the nearer-farer proximity of the area of activity the moderate *tectonic* earthquakes of shallow depth (0-70 kms) are very copious.
Low	*LAVA SHEET CLASS.* Lava volcanoes. *Explosivity:* extrusive, non-explosive, $E \leqslant 10$. *Kind of eruption:* central and linear, the latter generally from the fissures on the slope of the volcanic structure, in some places from parasite-craters, which are aligned along such fissures. *Seismicity:* the eruptions of the Hawaiian-type volcanoes (belonging to this class) are often preceded for months by certain volcanic shocks. The hypocentral-depth of these quakes at the beginning of the activity is about 50-60 kms or even greater under the volcano. As the magma is rising towards the surface the hypocentral-depth is decreasing. The surface eruption probably will start when the hypocentral-depth became practically zero kilometer. According to Minakami [13] these shocks belong to the type I (see later). The type II shocks are absent, but the type III shocks (originating from the weak explosions of gases liberated quickly from the basaltic magma) are transformed into the continuous volcanic vibrations (microshocks, shocks of type IV). *Dimensions of calderas of Hawaiian type:* according to Yagi [24] there exists a relationship between the diameter of calderas and the SiO_2-content of the lava. On the basis of Yagi' diagrams [24] (imposed on the data of about 40 calderas), the diameter of calderas of Hawaiian type is $\leqslant 11$ kms.
Medium	*LAVA TONGUE CLASS.* Lava volcanoes. *Explosivity:* extrusive, non-explosive, $E \leqslant 10$. *Kind of eruption:* central and linear. *Seismicity:* predominantly volcanic microshocks.

Table III (cont.)

Viscosity	Low gas-content
High	*LAVA DOME CLASS.* Lava volcanoes. *Explosivity:* extrusive, weakly explosive, $E = 10$. *Kind of eruption:* central. *Seismicity:* at the beginning of activity type I shocks with decreasing hypocentral-depth; later extraordinary crustal deformations (chiefly rising of the ground) may occur and type II shock-swarms at the same time with shocks of type I; at last type II earthquakes are present exclusively. (This example is valid for the case of volcano Showa Sinzan).

Table IV.

Viscosity	Medium gas-content
Low	*STROMBOLIAN CLASS.* Mixed, lava-rich volcanoes. *Explosivity:* moderate, $11 \geqslant E \leqslant 33$. *Kind of eruption:* central. *Seismicity:* continuous volcanic microshocks, pulsations (due to the moderate detonations) from a depth of maximally 1 km under the bottom of active crater (type IV shocks); furthermore type I shocks from a depth of 1-10 kms, sometimes directly preceding the eruptions, but in some other cases without effective surface eruptions, as indications of the gas-explosions and movements of magma in the depth. *Intensity of eruption:* (the explanation of this notion will be given later) generally is V°-VI° [22].
Medium	*VULCANIAN CLASS.* Mixed, intermediate volcanoes. *Explosivity:* strong, $34 \leqslant E \leqslant 66$. *Kind of eruption:* central and linear (very many parasi-et craters are to be found along splits on the slopes of volcanic structure, for example on the slope of Etna). *Seismicity:* type III shocks of explosive origin, their energy is somewhat higher than that of the type II shocks (which are also common from a depth of about 1-2 kms). Sometimes (for instance in the Sakurazima case) there are type I quakes, too, but their

Table IV (cont.)

Viscosity	Medium gas-content
	number relatively is small. *Intensity of eruption:* generally is VI°-VII°.
High	*PELEÉAN CLASS.* Mixed volcanoes, rich in solid fragments. *Explosivity:* very strong, $E \geqslant 67$. *Kind of eruption:* central. *Seismicity:* shocks of type III in connection with the strong detonations. *Intensity of eruption* (Mont Pelée, 1902): VII°.

Table V.

Viscosity	High gas-content
Medium	*PLINIAN CLASS.* Mixed volcanoes, rich in solid fragments. *Explosivity:* very strong, $E \geqslant 67$. *Kind of eruption:* central and — sometimes — linear. *Seismicity:* as the Plinian class essentially is the violent version of the Vulcanian Class, its seismic properties are similar to that of the Vulcanian Class. *Intensity of eruption:* generally $\geqslant$ VII°. *Dimensions of calderas of Krakatoan type:* SiO_2: 54-55%, diameter: 1-5 kms » 57-64%, » 1-15 kms » $\geqslant$ 65%, » 10-26 kms or even greater. (The estimations regarding the dimensions of calderas of Hawaiian and Krakatoan types are rather rough ones).
High	*IGNIMBRITIC CLASS.* Predominantly tephra volcanoes. *Explosivity:* extremely strong, $E > 67$. A part of the volcanic structure may be destroyed. *Kinp of eruption: subordinately* and sometimes central eruptions may *also* occur, but *predominantly* the eruption is linear. *Seismicity:* accepting the Gorshkov' (6) opinion, according to which the 1955-56 eruption of volcano Bezymianny of Kamchatka belonges to the Ignimbritic Class and thus it must be very similar to the eruption of Katmai of Alaska in 1912, this class of eruptions is started and the paroxysm is

Table V (cont.)

Viscosity	High gas-content
	preceded by many ten-thousands of rather strong earthquakes of *volcanic* origin. According to the field investigations, carried out by Tazieff et al. (20) — however — the Bezymianny eruption and the Katmai eruption represent two different kinds of activity, in spite of some real and interesting similarities between them. The most important argument against the Gorshkov's view is that in the Bezymianny case there was no any ignimbrite at all. According to Richter (16) immediately following the start of the Katmai eruption, along the Alaskan coast, rather near to the volcano, two earthquakes occurred, on June 7th, and 10th, 1912; strong the former ($M = 6.4$), very strong the latter ($M = 7$). Both shocks were of tectonic origin. However we have no evidence whether these earthquakes might have been in direct connection with the Katmai eruption or not. Also, we have no data about the seismic phenomena, preceding the eruption of Katmai, since the volcano is lying in a rather great distance from the seismological stations and at the time of the respective eruption in 1912, only very few seismological observatories had been working on the world. Accordingly the seismic properties of a real ignimbritic eruption is not known as yet.

introduction into the cathegories a type, he called as Icelandic one. The Ultrabasic Class is characterised by a very low viscosity and a low gas-content.

Some important data concerning the new classes (J, A, B, C, D, E, F, H and I) are to be found in Tables III., IV and V, respectively.

Phreatic and phreatomagmatic eruptions.

The exact definitions of phreatic and phreatomagmatic eruptions were given recently by Neumann van Padang (14). Accordingly: *phreatic eruption* is caused by the expansion of volatile matter above the roof of an igneous body. The ejecta blown out at relatively low temperature contain *no fresh incadescent matter*. However, in some cases fresh magmatic material may accompany a phreatic eruption.

Photo 5 – Electrical phenomena during the birth of Surtsey in 1963.

In those cases Stearns and MacDonald called the *phreatommagatic eruptions*. It is a volcanic eruption or explosion, ordinarily of extreme violence, produced when an ascending magma comes into contact with *ground water*. Essential as well as accessory ejecta are expelled. Such eruptions differ from typical magmatic explosions where the gases are chiefly derived from the magma ([14]) [pp. 660, 661, 663].

Table VI.

Viscosity	Medium or high gas-content
Medium or high	*PHREATIC AND PHREATOMAGMATIC ERUPTIONS.* Predominantly tephra-volcanoes. *Explosivity:* very strong, $E \geqslant 67$. *Kind of eruption:* central in meaning that usually the top-part of the volcanic structure (on which the central crater can be found) is destroyed by the strong detonations (for example: Bandai-san, 1888). Surface lava-flows usually don't exist, except the case of certain phreatomagmatic eruptions. *Seismicity:* type I shocks from a depth of 0,8-5 kms, the overwhelming majority of them come from a depth of 1-2 kms, within a circle with a radius of about 1,5 km measured from the central crater on the top of the volcanic structure. There are no type II and IV earthquakes (this latter statement is valid for the Hakone-eruption in 1960). Strong ground-motions of type III shocks are common as the consequence of the fast detonations. There may be — however — exceptional cases, for instance the phreatomagmatic eruption of volcano Taal in 1965 was not preceded by earthquakes and crustal deformations. *Intensity of eruption:* generally it is I-IV°, sometimes much higher (Taal: V°, Bandai-san: VII°).

In our system this kind of eruptions received the serial number 22. These eruptions represent such a case which has a position among *four* classes; namely phreatic and phreatomagmatic eruptions may occur alike in the cases of Vulcanian, Plinian, Peléean and Ignimbritic Classes. Furthermore, as we shall see in the detailed explanation of the system, there are some further types, in which the possibility of phreatic and/or phreatomagmatic eruptions exists.

In Table VI we gave a summary about the most important features of these kinds of eruptions.

Type of volcanic shocks.

It is noteworthy that in the original paper of Minakami ([13]) the signs of different kinds of volcanic earthquakes were type A and type B. The present author prefers the signs of type I, II, III and IV since the letters A and B in our present case mean two classes in the general system of volcanic activity.

Table VII.

Type	Characteristics
I (in Minakami's paper([13]): "A")	Earthquake-swarms usually from a depth of 1-10 kms, sometimes from 20 kms and — rarely — from a depth of 50-70 kms. They have their origin from the mass-movements and gas-explosions inside the magma-chamber and volcanic chimney, respectively. The epicenters are distributed on and around the active crater.
II (in Minakami's paper([13]): "B")	Earthquake-swarms, but from a depth smaller than type I shocks. The hypocentral-depth is about 0,1-1 km. The epicenters are distributed usually within a circle with a radius of 1 km, measured from the center of active crater. They have their origin from the explosions of gases as well as from the movement of magmatic masses, reached a very shallow level from the surface.
III	Earthquake-swarms from the same depth as of type II shocks, but their energy is higher than that of earthquakes of type II. They are the direct consequences of gas-explosions.
IV	Vibrations, pulsations of the ground, micro-earthquakes, tremors, due to the smaller but continuous gas-explosions. Their epicenter is just on the bottom of the active crater: it is the very strange case when the epicenter and hypocenter are the same.

In Table VII we summarized the most important properties of these types of volcanic shocks.

Table VIII.

SiO_2 content, per cent	Period of type IV shocks in seconds		Example
	a) short period	b) long period	
40	0,3 — 0,5		Nyiragongo
40?	0,7		Kitzembanyi
47	0,5 — 0,7	2,5 — 3,5	Kilanea
52	0,2 — 0,5		Mihara-yama
53	0,3 — 0,5		Aso-san
55 — 59	0,1 — 0,2	0,35 — 0,6	Paricutin
60	0,25 — 0,35		Sakura-zima

According to Shimozoru and Berg (18), the microshocks, belonging to type IV, can be classified into two groups, in accordance with the length of their period. It seems that the length of period is in a certain connection with the SiO_2-content of the erupted lava and — perhaps — at the same time with its temperature (Table VIII).

Disregarding from the case of Nyiragongo we can perceive the fact that the length of period of the microshocks generally is decreasing with the increase of SiO_2-content of erupted lava. Evidently it is in certain connection with the fact that the viscosity depends on the SiO_2-content.

Intensity and energy of eruptions.

As regards the *intensity* of eruptions we can refer to Tsuya (21), according to him the intensity is the function of quantity of ejecta (Table IX).

Table IX.

Intensity degree	Limit of volume of ejecta km^3
0	Volcanoes showing fumarole activity only
I	$<$ 0,00001
II	0,00001 — 0,0001
III	0,0001 — 0,001
IV	0,001 — 0,01
V	0,01 — 0,1
VI	0,1 — 1,0
VII	1,0 — 10,0
VIII	10,0 — 100,0
IX	$>$ 100,0

The author has established an empirical relationship between *intensity* and *(thermic) energy* of eruptions (9,10). On the other hand, Imbò (12) introduced the notion of *dynamic eruptive energy*. The empirical connection among the intensity, dynamic eruptive energy and the lower and upper limits of thermic energy *of the same eruption* can be found in Table X (11).

Table X.

Intensity degree	Quantity of lava or tephra m^3	Dynamic eruptive energy if the density is 1,8 $gr \cdot cm^{-3}$ ergs	Thermic energy, in ergs: in case of lava volcanoes	Thermic energy, in ergs: in case of volcanoes, the ejecta of which predominantly is tephra
I	$< 10^4$	$< 0{,}8 \cdot 10^{19}$	$5{,}25 \cdot 10^{19}$ — $4{,}79 \cdot 10^{20}$	$1{,}00 \cdot 10^{19}$ — $1{,}00 \cdot 10^{20}$
II	10^4 - 10^5	$0{,}8 \cdot 10^{19}$ — $0{,}8 \cdot 10^{20}$	$4{,}79 \cdot 10^{20}$ — $4{,}37 \cdot 10^{21}$	$1{,}00 \cdot 10^{20}$ — $1{,}00 \cdot 10^{21}$
III	10^5 - 10^6	$0{,}8 \cdot 10^{20}$ — $0{,}8 \cdot 10^{21}$	$4{,}37 \cdot 10^{21}$ — $3{,}98 \cdot 10^{22}$	$1{,}00 \cdot 10^{21}$ — $1{,}00 \cdot 10^{22}$
IV	10^6 - 10^7	$0{,}8 \cdot 10^{21}$ — $0{,}8 \cdot 10^{22}$	$3{,}98 \cdot 10^{22}$ — $3{,}63 \cdot 10^{23}$	$1{,}00 \cdot 10^{22}$ — $1{,}00 \cdot 10^{23}$
V	10^7 - 10^8	$0{,}8 \cdot 10^{22}$ — $0{,}8 \cdot 10^{23}$	$3{,}63 \cdot 10^{23}$ — $3{,}31 \cdot 10^{24}$	$1{,}00 \cdot 10^{23}$ — $1{,}00 \cdot 10^{24}$
VI	10^8 - 10^9	$0{,}8 \cdot 10^{23}$ — $0{,}8 \cdot 10^{24}$	$3{,}31 \cdot 10^{24}$ — $3{,}02 \cdot 10^{25}$	$1{,}00 \cdot 10^{24}$ — $1{,}00 \cdot 10^{25}$
VII	10^9 - 10^{10}	$0{,}8 \cdot 10^{24}$ — $0{,}8 \cdot 10^{25}$	$3{,}02 \cdot 10^{25}$ — $2{,}75 \cdot 10^{26}$	$1{,}00 \cdot 10^{25}$ — $1{,}00 \cdot 10^{26}$
VIII	10^{10} - 10^{11}	$0{,}8 \cdot 10^{25}$ — $0{,}8 \cdot 10^{26}$	$2{,}75 \cdot 10^{26}$ — $2{,}51 \cdot 10^{27}$	$1{,}00 \cdot 10^{26}$ — $1{,}00 \cdot 10^{27}$
IX	10^{11} - 10^{12}	$> 0{,}8 \cdot 10^{26}$	$2{,}51 \cdot 10^{27}$ — $2{,}29 \cdot 10^{28}$	$1{,}00 \cdot 10^{27}$ — $1{,}00 \cdot 10^{28}$

The new system in detail.

Fig. I shows the new system of volcanic activity, including not only the classes discussed previously but at the same time the types as well as the transitional types, too. The two great arrows show the increase of *explosivity* (EXPL.).

Legend:

PA.PR.: Pacific province of rocks (some examples)

ATL.PR.: Atlantic province of rocks (some examples)

α: abyssal rocks

β: effusive rocks

V_i: viscosity of erupted lava

VLo: very low

Lo: low

Me: medium

Hi: high

GC: gas-content of erupted lava

A, B, C, D, E, F, G, H and **I**: types in van Bemmelen's system

ba: basic andesite, SiO_2: 54 — 57 per cent

ia: intermediate andesite, SiO_2: 58 — 61 per cent

aa: acid andesite, SiO_2: 62 — 65 per cent.

Now let us go throughout the whole system beginning our way from the upper left corner of the Table, from *type 1*.

1. *Rift-valley type.* Very slow but continuous magma-flow from under the thin oceanic crust during millions of years along the great Rift-valley, the axis of Mid-oceanic Ridges, in connection with the phenomenon of *ocean-floor spreading*. In some places (e.g. South of Iceland, in the neighbourhood of volcanic island Surtsey) submarine eruptions are possible.

2. *Icelandic type.* Mighty lava-flows, the consequence of them are large lava-plateaus (e.g. in Columbia, Paraná, Deccan, Iceland). The lava in the overwhelming majority is originated from a primary, non-differentiated, ultrabasic one. In some places there are linear eruptions (Iceland: Laki, Eldgja, furthermore volcanoes along fissures: Katla, Hekla, etc.). The volcanic activity mainly is without

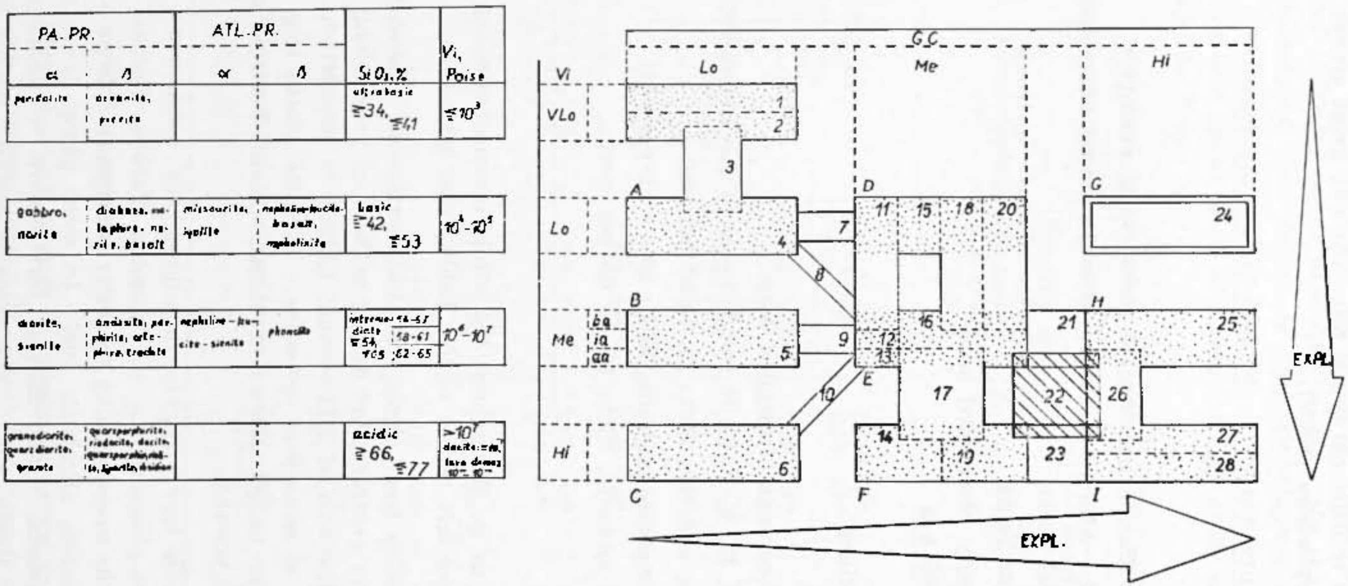

Fig. I – The new system of volcanic activity.

explosions or is with weak or moderate explosions; however the Hekla had such kind of eruption when its explosivity-index reached the value of 39 and the SiO_2-content of its lava had been 58 – 60 per cent, thus the lava was andesite-like temporarily.

Photo 6 – Electrical phenomena during the eruption of Cerro Negro of Nicaragua in 1971: it is surprisingly similar to that of Surtsey. The photo has been made by Ingeniero Franco Penàlba Estudios Penãlba Nicaragua (Special Report of Center for Short-Lived Phenomena, Smithsonian Institution, written by J. G. Viramonte, E. Ubeda and M. Martinez, April 15, 1971.

3. *Lava-lake type.* Basaltic lava, very fluid, on the surface of which thin crust may exists temporarily. Great lava-fountains may occur. "Pelee's hair" and "tear". Very moderate explosivity. Examples: Halemaumau, Nyiragongo.

Drawing II

4. *Hawaiian type.* It is identical with the Lava Sheet Class (see in Table III). Very fluid lava, the speed of which on the flanks of the volcanic structure may reach the value of 40 – 50 kms/hour. The gases can liberate from the lava quickly and easily. Lava-fountains. There is none formation of ashes and scoriae, or if there is, it is only in a very small amount at the vent of the crater. The duration of eruptions may vary from some days to many months. Shield-volcanoes. Examples: Mauna Loa, Mauna Kea, Kilauea.

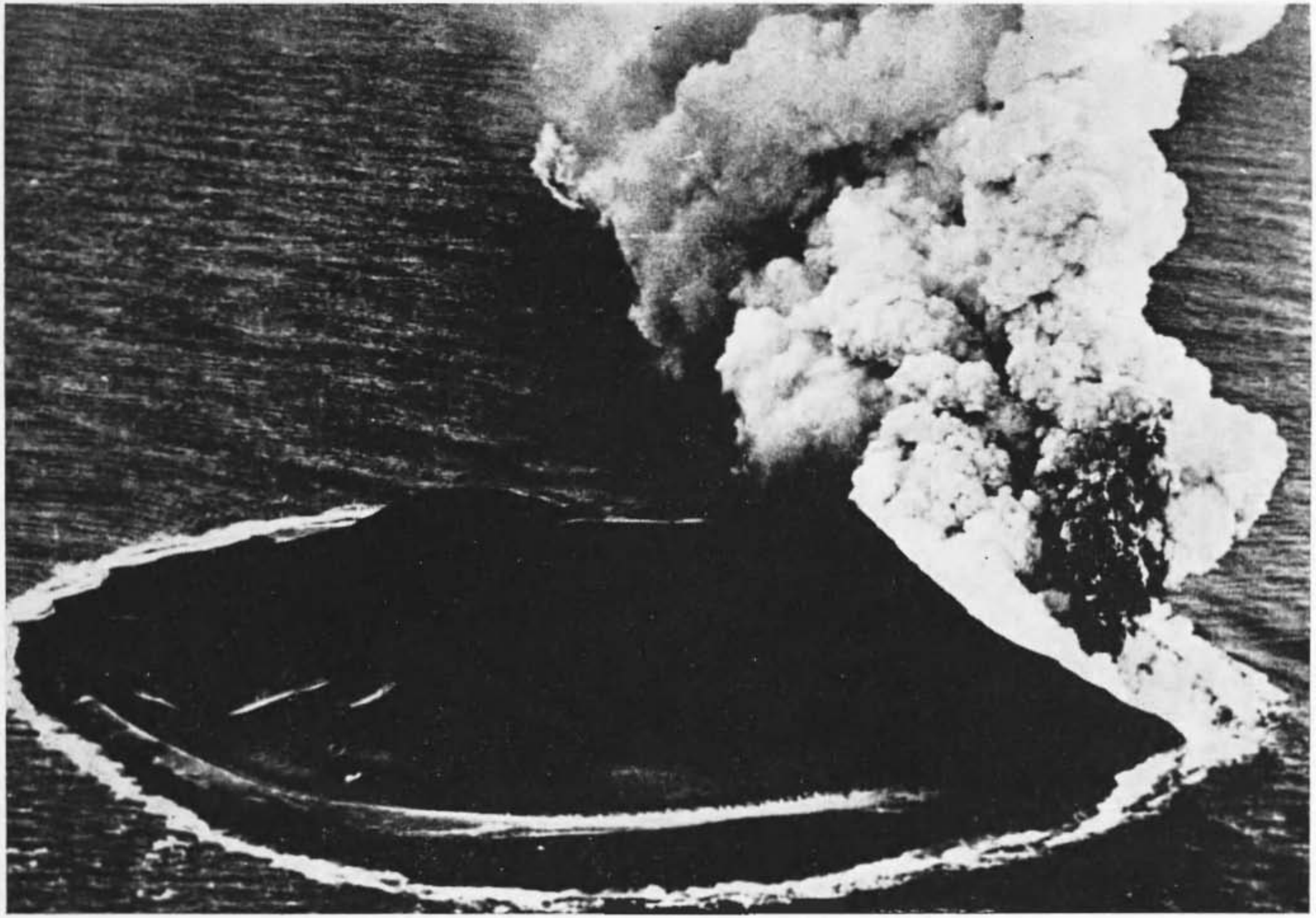

Photo 7 – The cone of Surtsey, originated by submarine activity.

5. *Lava-tongue type.* It is identical with the Lava Tongue Class (see in Table III). Less fluid lava with medium viscosity, usually solidifies in the valleys thus forming there a flat tongue. Similar, subsequent lava-flows on the same place of the respective valleys may lead to an inversion of the relief (4). Classical example: the extinct volcano Mount Egmont, New Zealand.

Photo 8 – Submarine eruption in the Pacific Ocean (Myoozin, 1952).

6. *Lava-dome type.* It is identical with Lava Dome Class (see in Table III). The erupted lava is very viscous. Inside the crater there originates a lava-dome, the dimensions of which are increasing with time. Example: Showa Sinzan, Japan.

7. *Mihara-yama type* (on the basis of its activity in 1950-51). Weak explosions, the quantity of scoriae, ashes and bombs is moderate. From time-to-time the character of activity is purely Hawaiian, in other times it is typically Strombolian.

Photo 9 – The Halemaumau lava-lake at Hawaii.

8. *Polsky Tolbachik type.* This volcano of Kamchatka often has a Hawaiian activity, however on its slopes there are many active parasitic (secondary) craters, similar to the case of Etna.

9. *Alphonsus type.* In 1956, D. Alter has observed a gas-emission in the ring-mountain Alphonsus of the Moon. On the night of November 2, 1958, N. Kosyrev has observed a real volcanic eruption at the central peak of Alphonsus. At first, as he observed, the central peak became deep-red — the cause of this phenomenon probably was the scattering-process of red-hot volcanic ashes and small fragments —, and later the central elevation of the respective ring-mountain became suddenly unusually bright. According to the photo-spectral investigations, carried out during these phenomena, there occurred an emission of C_2 gases. H. P. Wilkins, founder and first president of *Inter-*

Photo 10 – The lava-lake of Nyiragongo in Africa.

national Lunar Society reported later, that after the above mentioned events on the Moon, he discovered a new, elliptical or circular reddish spot with a diameter of 2-3 kms at the foot of the central cone of Alphonsus. This observation had been confirmed later by other explorers, the more, in later years some further gas-emissions and new reddish spatches were also observed. Similar reddish spots had been observed later in other craters of the Moon, too.

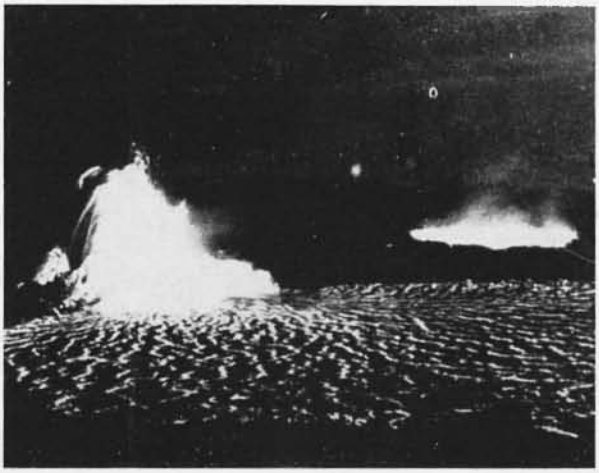

Photo 11 – Lava-flow and fountain on the flank of Mihara-yama (Japan in 1951).

According to Kosyrev the quantity of escaped gases at the observed eruption of Alphonsus in 1958 might have been very small. It was estimated by him to be about 100 000 m^3 only.

The area, on which one can find the ring-mountain Alphonsus, is a continental-like one, the surface rocks of which belong to the intermediate class between the basic and acid rock-categories.

The lava-spot, observed by Wilkins, didn't flow too far from the active vent or crater. Therefore we may suppose that it might have had a character similar to the lava-tongues. Accordingly the Alphonsus type may be regarded as a transitional one between type 5 (lava-tongue) and type 12 (Asama-yama).

It is noteworthy that since these classical first observations of the activity of a lunar volcano, it came into light that the "volcanic" or "transient" lunar phenomena (*TLP* or *LTP*) are rather frequent ones on the surface of the Moon. The transient lunar phenomena can be regarded as:

a) lava and/or pyroclastic-flows with small amount (reddish spatches);

b) gas emissions;

c) scattering of ashes, lapillis and bombs;

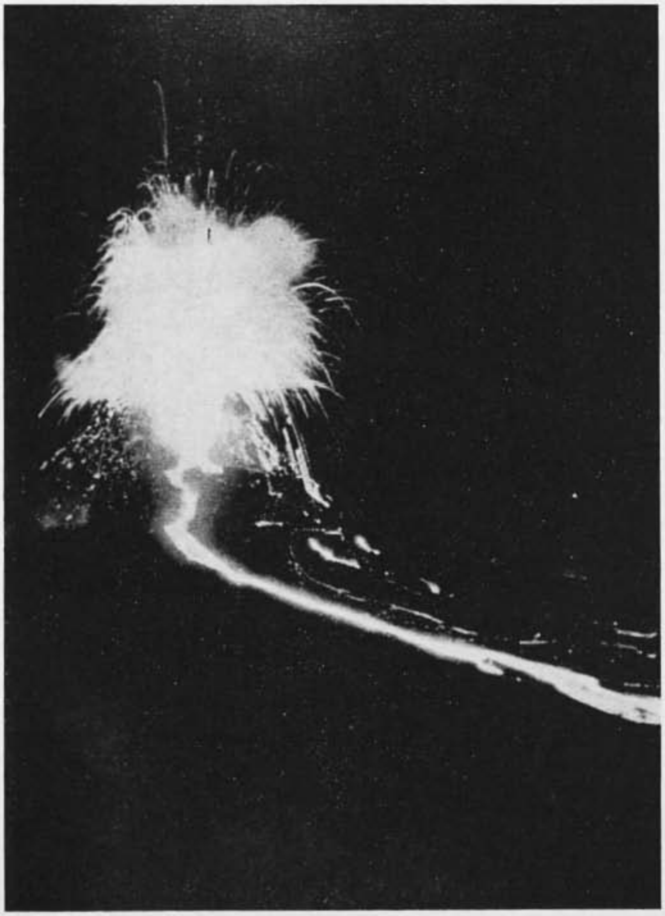

Photo 12 – Lava-flow and glowing fragments at the Nyamlagira, Africa (after Tazieff).

all of which belong to the category of volcanic and/or postvolcanic events.

10. *Shin Iojima — Mjojinsho type.* Both volcanoes were submarine ones near Japan; the former erupted in 1934-35, the latter in

Photo 13 - The lava reaches the houses of San Sebastiano during the eruption of Vesuv, 1944 (after Imbo).

1952. Explosive eruptions, followed by the origin of submarine lava-domes, made up by acid andesite or dacite. Great quantity of pumice on the surface of the open water.

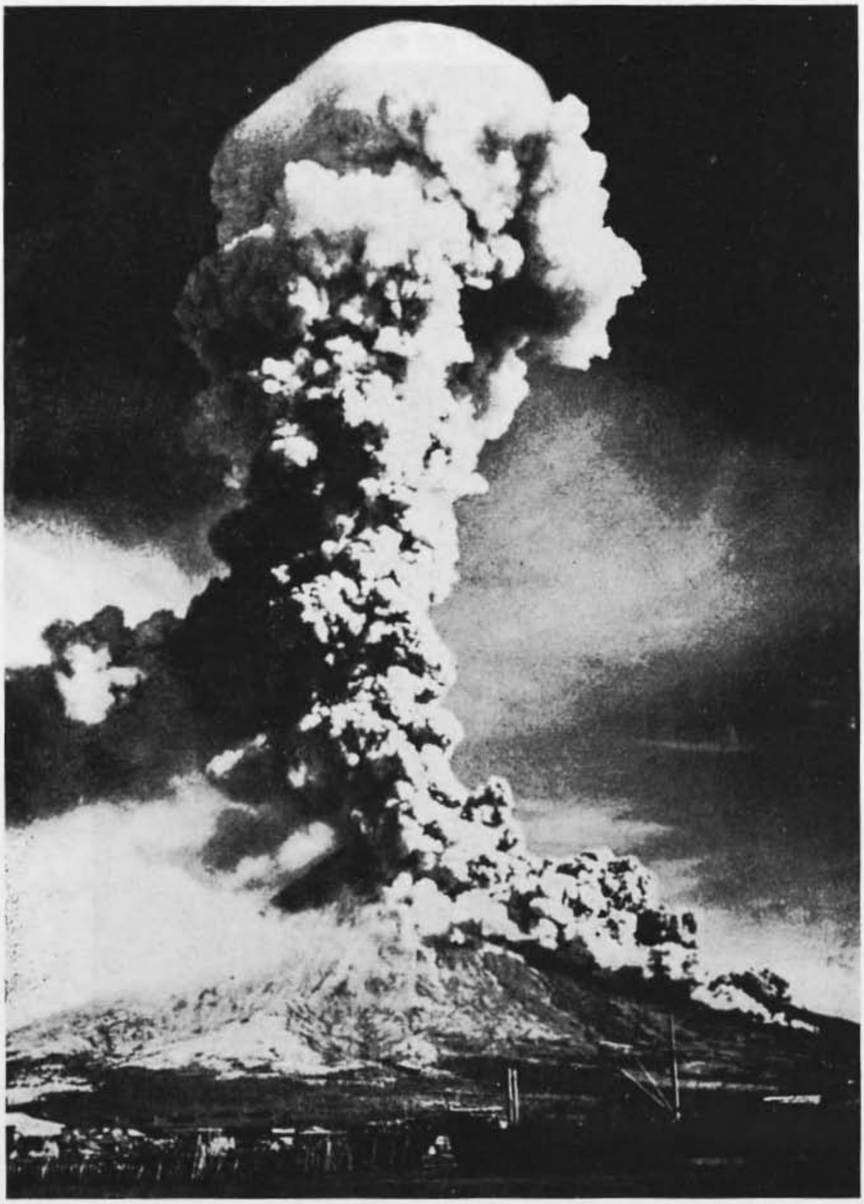

Photo 14 – Eruption-cloud of Mayon (Philippines) in 1938.

11. *Tori-shima type.* It is a transitional type between the Strombolian Class and the Volcanian Class. The lava is basaltic or basic-andesitic. Explosive character, with many bombs, scoriae, ashes and pyroclastic-flows. Examples: Tori-shima (1939), Miyake-zima (1940) and some phases in the activity of Mihara-yama in 1950-51. All mentioned examples are Japanese.

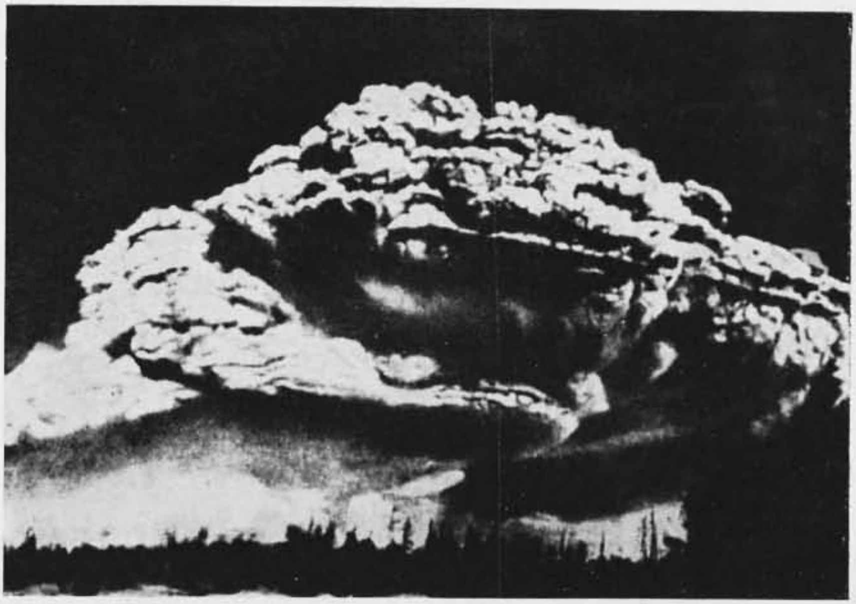

Photo 15 – The 36 km high eruption-cloud of Bezymianny (Kamchatka) in 1956 (after Gorshkov).

12. *Asama-yama type.* It is in a close relationship with the Vulcanian Class. Its lava is transitional andesitic. Lava-flows and pyroclastic-falls as well as pyroclastic-flows. Strong explosivity. Dark ashes-clouds with an height of 1000 metres or more; inside the clouds strange electrical phenomena may occur. Great quantity of pumice. Examples: Asama-yama (1783), Sakura-zima (1914 and 1946), both are Japanese volcanoes.

13. *Tarumai-san type.* It is also in close relationship with the Vulcanian Class and at the same time it is in a somewhat farther relationship with the Lava Dome Class. It differs from types 11 and 12 in the meaning that in its case, — following the explosive erup-

tions — there is a possibility for the origin of domes of acid andesite. Pyroclastic-flows and -falls are also possible. Example: Tarumai-san of Japan in 1909.

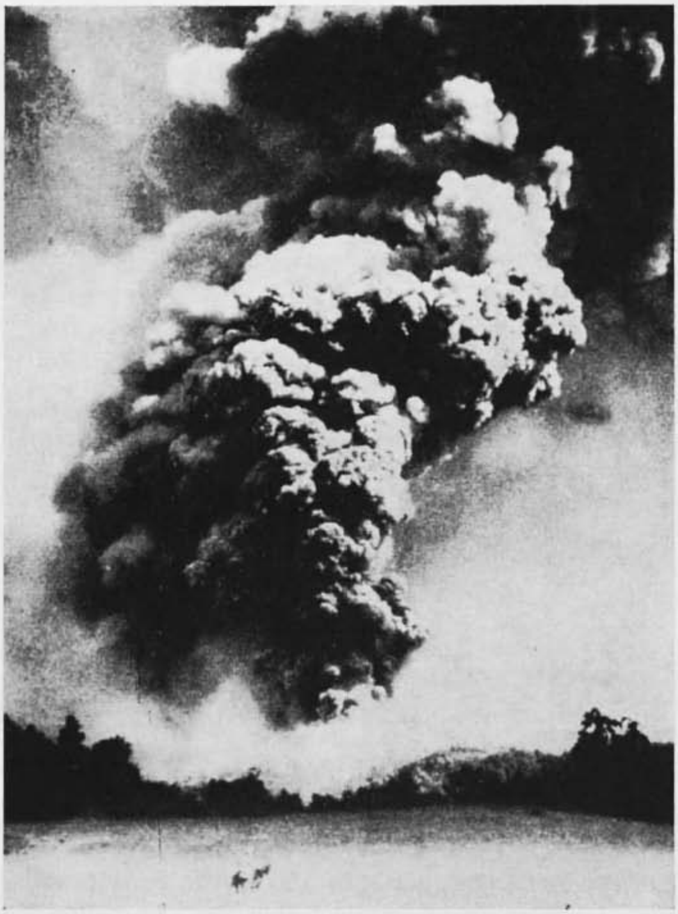

Photo 16 – The birth of Paricutin (Mexico; 1943).

14. *Merapi type.* In very close relationship with the Peléean Class. Very strong explosive activity, swelling dome from a very viscous, usually dacitic lava.

Subtypes:

a) glowing avalanches of explosive origin;

b) glowing avalanches of collapse origin;

c) glowing avalanches of complex explosive-collapse origin.

Photo 17 – A typical califlower-form cloud over the Vesuv (after Imbò).

These subtypes can be experienced from time-to-time in the activity of Javanese volcano Merapi.

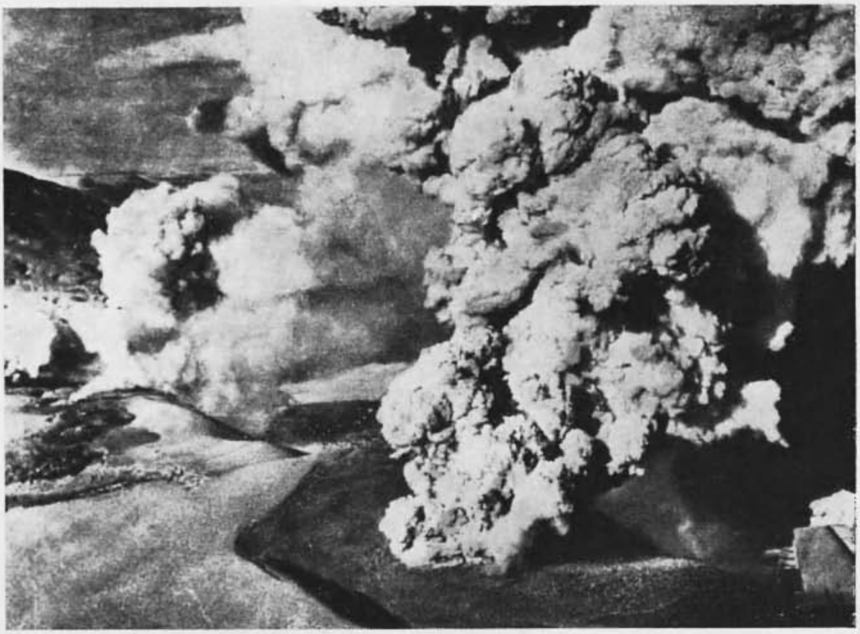

Photo 18 – Eruption of Puyehue of Chile in 1960, immediately following the strongest shock of the great Chilean earthquake-sequence.

15. *Strombolian type.* It is identical with the Strombolian Class (see Table IV). Continuous activity during hundreds and thousands of years. Rhytmic gas-explosions. The gas-pressure however is not too strong. The volcano produces glowing fragments of lava, however the quantity of ashes is very small and thus the eruption-cloud is white. The fragments of lava usually fall into the active crater itself. On the surface of the lava in the crater there is only a thin crust. The explosions break out this crust. A volcano, belonging to the Strombolian type sometimes may have a typically Hawaiian character (for instance: Mihara-yama, 1950-51). On the other hand, a volcano which belongs to the Vulcanian type, may produce phenomena characteristic of the Strombolian activity (for example: Etna, Vesuv). Further examples: Izalco (Salvador), Aso-san (Japan), Alaid (Kuriles), Uracas (Izu-Mariana group).

16. *Vulcanian type.* It is identical with the Vulcanian Class (see Table IV). The name of this type originates from the name of Vulcano of the Lipari-islands, the activity of this volcano between 1888 and 1890 had been typically "Vulcanian". The Vesuv, however, often shows phenomena which are still more characteristic ones by the respective type than that of the Vulcano itself. The Vulcanian type probably is the most common one among the volcanoes of the Earth.

The lava is very viscous. It doesn't remain fluid a long time — on the contrary — it solidifies quickly still in the crater.

Owing to the strong explosivity, the gases carry a great quantity of ashes and other small fragments into the air. Therefore the califlower-shaped eruption-cloud is very dark. The crust of the volcanic bombs is similar to that of the bread. The form of the bombs is often angular. They originated partly from the lava, solidified inside the crater and partly from the older rocks of the crater-walls.

The first part of activity is somewhat similar to that of the Peléean type, but without *nuées ardentes.* The lava-flows are extremely rare, but lava-plugs are possible. The gas-explosions may destroy these plugs. If there are lava-flows, then it is a typical Vesuvian activity (Vesuv-I type which is *not* identical with the Plinian outburst, that is with Vesuv-II type, see later).

Some examples are as follows: Parícutin (Mexico), Asama-yama, Minami-dake, Sakura-zima (not in every cases but casually these three Japanese volcanoes show Vulcanian activity), Anak Krakatoa (Indonesia, inside the Krakatoa-caldera), Palea and Nea Kameni (Greece, inside the Santorin-caldera), Lassen Peak (USA, not in the case of all of its outbursts), Kljuchewskaja, Mali Semjachik, Karymsky, Avachinsky, Chikurachky, Ksudach, Ilinsky, Ebeko, Sarichew, Kizimen, Zupanowsky, Koriatsky, Mutnovsky, Goreli Khrebet, Zelthowsky, Nemo Peak, Raikoke, Berg, Kudriavi, Atsonopuri (Kamchatka).

17. *Tokachidake type* (on the basis of its activity in 1926). Pyroclastic-fall and -flow of andesitic, usually acid andesitic materials. Explosive eruption of dacitic lava is possible. The explosivity is stronger than in the case of the proper Vulcanian type (point 16). It is a transition from the Vulcanian type towards the Merapi- and Peléean types. Examples: Sakura-zima in 1939 (this outburst was followed by a small but typical *nuée ardente*), Komagatake (also of Japan) in 1939. The eruption of Komagatake in 1939 was followed from the emergence of an eruption-cloud with a height of 15 kms (!).

18. *Suwanose-jima type.* Basaltic and basic andesitic eruptions, in close relationship with the Strombolian type (point 15). The detonations are not totally rhytmic, since sometimes there are strong and very strong explosions too, inside a series of the detonations. The pause between two consecutive explosions is rather short, usually some seconds only. Many ashes and scoriae. Example: sometimes the Mihara-yama; in such cases it has an effusive and mixed character. During the last eruption in 1707, the Fuji Yama of Japan showed phenomena characteristic to this type.

19. *Peléean type.* It is identical with the Peléean Class (see Table IV). It is the most explosive type among the other ones, discussed till the present point. Gigantic quantity of fragmentary- and ashes-material. In the crater a lava-plug originates, which may be lifted later by the gas-pressure and thus it forms a lava-spin or lava-tower. The explosions from beneath such a lava-tower have a more or less horizontal direction. There is no lava-flow, except the case when the lava-tower collapses or explodes. *Nuées ardentes* and *directed volcanic blasts* [the denomination of the latter phenomenon is due to Gorshkov (7)] are frequent. These directed blasts, however, are weaker than that of Bezymianny (see in point 23). The directed volcanic blast in case of Peléean type *doesn't* destroy the volcanic structure. Its energy — also according to Gorshkov (7), — is $\leqq 10^{21}$ ergs which is the order of the total explosive energy of an atomic bomb of Bikini-type. The energy of directed volcanic blasts in the Bezymianny case is ten-, hundred, or even thousand-times bigger than in the case of Peléean type.

Subtypes:

a) Lassen Peak (without glowing avalanches);

b) Hibok-Hibok (with glowing avalanches).

Examples: Mont Pelée, 1902. V. 8, V. 20, VIII. 30; Sheveluch of Kamchatka in more occasions between 1946 and 1950; Lassen Peak of California, 1915. V. 19, and V. 22; Lamington of New Guinea, 1951; Hibok-Hibok of Philippines, 1951; La Soufrière of St. Vincent in 1902, preceding with only two days of the great eruption of Mount Pelée of Martinique.

According to Tazieff (19), Nea Kameni, the active volcanic island at the center of the Santorin-caldera, often has a Peléean activity (and in other times it has the characteristics of Vulcanian eruptions, as it was mentioned earlier).

20. *Aso Nakadate type.* It is in close relationship with the Suwanose-jima type, discussed in point 18. Its activity, however, is never effusive or mixed but always fragmentary. The material of its tephra is basaltic or basic andesitic.

21. *Vesuv-I type.* It represents a form of volcanic activity, which directly precedes the Plinian type (see in point 25) and especially the paroxysm of the Plinian eruption. At the same time it is the more violent version of the Strombolian- and Vulcanian Classes. It is sometimes preceded by phreatic activity. The gigantic eruption-cloud has a califlower-shape, which is extremely dark and in which fantastic electrical phenomena may occur (example: the eruption of Vesuv-March, 1944).

The difference between the Vulcanian type and Vesuv-I type is that in the latter case the lava-flows are possible ([3]).

22. *Phreatic and phreatomagmatic types.* See Table VI.

23. *Bezymianny type* (on the basis of the activity of this volcano of Kamchatka in 1955-56). After many thousands preliminary earthquakes a gigantic directed blast occurred and destroyed a great part of the volcanic structure. Pyroclastic-flow with a length of 18 kms. Very strong air-wave(s). New caldera of explosive origin. Inside the caldera a new dome formed from very viscous lava and increased gradually as the time elapsed. However some relationship is without doubt with the eruption of Katmai in 1912 — according to Tazieff ([20]) — their character evidently was not quite the same, against the Gorshkov's opinion ([5]). In the case of Bezymianny — namely — *there was no ignimbrite at all* and the eruption was a *central* one; while in the Katmai eruption *an ignimbritic outbursts* occurred from *linear fissures*.

According to Gorshkov ([8]) the eruption of Seveluch - Kamchatka (November 12th, 1964) also belonged to the Bezymianny type.

24. *Ytrian type.* In accordance with the statements, discussed previously in this paper, the eruption of Ytri had been — for a certain degree — a pseudovolcanic phenomenon, since its high gas-content was the consequence of a subglacial eruption ([2]).

25. *Vesuv-II. (Plinian) type.* One of the main characteristics of such kind of eruptions is the transformation of the form of the top

of volcanic mount, partly and in a smaller measure by very strong explosions and partly, on a larger scale as a consequence of gravity slides, producing the wall(s) of the somma (see the Introduction). Many millions tons of ashes, lapillis and bombs. Extremely dark the eruption-cloud which becomes later similar to the shape of a gigantic pine-tree. Inside the crater there had been a lava-plug, but during the Plinian phase this plug is destroying partly or totally by the force of detonations. After this event there may be lava-flows, sometimes on a great scale. According to Cotton (4) the most violent volcanic outbursts of the human history belonged to this type. Plinian eruptions occur usually after a long dormancy of a volcano. The period of quiescence may be hundreds or thousands of years. According to Cotton the "Pompeian" eruption of Vesuv (79, A.D.) might have been partly a phreatic (ultravulcanian) one.

Perret-phase (gas-phase): the paroxysm of the Plinian type. More details are in Van Bemmelen's paper (2).

Examples for the Plinian type: Vesuv 79, A. D., and Merapi, 1006, A. D.

26. *Santorin type* (on the basis of its prehistoric so called "Minoan" activity, between 1500 and 1400, B. C.). It is in a *very* close relationship with the Plinian type. The only difference between the Plinian type and the Santorin type is that in the Santorin case a great deal of the volcanic structure "disappeared" from the surface of the Earth while in the case of the "Pompeian" eruption of Vesuv only the material of the top of the volcanic mount had been transformed by slide(s).

Disregarding from this difference, the "Minoan" eruption of Santorin had been a typically Plinian one (2,15,22 etc.). The collapse of the volcanic structure was the direct consequence of the collapse of the upper part (roof) of the magma-chamber. However about one per cent of the volcanic mount had been destroyed by effective explosions (Fouqué). Glowing avalanches, *nuées ardentes*, extremely strong air- and sea-waves *(tsunamis)* as well as tornadoes and heavy rains were also possible, probably together with *lahars*. Gigantic quantity of tephra, including pumice. It is possible that the "Minoan" eruption began as a phreatic (or phreatomagmatic) one.

Examples: Mount Mazama (Crater Lake, Oregon) about 6000, B. C.: Tambora (Indonesia) 1815: Krakatoa (Indonesia) 1883. *Tsunamis* occurred in case of Tambora and Krakatoa outbursts.

27. *Katmaian type.* The *only* example for *true ignimbritic* eruptions in the historical times. According to van Bemmelen (1), it differs from the Plinian type in the meaning that its energy as well as the volume of its tephra was still greater than that of the Plinian outburst of Vesuv in 79, A. D. On the other hand the eruption of Katmai of Alaska was not central but linear. Directed volcanic blasts, *nuées ardentes* has taken place. Extremely dark eruption-cloud. The lava had been foamed at the edge of the open fissures. The tephra didn't fly high into the air from the fissures. Origin of ignimbrite. The activity might have started as a phreatic eruption.

28. *Type of prehistoric ignimbritic eruptions.* In the geological past time the ignimbritic eruptions had been more frequent than at present time and they had been still stronger than the Katmai outburst in 1912.

Example: New Zealand.

* * *

As it was partly mentioned earlier, too, the phreatic and/or phreatomagmatic eruptions have or at least may have a role in the activity of types 16, 19, 21, 23, 25, 26, and 27.

* * *

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REFERENCES

(1) BEMMELEN R. W., VAN, *Volcanology and Geology of Ignimbrites in Indonesia, North Italy, and the U.S.A.* "Bulletin volcanologique", XXV, 1963.

(2) BEMMELEN R. W., van, *Four Volcanic Outbursts that Influenced Human History – Toba, Sunda, Merapi and Thera.* Lecture on International Scientific Congress on the Volcano of Thera (ISCVT), Athens, 1969. (All papers of lectures on ISCVT will be published in the Acta of the Congress).

(3) BULLARD F. M., *Volcanoes in History, in Theory, in Eruption.* Austin, 1968.

(4) COTTON C. A., *Volcanoes as Landscape Forms.* New York, 1969.

(5) GORSHKOV G. S., *Gigantic Eruption of the Volcano Bezymianny.* "Bulletin volcanologique", Série II, **XX**, 1959.

(6) GORSHKOV G. S., *On the Classification and Terminology of Pelée and Katmai Type Eruptions.* "Bulletin volcanologique", **XXIV**, 1962.

(7) GORSHKOV G. S., *Directed Volcanic Blasts.* "Bulletin volcanologique", **XXVI**, 1963.

(8) GORSHKOV G. S., *Gigantic Directed Blast at Sheveluch Volcano, Kamchatka).* "Bulletin volcanologique", **XXXIV**, 1, 1970.

(9) HÉDERVÁRI P., *A New Classification of the Volcanic Eruptions,* "Gerlands Beiträge zur Geophysik", **71**, 2, 1962.

(10) HÉDERVÁRI P., *On the Energy and Magnitude of Volcanic Eruptions.* "Bulletin volcanologique", **XXV**, 1963.

(11) HÉDERVÁRI P., Volcanophysics; *Energetics of Eruption* and: Volcanophysics; *Magnitude of Eruptions.* Encyclopedia of Geophysics, Structure and Petrology (ed.: FAIRBRIDGE R. W.), in press, 1970.

(12) IMBÒ G., *Eruptive Energies.* "Annali dell'Osservatorio Vesuviano", Serie VI, **VII**, 1965.

(13) MINAKAMI T., *Fundamental Research for Predicting Volcanic Eruptions.* Part. I. "Bulletin of Earthquake Research Institute", **38**, 4, 1960.

(14) NEUMANN VAN PADANG N. M., Discussion on the Paper "*A Suggestion for the Application of New Symbols in the Short Description of Different Volcanic Phenomena*" by P. HÉDERVÁRI. "Bulletin volcanologique", **XXXIII**, 2, 1969a.

(15) NEUMANN VAN PADANG N. M., *Two Catastrophic Eruptions in Indonesia, Comparable with the Plinian Outburst of the Volcano of Thera (Santorini) in Minoan Time.* ISCVT, 1969b.

(16) RICHTER C. F., *Elementary Seismology.* San Francisco, 1958.

(17) RITTMANN A., *Volcanoes and their Activity.* New York, 1962.

(18) SHIMOZURU D., BERG E., *Seismological Study of the Nyiragongo Volcano.* "Bull. des Sciences, Ac. Royale des Sci. d'Outre-Mer", **VII**, 4, 1961.

(19) TAZIEFF H., *Volcanoes.* Paris, 1961.

(20) TAZIEFF H. et al., *Contribution à l'étude Volcanologique du Katmai et de la Vallée des Dix Mille Fumées (Alaska),* "Mémoires de la Société Belge de Géologie", Série in 8, No. 7, 1963.

(21) TSUYA H., MORIMOTO R., *Types of Volcanic Eruptions in Japan.* "Bullettin volcanologique", **XXVI**, 1963.

([22]) VITALIANO CH. J., VITALIANO D. B., *Plinian Eruptions, Earthquakes, and Santorin.* "A Review", ISCVT, 1969.

([23]) VLODAVETZ V. I. et al., *Relations Between the Type of Eruptions and the Composition of lava as Exemplified by Kamchatka and Kuriles Volcanoes.* "Bulletin volcanologique", XXVI, 1963.

([24]) YAGI K., *Some Genetic Problems of the Calderas in Japan.* ISCVT, 1969.
