On the classification and terminology of Pelée and Katmai type eruptions.

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The eruptions of the volcanoes Pelée and Katmai still attract the attention of volcanologists as in spite of a great number of investigations there are still a lot of vague points about the processes of these eruptions and their classification.

The author observed and studied the eruptions of Sheveluch (1948-1950) and Bezymianny (1955-1956) volcanoes in Kamchatka which resemble in some respects those of Pelée and Katmai. Especially important data were obtained in the course of study of the Bezymianny eruption. The consequences of the paroxismal explosion and the following agglomerate flow were studied fresh; the first author's expedition reached the place of action three weeks after the blast and in four months all the details were studied in detail. The results of this study and also the analysis of the available literature make it possible to come to some new conclusions and to define more precisely the classification of eruptions so called Pelée and Katmai types.

The report on the eruption of the Bezymianny Volcano was presented by the author at the last IAV Assembly in Toronto, Canada (14). Without repetition of all facts it is possible to note only most essential features of this eruption:

The explosion of March 30, 1956 was directed to SE under the angle of 30–45° to the horizon; the most part of the volcanic edifice was destroyed. The explosion wave covered 500 km². The material of the explosion was fine-grained (sand and ashes); it bursts with a great force and many trees were broken or partially burnt at the distance of 25-27 km though the thickness of sand there did not exceed some centimetres; the bark of trees and bushes and sometimes the wood were torn off from the side of the volcano. The material of the directed explosions possessed a high temperature but lacked high mobility and therefore deposited in the depressions of the relief as well as on the hills.

After the directed blast a huge agglomerate flow gushed through the notch formed; the flow progressed at the distance of 18 km and filled up a broad river valley completely levelling the terrain (¹); the « Kamchatka Valley of Ten Thousand Smokes » was formed closely resembling that of Katmai. The agglomerate material of the flow also blew up with a great force at least at the first moment. Great masses of agglomerate were thrown over the rims of the crater and over deep river valleys at the distance of 8-9 km from the crater giving rise to independent agglomerate flows which had no visible connection with the main flow and with the crater. The agglomerate was very mobile at the moment of the eruption, it rolled down easily and stopped only where the inclination did not exceed 2-3° therefore at the base of the volcano (even at the points where the inclination was 4-5°) the sediments of the agglomerate are of little thickness, and on more steep slopes are absent completely. The agglomerate flow is distinctly pronounced and is of great thickness only at a distance of 7-8 km from the crater and further down the valley where the inclination of the terrain is less. Thus it seems as if the deposition of agglomerate were not connected to the Bezymianny Volcano crater.

As we see the eruption of the Bezymianny Volcano was highly original; it was characterised by a mighty laterally directed blast with the energy of air wave of order 10^{22} - 10^{23} ergs, by great destruction of the volcanic edifice and by the subsequent formation of exceptionally powerful agglomerate flows from the summit crater. The deposits of the directed blast were insignificant in the thickness and coarse material was absent. The agglomerate flow had no visible connection with the crater. We propose to term the eruptions of such type as « the Bezymianny type » (as such type was first investigated just at this volcano).

The ideas of Fenner about the eruption of Katmai are well known (7, 8, 9, 10, 11, 13) and there is no need to repeat them here. Very interesting developments based on the analysis of literature were contributed to the problem by MacGregor at IX Assembly of IAV (24). Fenner's views in short are the following: the volcano of Katmai has no direct relations to the formation of deposits of « sand flow »

(¹) The volume of main mass of the flow deposits according to detailed data is 1 km³ (Report by G. E. Bogoiavlenskaia at this Assembly).

in the Valley of Ten Thousand Smokes; the source of « sand flow » was a network of fissures in the Valley floor proper.

In 1953-1954 the region of Katmai was again investigated by a group of American scientists; as a result of the investigation they did not agree to some of Fenner's ideas, but his main thesis still stood: as the supplying channels for the material of « sand flow » is still to be considered a network of fissures at the head of the Valley (3, 4, 22, 28). Unfortunately a detailed report about this work has not yet been known for the author.

The Fenner's ideas about the Katmai eruption based on the observations performed 7 years after the eruption when the important details had already been obliterated as Lacroix correctly stated (21) were purely deductive and need checking on similar eruptions in the future. Now after the eruption of the Bezymianny Volcano such checking and comparison became possible.

A careful study of literature concerning the eruption of Katmai led the author to the conclusion that the eruptions of Katmai and of Bezymianny were in the main alike.

The sequence of the main events at Katmai may be imagined as the following: paroxysmal explosion in the summit crater of Katmai greatly destroyed the top of the cone. The blast was not vertical but directed laterally; the direction of the blast was distinctly NW, where vegetation was partially burnt or broken. The fallen trees were found in the region of Butriss ridge 20 km West of the crater where hardly passable piles of trees were formed (10) and on Katolinat ridge 30 km NW of the volcano (17). Unfortunately this phenomenon did not arrest the attention of the first investigators and the zone of destroyed trees and the boundary of the fallen ones was neither mapper nor more or less carefully described. It is necessary to note that the loss of the trees was not caused by the usual ash fall as the zone of the maximum ash fall extends to SE from the volcano and along this direction the trees did not perish even under a layer of ash almost 1.5 m thickness (Amalik Bay) and the thickness of an ash bed is much less to NW where the mass of the fallen trees was observed. The ashes issued at the first stage of the eruption (non-pyroxene) is of great thickness in the region of Peak Knife 8 km NW from Katmai i. e. in absolutely opposite direction to the wind at the beginning of the eruption and therefore the source of the ashes was not clear (3). From our point of view these are ashes of the directed blast the deposits of which do not depend upon the direction of wind. (Just NW rim of the new crater of Katmai has greatest sinking). It is quite possible that the explosion was directed also the South i. e. to the valley of Katmai River. (The crater has a notch also to the South). Such a supposition belonged to Martin who was the first to visit the mouth of Katmai River two months after the explosion (25).

Immediately after the powerful laterally directed explosion which destroyed the summit of the volcano the gigantic agglomerate flow rushed down from the summit crater (« sand flow »). The only witness of the explosion from a short distance an Indian named American Pete was at the moment in the valley of Ukak River approximately 30 km North of the volcano. According to him: « The Katmai Mountain blew up with lots of fire and fire came down trail from Katmai with lots of smoke » (17). This evidence gives a picture of an agglomerate flow with a cloud of ashes over it rolling down from the summit crater of Katmai. The main masses of the agglomerate were rolling down along the NW slope of the volcano, some of the material was blown up with a great force and disperced irrespectively of the relief (as it was determined at Bezymianny) at a distance of 7-8 km from the crater. The loose material was very mobile and rolled down the hills to the depressions; thus comparatively thin deposits of agglomerate were formed at the Katmai pass from which they rolled down to Mageik Creek. It is impossible to explain the formation of these deposits otherwise Fenner and others belive the deposits were issued from the Novarupta Volcano, but the Katmai Pass is 100 m higher than Novarupta and is separated from the latter by a high dome of Falling and therefore Novarupta cannot be a source of the deposits on the Pass. Less thick flow obviously rolled down along the Southern slope of the volcano and along the valley of Katmai River reached the sea. The impression of the valley of Katmai River was figuratively described by Martin: « A breath of hell swept down the valley bringing death even to the trees », but the vegetation to the West of the valley was left intact. The thickness of the agglomerate flow in the valley of Katmai River as it seems did not exceed some meters, may be here we have not a pure agglomerate flow, but a mud flow with a great quantity of fresh material (lahar). Great masses of pumice were transported into Katmai Bay which formed the big floating fields bearing the weight of a man; the water in the bay according to the Indians who were sailing in a boat at that moment became warm (25).

From the steep slopes of the Katmai Volcano the agglomerate material slid down and stopped only where the small inclination of the relief allowed it. Thus we have (as at the Bezymianny Volcano) a seeming independence of deposits of « sand flow » from the crater of Katmai. However the glaciers at Katmai as it was determined latter (29) were still buried under a thick layer of pumice. The comparison of a map of the « sand flow » by Griggs (1922) and the map of a recent years (19) shows the glaciers from Katmai have moved ahead substantially (up to 1 km) during the last 30-35 years and overlaid the « sand flow » deposits at the head of Knife Creek. As it seems prior the eruption the glaciers occupied at least the same position as it is now, but under the influence of incandescent agglomerate rolling down from the crater during the eruption they have been partially melted and now are regaining their former sizes.

After the eruption of the « sand flow » the summit crater of Katmai commenced mighty Volcanian and Plinian activity discharging huge masses of ashes which formed some beds SE of the volcano. It is possible that as a result of the subsequent activity the volcano crater got more wide may be because of the collapse.

On the South slope of Katmai there are traces of the second « tuff flow » which Fenner associates direct with the summit crater of Katmai (8, 13). The second agglomerate flow has overlaid the bedded ashes of the former explosions. As a result of the eruption of the second flow obviously was formed that « mysterious » layer of welded tuff discovered in the crater of Katmai and the origin of which was « left undetermined » (3). The final stage of the Katmai eruption was squeesing out the small dacite dome on the bottom of the top crater.

The whole scale of the phenomena which had taken place in the summit crater of Katmai can be quite compared with the volume of the deposits of the « sand flow » of the Valley of Ten Thousand Smokes. It should be added that the composition of the pumice of the primary stage of the eruption corresponded rhyolite with 76 % SiO_2 and the lava of the Katmai dome was dacite with 66 % SiO_2. Such a change in composition indicates that there must have been erupted a great amount of the differentiated in the chimney lava prior to substitution by more deeply situated dacite. The change of composition of acidic lavas to more basic in the course of one eruption was observed many times at many volcanoes and it is quite regularly.

The formation of Novarupta dome in one row with more ancient domes of Cerberus and Falling had taken place after the formation of « sand flow » and was a phenomenon of minor importance. Ejecta of Novarupta rests on the deposits of agglomerate flow and is largely consists of the fragments of the base, this clearly indicates that the chimney of Novarupta had been formed after the deposition of « sand flow ». The formation and widening of the new vent was followed by Volcanian explosions which formed a comparatively large deposits of ashes in the vicinity of Novarupta but as a whole the scale of Novarupta eruption was quite moderate and uncomparable to the scale of « sand flow » formation. As it was already said the deposits of the « sand flow » on the Katmai Pass and all events in Katmai River valley are absolutely not related to the volcano of Novarupta.

Thus, all the phenomena at Katmai including the formation of the « sand flow » in the Valley of Ten Thousand Smokes and the flows on the Pass and in the valley of Katmai River may be well explained if we suppose that the progress of eruption was in general the same as that of the Bezymianny Volcano. In other words the Katmai eruption in 1912 may be related to the « Bezymianny-type ». The term « Katmai-type » indicates quite another mechanism of the eruption and in the light of new facts this term should be abolished.

In some respects the eruptions of the « Pelée-type » are related to the eruptions of Katmai and Bezymianny volcanoes.

During the eruption of Mt. Pelée in 1902-1904 after which this type was named one should distinguish two kinds of phenomena:

1) On May 8, 1902 an explosion directed SW and which embraced the area about 60 km^2 took place. The explosion destroyed the town of St. Pierre situated at a distance of 7-8 km from the crater and which was separated from the volcano by several river valleys. The houses were damaged and partially destroyed and of 26000 inhabitans only two survived. The thickness of sand deposits was only one inch and a coarse material was absent at all. Otherwise here an explosion resembling a directed explosion of the « Bezymianny-type » originated. This was more weak without the destruction of volcanic edifice. The similar explosions occured again on May 20 and August 30 in the same year. The energy of the last explosion wave was determined by the author as beeing of the order of 10^{21} ergs (14). All these explosions influenced some area irrespective of the relief and the products of the explosions were represented by finely crushed material.

2) After May 8, 1902 in connection with the growth of the dome numerous incandescent avalanches were formed and their way was determined only by the gravity. They deposited coarse agglomerate material on their way. A well known photo of the so called glowing cloud (nuée ardente) by Lacroix (19) is attributed to this type.

The formation of incandescent avalanches was observed and studied at many volcanoes (Mt. Pelée in 1902-1904 and 1929-1932, Sheveluch in Kamchatka in 1946-1950, many volcanoes of Central America and Indonesia etc. — the references: 1, 2, 5, 6, 16, 18, 20, 21, 23, 24, 26, 27). The most detailed investigations were performed by Perret during the eruption of Mt. Pelée in 1929-1932 and Dutsh volcanologists in Java especially at the Merapy Volcano (van Bemmelen, Escher, Neumann van Padang and others).

The formation of incandescent avalanches is connected to the formation of domes, the avalanches being formed both as a result of simple collapse of still hot parts of the dome and as a result of comparatively weak explosions on its periphery.

In the existing classifications (2, 6, 21, 24) the incandescent avalanches formed by the collapse of the dome (Merapy-type) are differentiated distinctly from the avalanches formed by the explosions, however these last are often united with the laterally directed explosions similar to those which destroyed the town of St. Pierre (Pelée-type).

The analysis of the literature and also personal observations of the incandescent avalanches at Seveluch and Bezymianny volcanoes in Kamchatka led the author to the conclusion that:

a) There is no principal difference between the incandescent avalanches of explosive and collapse types as we have all transitional stages here; both usually occur at the same volcano often intermitting or taking place simultaneously. The path of the incandescent avalanches is wholly restricted by the gravity; they run like water streams or lava flows along depressions of the relief and along river valleys leaving behind rather thick deposits of coarse agglomerate; both avalanches do not differ in the character of their deposits.

b) The laterally directed exposions (the type of Pelée on May 8) are radically different in all their characteristics from the lagest incandescent avalanches of the explosive type; they embrace vast areas (from tens to hundreds of square kilometres), the material discharged during the explosions is finely ground, it is erupted with a great force and distributed irrespective of the relief depositing thin layer of sand.

The author proposes to limit the term the « Pelée-type » of eruptions only by the laterally directed explosions without destruction of volcanic edifice having excluded from this type explosive incandescent avalanshes. And vice versa it it proposed to extend the term the « Merapi-type », including here all incandescent avalanches both collapse and explosive. For each separate avalansh it is possible to add adjectives « explosive » or « Collapse ».

The directed explosions of May 19 and 22, 1915 at Lassen Peak in California (5) undoubtedly belong to the Pelée-type. These explosions were not followed by the formation of incandescent avalanches but mud flows were formed as a result of snow melting under a layer of hot ashes. Apparently it is possible to include the eruptions of Lamington Volcano in New Guines in 1951 (27) and of Hibok-Hibok in the Philippines of the same year (23) into the Pelée-type. In both cases the directed explosions (covering some area) were followed by rather powerful incandescent avalanches which rolled down the valleys as usual.

Thus, the laterally directed explosions of the Pelée-type in some cases are followed by the incandescent avalanches and are not followed by them in the other cases; may be we should distinguish two subtypes having in mind these two phenomena.

Great mobility of agglomerate flows and incandescent avalanches is stimulated, as it is well known, by the release of gas from the particles of a flow or an avalanche or in other words by self-explosivety ([2]).

Because of this phenomena an ash-gaseous cloud is formed over this avalansh which is sometimes very effective. These clouds are usually called « glowing clouds » (nuées ardentes).

However such frightening term is hardly justified for these clouds. Perret noted that when he got into an ash cloud of a nuée ardent he did not feel any rise of temperature of the air. The author of this report standing as close as 20 m to a rather powerful rolling incandescent avalanche also did not feel any warmth from the cloud though the blocks of agglomerate after the stop of the avalanche were

([2]) Similar phenomena are used in the engeneering for the transportation of loose products - this is so called « transportation in the sliding air » or « fluid-process ».

red hot in cracks; the ashes falling down from the cloud ware cold and the snow under it did not melt.

With a quick expansion of gas its cooling takes place. The clouds rising over incandescent avalanches are generated in the avalanche, rise upwards vertically without expanding laterally and lack the destructive force. These clouds are in fact cold and cannot burn anything and that is way do not deserve the name « glowing ». True glowing clouds exterminating all living on its way occur in the point of eruption and are in fact explosive waves of directed explosions carring scorching material (Pelée and Bezymianny types).

To conclude the paper we propose the following mode of classification:

Type	Characteristics	Examples
Bezymianny	Powerful directed explosion (nuée ardente) followed by the destruction of volcanic edifice. The formation of thick agglomerate flows from the central crater. The energy of the explosion wave is 10^{22} - 10^{23} ergs (and more?).	Bezymianny, 1956 Katmai, 1912
Pelée	Directed explosion without destruction of volcanic edifice. The energy of the explosion wave is 10^{21} ergs (and less?). Formation of incandescent avalanches is possible.	Mt. Pelée May 8, May 20 and August 30, 1902. Lassen Peak, 1915. Lamington, 1951. Hibok-Hibok, 1051.
Merapi *a*) explosive *b*) collapse	Descending incandescent avalanches following the depressions of relief under the influence of gravity, which are connected with the formation of extrusive domes only.	Merapi. Pelée 1902-1914. and 1929-1932. Santa-Maria, 1929. Sheveluch 1946-1950. and many others.

The eruptions of incandescent avalanches from the open crater (the Soufrière of St Vincent in 1902, Avacha in Kamchatka in 1945, Sarychev Peak in the Kuriles in 1946 and many others) are very close to the Merapi type and may be to the Pelée type. They deserve further study and classification.

BIBLIOGRAPHY

1. ANDERSON, T. and FLETT, J. S. - *Report on the eruption of the Soufrière in St. Vincent, in 1902 and on a visit to Montagne Pelée in Martinique* - Pt. I. Philos Trans. Roy. Soc. London, v. 200, p. 353-553 (1903).
2. VAN BEMMELEN, R. W. - *The Geology of Indonesia* - v. IA. The Hague (1949).
3. CURTIS, G. H. - *Importance of Novarupta during eruption of Mt. Katmai, Alaska, in 1912* (abstract) - Bull. Geol. Soc. Amer., v. 66, No 12, pt. 2, p.. 1547 (1955).
4. CURTIS G. H., WILLIAMS, H. and JUHLE, W. - *Evidence against assimilation of andesites by rhyolite in the Valley of 10,000 Smokes, Alaska.* (abstract) - Trans. Amer. Geoph. Un., v. 35, No. 2, p. 378 (1954).
5. DAY, A. L., and ALLEN, E. T. - *The volcanic activity and hot springs of Lassen Peak* - Carn. Inst. Wash., Publ. No 360 (1925).
6. ESCHER, B. G. - (1) *On a classification of central eruption according to gas pressure of the magma and viscosity of the lava* - (2) *On the character of the Merapi eruption in Central Java* - Leid. Geol. Meded., Deel VI, Afl. I, Blz. 45-58 (1933).
7. FENNER, C. N. - *The Katmai Region, Alaska, and the great eruption of 1912* - Journ. Geol., v. 28, No 7, p. 569-606 (1920).
8. ——— - *The origin and mode of emplacement of the great tuff deposit of the Valley of Ten Thousand Smokes* - Nat. Geogr. Soc., Contr. Techn. Pap., Katmai Series, No. 1 (1923).
9. ——— - *Earth movement accompanying the Katmai eruption.* - Journ. Geol., v. 33, No 2-3, p. 116-139, 193-223 (1925).
10. ——— - *Mount Katmai and Mount Mageik* - Zeitschrift für Vulk., B. 13, s. 1-24 (1930).
11. ——— - *Tuffs and other volcanic deposits of Katmai and Yellowstone Park* - Trans. Amer. Geoph. Un., 18th Annual Meeting, p. 236-239 (1937).
12. ——— - *The phenomena of Falling Mountain* - Amer. Journ. Sc., V. v. 35A, p. 35-48 (1938).
13. ——— - *The chemical kinetics of the Katmai eruption* - Amer. Journ. Sc., v. 248, No 9-10, p. 593-627, 697-725 (1950).
14. GORSHKOV, G. S. - *Gigantic eruption of the Volcano Bezymianny* - Bull. Volc. Ser. II, t. 20, p. 77-109 (1959).
15. ——— - *Determination of the explosion power for certain volcanoes by barograms* - Bull. Volc., Ser. II, t. 23 (1960).
16. GORSHKOV, G. S., and BYLINKINA, A. A. - *The observations of the Sheveluch Volcano eruption in 1948-1950* - Bull. Volc. Station, No 20, Publ. Ac. Sc. USSR, Moscow. (in Russian) (1954).
17. GRIGGS, R. F. - *The Valley of Ten Thousand Smokes* - Nat. Geogr. Soc., Washington (1922).
18. JAGGAR, T. A. *Steam blast volcanic eruption* - 8th Speci Rep. Hawaiian Volc. Observatory. Honolulu (1949).
19. KELLER, A. S., and REISER, H. N. - *Geology of the Mount Katmai Area Alaska* - Geol. Surv., Bull. 1058-G. Washington (1959).
20. LACROIX, A. - *La Montagne Pelée et ses eruptions* - Paris (1904).
21. ——— - *Remarques sur les matériaux de projection des volcans et sur la genèse des roches pyroclastiques gu'ils constituent* - Centenaire de la Société Géologique de France. Livhe Jubilaire 1830-1930, t. 2, p. 431-472 (1930).

G. M. ZARIDZE and N. F. TATRISHVILI — *Depth assimilation and late metasomatose processes during the formation of the Upper Cretaceous volcanogenous deposits of South-East Georgia.*

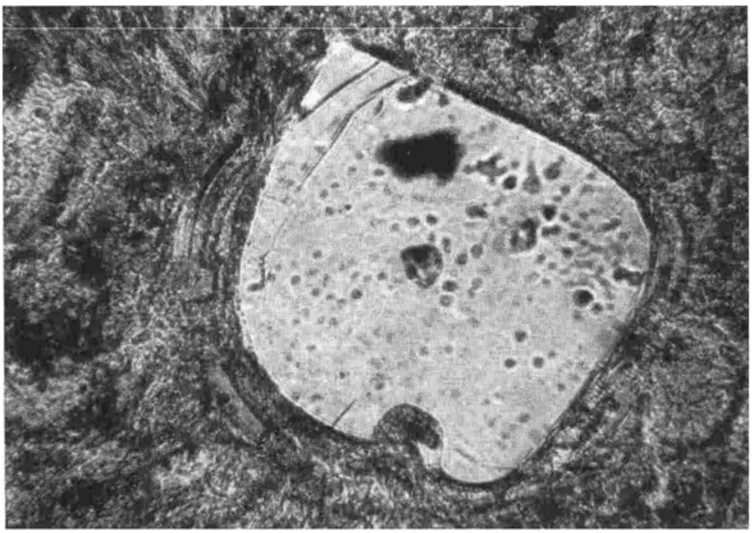

Fig. 2 - Alternating concentric stripes consisting of glass and small quartz grains around the xenolithic quartz in the porphyrite. Magnification 40, Ni crossed.

22. LUNTEY, R. S. - *Katmai National Monument* - Nat. Parks Magaz., v. 30, No 124, p. 7-15, 36-37.

23. MACDONALD, G. A., and ALCAREZ, A. - *Nuées ardentes of the 1948-1953 eruption of Hibok-Hibok* - Bull. Volc., Ser. II, t. 18, p. 169-178 (1956).

24. MACGREGOR, A. C. - *Eruptive mechanisms: Mt. Pelée, the Soufrière of St. Vincent and the Valley of Ten Thousand Smokes* - Bull. Volc., Ser. II, t. 12, p. 49-74 (1952).

25. MARTIN G. S. - *The recent eruption of Katmai Volcano in Alaska* - Nat. Geogr. Magaz., v. 24, No. 2, p. 131-187 (1913).

26. PERRET, F. A. - *The eruption of Mt. Pelée 1929-32* - Carn. Inst. Wash., Publ. No 458. Washington (1935).

27. TAYLOR, G. A. - *The 1951 eruption of Mount Lamington, Papua* - Bull. Nat. Devel., Bur. Miner. Resources, Geol. and Geoph. Bull. No 38. Canberra (1958).

28. WILLIAMS, H., CURTIS, G., and JUHLE, W. - *Mount Katmai and the Valley of Ten Thousand Smokes, Alaska* (abstract) - Proc. 8th Pacific Sc. Congr., v. II, p. 129 (1956).