36. *On the Form and Structure of Volcanic Bombs from Volcano Miyake-sima.**

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Introduction.

In a previous paper[1] dealing with the form and structure of volcanic bombs, with special reference to the origin of the basaltic bombs from Volcano Huzi, a volcanic bomb was defined as a piece of juvenile lava ejected in the air at the time of an eruption, and having (irrespective of size) certain characteristics peculier to one of a few distinct morphological and structural types. With this distinction, the basaltic bombs from Huzi were classified into fourteen types—(1) spindle-shaped, (2) conical, (3) spheroidal, (4) disk-shaped, (5) square, (6) dish-shaped, (7) twin, (8) cylindrical (long), (9) cylindrical (short), (10) leaf blade-shaped, (11) ribbon-shaped, (12) ellipsoidal, (13) goat's horn-shaped, and (14) hemispheroidal bombs. From a study of these bombs both in the field and in the laboratory, it was concluded that the characteristic shape and inner structure of the bombs could probably be traced to the "schlieren" (flow structure) that developed in the flowing lava within the crater from which they were ejected, although subjected to deformation later in their passage through the air.

The results of the writer's studies of volcanic bombs, both in the field and in the laboratory, on the occasion of the last eruption of Volcano Miyake-sima, in July 1940, amply confirm his views regarding their origin.

Mode of Occurrence of Volcanic Bombs.

Miyake-sima, one of the most distinguished basaltic volcanoes in Japan, together with Huzi, O-sima, Hatizyô-sima, etc., are rich in volcanic bombs. On the volcano, the bombs are frequently met with among old and new fragmentary ejecta, scattered about the craters on the

* Dedicated to the late Professor Mishio Ishimoto.

1) H. TSUYA, *Bull. Earthq. Res. Inst.*, 17 (1939), 809~825.

summit as well as on the flanks of the somma, their chief localities so far observed being Akabakkyô, Bôzu-yama, and Oyama, where they occur in the following manner:

Akabakkyô. As already mentioned in a previous paper,[2] in the northern part of the bay of Akabakkyô, near Simasita, on the northeastern foot of the volcano, a submerged crater of unknown age is now buried under the ejecta of 1940. On the cliff of Akabakkyô-hana (point), which before the late eruption (1940) was a sea-cliff facing the former bay, beds of old ejecta are exposed, which, from their structure, are regarded as products of a crater believed to be submerged now in the bay. These beds, which are composed of reddish-brown fragmentary ejecta, are intercalated in the middle horizon of the cliff by a lava-flow, about 3 m thick, dipping about 15° NW. The lava is an augite-olivine-basalt, containing large phenocrysts of anorthite, exceeding 1 cm in diameter. Before the late eruption, the same lava could be seen exposed on the northern shore of the former bay of Akabakkyô, forming a coastal platform, about 15 m above the sea, on which stood the fishing village of Simasita, most of which at present, however, is buried beneath the new Akabakkyô lava-flow of 1940. The fragmentary ejecta, which are petrographically identical with the lava, consist of scoriaceous lapilli, blocks, and bombs, of which, the bombs, 5∼30 cm in diameter, occur more thickly in the upper horizon of the ejecta beds than in the lower. Before the late eruption, these bombs were found in great abundance on the lava-platform of Simasita.

The fairly large number of volcanic bombs that were ejected at the time of the eruption of 1940 came from about twenty new craters on the northeastern flank of of the somma, including those thrown up from the bay of Akabakkyô, and along with the other fragmentary ejecta, they have accumulated thickly on the ground around the new craters, particularly around the Hyôtan-yama craters (G and H), crater D, and on the mountain slope adjoining the northern side of the B′ rift-crater.[3] The diameter of most of the bombs exceed 10 cm, the largest one so far found being about 10 m, while those of less than 5 cm are rare. These bombs are divided, petrographically, into two kinds, porphyritic and almost-aphanitic bombs. The porphyritic bombs, which were ejected exclusively from the Hyôtan-yama craters, are augite-olivine-basalt, containing large megascopic phenocrysts of anorthite, while the aphanitic bombs, which were projected from all the new

2) H. TSUYA, *Bull. Earthq. Res. Inst.*, **19** (1941), 265.
3) H. TSUYA, *Bull. Earthq. Res. Inst.*, **19** (1941), 650.

craters, except those from Hyôtan-yama, are basaltic andesite. Judging from the distribution of these bombs, most of them were ejected from a crater at a late stage of its eruption. For example, although Hyôtan-yama is thickly covered with porphyritic bombs, its inner part as seen on the sea-cliff on its eastern side, is largely composed of beds of reddish-brown, scoriaceous lapilli and blocks, underlain by a lava-flow (Hyôtan-yama lava).

Bôzu-yama. Bôzu-yama, which is a parasitic knob, lying halfway up the north-northeastern flank of the somma, is thickly covered with fragmentary material ejected by the eruption of 1874. The fragmentary material occurs as black, scoriaceous lapilli, crystal-lapilli of anorthite, and volcanic bombs. Of these, the bombs are found in great numbers in a small area on and around the top of the mound, suggesting that they are products of a later stage of the eruption. Although ejection of the fragmentary material was followed by outpouring of lava, the latter occurred from a vent lying some distance away from the vents of the former. Thus, the lava-flow of 1874 outpoured from a deep fissure-like opening, situated about 550 m above the sea, outside the western wall of the Kosiki-ana parasitic crater on the north-northeast slope of the somma, and descended the mountain slope northward into the sea, east of the village of Kamituki, while the fragmentary ejecta, which occupy a wide area adjoining the eastern margin of the lava-flow, including Bôzu-yama, were ejected, mostly previous to the lava outpouring, from several openings, which, together with a number of fissure-like depressions, are arranged in a zone running from the vent of the lava NNE toward Bôzu-yama.

The volcanic bombs from Bôzu-yama are fairly small, their diameters being generally less than 5 cm. Petrographically, they are identical with the lava of 1874, which is an augite-olivine-basalt, containing large megascopic phenocrysts of anorthite.

Oyama (the central cone). Before the eruption of 1940, the central cone Oyama, situated slightly south of the caldera on the top of the somma, was truncated at the top, with walls surrounding a composite crater, consisting of three bowls aligned in an east-west direction—the first (the easternmost), the second (Oana), and the third (the westernmost) craters. Along with scoriaceous lapilli and anorthite crystal-lapilli, volcanic bombs were thickly scattered about the floor of of the first crater, being underlain by a lava more than 20 m thick which, as inferred from an exposure on the eastern wall of the second crater, must have once formed a lava-lake that filled the first crater. Similar bombs were also found on the slope outside the northeastern rim of the first crater, as well as in the northeastern part of the Hayono-tairo atrio, although they are now buried beneath the material thrown out by the late eruption. The bombs, the largest of which have a diameter of about 2 m, differ petrographically from the rock of the solidified lava-lake in the first crater. The former is an augite-olivine-basalt, containing large megascopic phenocrysts of anorthite, while the latter is an almost aphyric augite-olivine-basalt, without any conspicuous megascopic phenocrysts, except a few very small olivine and plagioclase (anorthite-bytownite). Judging from their fresh appearance in the field as well as in the laboratory, the bombs must have been ejected, together with the other fragmentary material that accompanied them, from the second crater in the remote past.

During the summit eruption that lasted from July 13 to August 5, 1940, a large number of bombs were ejected together with other fragmentary ejecta, from the second and the third craters on the central cone, resulting in the formation of a new composite central cone in the craters. The bombs are scattered over an oval area, measuring about 850 m from WNW to ESE, with the new central cone as the centre. Thus they lie scattered in the central part of the Hayono-tairo atrio as well as on the ground outside the southern rim of the second crater (Oana). On the northern flank of the old central cone a considerable number of bombs are found that reach a maximum diameter of about 3 m. Similar large bombs are also found on the southeastern part of the crater bottom of Oana, adjacent to the southeastern foot of the new central cone, where they are accumulated perhaps more than 10 m deep, together with smaller ejecta. A number of smaller bombs, 1～5 cm in diameter, are accumulated, together with scoriaceous lapilli and sand, on the floor of the first crater, where formerly bombs, lava-blocks, and anorthite lapilli of unknown age were found.

Although the summit eruption of 1940 began in the night of July 12/13, the ejection of new volcanic bombs first became notable about a week later. Thus, during the four days that ended July 18, fragments of the old cone material alone were ejected in the form of ash and sand; during the next two days, angular blocks of the old cone material were ejected along with those of a fresh, dense lava that were probably torn off by the force of the explosions from the top of the lava plug that had risen near the crater floor from the interior of the volcano. The next day (July 21) in addition to ash, a juvenile lava began to pour out in the form of scoriaceous lapilli; and lastly, since the middle of the night of July 22, bombs were ejected every few seconds, together with ash, lapilli, and lava-blocks, until Aug. 5, when the summit eruption practically ceased.

On the northwestern foot of the new central cone is a new lava coulee circumscribed on all sides by the rim of the third (westernmost) crater, except on its southeast, where it is buried beneath the new central cone. The western front of the coulee bulges out only a few meters westward over the rim of the western wall of the crater. Although we do not know when this lava extruded, it is inferred that it appeared in the form of a lava-pool in the crater where the eruption was going on, already before the new central cone had attained its present size, and that the level of the lava-pool had risen sometime, between July 25 and 31, as high as the western rim of the old third crater, where the lava was about to flow over the crater rim. The lava coulee is covered with fragmentary ejecta, including quite a number of volcanic bombs, which accumulated more than 1 m deep in the southeastern part near the foot of the new central cone. Petrographically, the new bombs are identical with the new lava, both being an almost-aphanitic olivine-two-pyroxene-basaltic andesite.

Form and Inner Structure of Volcanic Bombs.

So far as the specimens of more than a hundred volcanic bombs collected by the writer from Miyake-sima are concerned, they may be grouped, according to their external forms, into twelve types, as follows:

1) Spheroidal (Fig. 1)
2) Disk-shaped (Fig. 2)
3) Ellipsoidal (Fig. 3)
4) Conical (Fig. 4)
5) Square (Fig. 5)
6) Spindle-shaped (Figs. 6 a—d)
7) Cylindrical (short) (Fig. 7)
8) Cylindrical (long) (Fig. 8)
9) Leaf blade-shaped (Fig. 9)
10) Goat's horn-shaped (Fig. 10)
11) Ribbon-shaped (Fig. 11)
12) Twin bombs. (Figs. 12 a—d)

Morphologically, these types are almost identical with the respective types of bombs from Volcano Huzi, so that there is no need to describe their external forms once more. It is, however, notable that the twin bombs from Miyake-sima have a greater number of forms than bombs of similar type from Huzi. Thus, the twin bombs from Huzi have the shape of a fiddle, only they are not flat, but consist of two lumps, joined together at the middle, with their longer axes in common, while the twin bombs from Miyake-sima consist of two bomb-shaped lumps which, besides being joined together in the shape of a gourd, as in Fig. 12 a, in contact with each other either in a parallel position, as in Fig. 12 c, or in an oblique position, as in Figs. 12 b, 12 d. Although the Huzi bombs include dish-shaped and hemispheroidal bombs, besides the twelve types mentioned above, neither of these two types is represented in the samples from Miyake-sima.

The bombs, except the spheroidal, disk-shaped, and square forms, frequently have either parallel grooves or ridges on their surfaces in the direction of their longer axes (Fig. 6 d). Regardless of these grooves or ridges, most of them have uneven surfaces, to which are sometimes attached irregularly shaped lumps of the same material as the bombs themselves. There are besides various transitional forms, ranging from the typical bombs to the irregularly shaped lava-blocks, as extreme examples of which are lava-blocks on the surface of which a bomb-like form is partially developed, as shown in Figs. 15 a—c.

The types just enumerated are most common in those of diameters ranging from about 5 cm to 10 cm, although a large proportion of them are also met with in smaller bombs, as shown in Figs. 13, 14. The larger bombs, having an extreme diameter of several meters, are usually spindle-shaped, disk-shaped, spheroidal, and ellipsoidal.

The inner structures of these bombs exhibit multifarious types according to their external forms. So far as have been observed in sections cut from several bombs of different morphological types, we have the following four principal structural types:

Type A.

Bombs of this type have solid inclusions in their cores. Petrographically the inclusions are divided into three kinds—juvenile, accessory, and accidental inclusions. The juvenile inclusions are represented by isolated crystals of anorthite (Fig. 16) and an allivalitic aggregate of anorthite and olivine (Fig. 17), besides lava-fragments which, petrographically, are identical with the bomb-forming lava with which they are coated. These crystal-inclusions are frequently met with in the bombs of 1874 (Bôzu-yama) and the Hyôtan-yama bombs of 1940. They are nothing but segregations in the bomb-forming lavas, seeing that both the lava of 1874 and the Hyôtan-yama lava of 1940 contain large megascopic phenocrysts of anorthite and olivine.

The accessory inclusions are represented by fragments of the old cone material, which differ only slightly in microscopic texture and mineral composition from the bomb-forming lavas in which they are enclosed (Figs. 20, 21).

The accidental inclusions are fragments of foreign rocks which must have come from the wall of the volcano conduit at depth, and which are believed to represent the rocks that lie underneath the volcano. The writer collected two spheroidal bombs from the new central cone of 1940, in which accidental inclusions were found. One of them carries a block of tuff (Fig. 18), about 5 cm in diameter, and the other a block of an acid, porous rock (Fig. 19), about 10 cm in diameter.[4]

Bombs of the foregoing type are mostly spheroidal, disk-shaped, or spindle-shaped, although the inclusions that are found in their cores have various shapes. Microscopic examination of thin sections of these bombs shows that the lava-crust of such a bomb, which surrounds an inclusion, has a flow structure. Thus the lath-shaped crystals (plagioclase and pyroxene) that are found in the lava-crust show a parallel disposition in consequence of the flow of lava around the inclusion, their longer axes being roughly tangential to the outline of the inclusion (Figs. 21 b—c). The parallel arrangement of the crystals is seen more regularly in the outer part of the lava-crust than in the inner part near the surface of the inclusion. In the outermost part near the surface of the bomb, the flow-lines as revealed by the crystal-arrangement follow almost exactly the outline of the bomb.

Type B.

Bombs of this type have a zonal structure (or shell-structure), consisting of thin lava-layers which are alternately vesicular and compact, but which are exclusively of the same juvenile material. This structure is most frequently seen in the spindle-shaped and ellipsoidal bombs (Figs. 22~27).

The zonally-built bombs have a core which may be either vesicular or compact, in a variety of forms and sizes. Sometimes the core has the same form as the external form of the bomb in which it is found (Figs. 22, 27); and although the core is usually single, it occasionally occurs as a doublet (Figs. 24, 25). In some zonally-built bombs that belong also to type A, their cores may be the one of the two kinds of inclusions (juvenile and accessory) just mentioned.

4) The tuff contains a large amount of anhydrite, while the acid, porous rock consists wholly of colorless glass, except dust material and a few fragments of quartz and feldspar. These rocks are more or less thermally metamorphosed. Petrographic descriptions of them will be given in Part III of the paper on the eruption of Miyake-sima in 1940, Parts I and II of which have already appeared in this Bulletin, 19 (1941).

The outer shells of the zonally-built bombs surround the cores successively outward, conforming to the outlines of the latter. Thus in the longitudinal section of a flattened spindle-shaped bomb (Fig. 22), the shells show a lenticular flow-banding. In certain spindle-shaped and ellipsoidal bombs, the transverse sections of which are nearly circular, the shells are either concentric or there are spiral bandings surrounding the core. Not all the layers forming the shells of a bomb run the whole length around its core, some layers thinning out to half the size. Often, the two adjoining layers of the shells have gaps between them (Fig. 22). The shells of a bomb containing such gaps can be torn off one by one (Fig. 6 d).

Microscopically, the lath-shaped crystals in type B bombs, like those in type A, show a parallel disposition in consequence of flow according to the zonal banding (Figs. 27 b, c).

Type C.

Bombs of this type have a cavity in their cores (Fig. 28). They are frequently met with among bombs of the spheroidal, disk-shaped, ellipsoidal, and spindle-shaped types. Besides the cavity in the core, some large cavities are occasionally met with slightly below the surface of the bomb. In a spindle-shaped bomb, these cavities are drawn out in the direction of the longer axis of the bomb (Fig. 29).

Type D.

Bombs of this type have relatively smooth surfaces, and are compact inside. They are occasionally found among bombs of every morphological type (Figs. 30∼33). Some of them are nothing but compact cores of bombs of type B that had been stripped of their shells at the time when they fell upon the ground.

Although these bombs are more or less compact fragments of a juvenile lava inside, good sections of the majority of them show either zonal structure or flow-pattern as recognized by differences in color of the various parts of the sections (Figs. 30, 31, 33). These structures are seen most clearly in thin sections of compact bombs (Figs. 32 a, 34∼38, 39 a, 40 a). Thus thin sections show that these bombs consist of two parts, one darker in color than the other, which are arranged either zonally or in some complicated flow pattern. Microscopically, the groundmass of the darker part is thickly crowded with an opaque, black material, including a large proportion of magnetite granules, while the groundmass of the lighter part contains a light-brownish glass in place of the black material.

The lath-shaped crystals in bombs of this type also show a parallel arrangement following the outer form and the inner structure of the bombs. This parallel arrangement is usually more regular in the lighter-colored part than in the darker part (Figs. 32 b, 39 b, 40 b, 40 c). The microscopic vesicular cavities with which bombs of the present type are often studded, also show banded arrangement conforming to the parallel arrangement of the crystals (Fig. 40 c).

Origin of Volcanic Bombs.

From his studies of the basaltic bombs from Huzi, the writer concludes that the characteristic shape and inner structure of the bombs originated from flow-banding ("Schlieren") that developed in the flowing lava within the crater from which they were ejected, subjected, however, to deformation in their passage through the air—a conclusion that applies also to the basaltic bombs from Miyake-sima, which, as mentioned above, show almost the same morphological and structural features as the Huzi bombs, besides some additional characteristics that further support the conclusion. The various inner structures of the Miyake-sima bombs are thus regarded as showing fluxion phenomena, including flow lines, parallel arrangement of crystals, banding, drawing out of vesicles, etc., that developed in the conduit lava from which they were ejected. The origin of these structures in the conduit lava is interpreted as due to segregation of phenocrystic minerals, capturing of xenoliths, irregular cooling, and local segregation of gas bubbles, forming vesicular parts in the lava at a shallow horizon near the top of the conduit, where the lava probably remains in a state of viscous, differential flow.

Although the outer forms of the bombs conform to their inner structures, it is unlikely that the latter were formed under the control of the former during the cooling of the bombs after they were thrown out from a crater. On the contrary, it is probable that the outer forms of the bombs were virtually determined by their inner structures, and consequently by the various structural heterogeneities just referred to in the lava from which they were torn off by volcanic explosions. Although the bombs might have deformed in their passage through the air as well as in striking the ground, it is not likely that the deformation was of such a nature as radically to change theis original shape and inner structure. For example, the origin of the shape and inner structure of the spindle-shaped bombs cannot be regarded as due to their rotatory motion in the air, seeing that, in the writer's experience, few bombs, if any at all, show in their flight upward into the air rotation of such high velocity as would explain some of the spindle-shaped bombs. For example, in July 25, 1940, when the writer was observing the summit eruption of Miyake-sima at close range, some of the long and slender bombs were seen to revolve about their shorter axes in flying up into the air, but at a rate of only once or twice a second.

In short, most of the external forms and inner structures of basaltic bombs are believed to be virtually determined by the structural pattern of the lava from which they were detached by the force of the explosion. When the lava has an intricate flow-banding caused by local vesiculation, segregation of crystals, capturing of xenoliths, etc., it is liable to be broken by the force of the explosion into pieces along a boundary surface of least resistance between two adjoining layers in the banding, resulting in various kinds of bombs.

EXAPLANATION OF PLATES.

Volcanic Bombs from Miyake-sima.

Fig. 1. Spheroidal bomb (×2/3).
Fig. 2. Disk-shaped bomb (×2/3).
Fig. 3. Ellipsoidal bomb (×2/3).
Fig. 4. Conical bomb (×2/3).
} Ejecta of 1940. Locality: Oyama.

Fig. 5. Square bomb (×2/3). Ejecta of 1874. Locality: Bôzu-yama.

Figs. 6 a—d. Spindle-shaped bombs (×2/3).
Fig. 7. Cylindrical (short) bomb (×2/3).
Fig. 8. Cylindrical (long) bomb (×2/3).
Fig. 9. Leaf blade-shaped bomb (×2/3).
Fig. 10. Goat's horn-shaped bomb (×2/3).
Fig. 11. Ribbon-shaped bomb (×2/3).
} Ejecta of 1940. Locality: Oyama.

Figs. 12 a—d. Twin bombs (natural sizes). Ejecta of 1874. Locality: Bôzu-yama.

Figs. 13 a—f. Various forms of smaller bombs (natural sizes). Ejecta of 1940. Locality: Oyama.

Fig. 14. Various forms of smaller bombs (natural sizes). Ejecta of 1874. Locality: Bôzu-yama.

Figs. 15 a, b. Lava-blocks in which bomb-shaped parts are developed. (×1/2). Ejecta of 1940. Locality: Oyama.

Fig. 15 c. Do. Ejecta of 1874. Locality: Bôzu-yama.

Fig. 16. Section of a spheroidal bomb containing a large anorthite crystal in the core (natural size).
Fig. 17. Section of a spindle-shaped bomb containing an allivalitic segregation in the core.
} Ejecta of 1940. Locality: Hyôtan-yama.

Fig. 18. Section of a spheroidal bomb with an accidental xenolith (a white tuff containing anhydrite in the core (natural size).

Fig. 19. Piece of a spheroidal bomb with an accidental xenolith (an acid, glassy rock) in the core (natural size).

Fig. 20. Section of a spheroidal bomb with an accessory inclusion (porphyritic olivine-pyroxene-andesite) in the core (natural size).

Fig. 21 a. Section of a spheroidal bomb with an accessory inclusion (porphyritic augite-andesite) in the core (natural size).

Fig. 21 b. Thin section of the same bomb.

Fig. 21 c. Microphotograph of the part marked by a circle in the same thin section (×10).

Fig. 22. Section of a spindle-shaped bomb showing a zonal banding (natural size).

Fig. 23. Cross section of a cylindrical (short) bomb, showing a concentric zonal structure (×2/3).

Fig. 24. Section of a disk-shaped bomb, showing vesicular shells and compact lenticular cores (natural size).

Fig. 25. Cross section of a spindle-shaped bomb, showing two lenticular cores surrounded by scoriaceous shells (×2).

Fig. 26. Longitudinal section of a spindle-shaped bomb having a scoriaceous core (×1/2).

Fig. 27 a. Longitudinal section of a spindle-shaped bomb, show a lenticular compact core surrouuded by scoriaceous shells (natural size).

Fig. 27 b. Thin section of the same bomb.

Fig. 27 c. Microphotograph of the part marked by a circle in the same thin section (×10).

Fig. 28. Ellipsoidal bomb containing a lenticular cavity in the core (×2/3).

Fig. 29. Spindle-shaped bomb, containing cylindrical cavities, drawn in the direction of its longer axis (natural size).

[Figs. 18~29. Ejecta of 1940. Locality: Oyama.]

Fig. 30. Cross section of a spindle-shaped bomb, showing the compact inside (×2/3). Ejecta of 1940. Locality: Hyôtan-yama.

Fig. 31. Cross section of a spindle-shaped bomb, showing the compact inside (natural size). A faint zonal structure is seen by difference in color of the core and the shells. Ejecta of 1940. Locality: Oyama.

Fig. 32 a. Longitudinal thin section of a spindle-shaped bomb (Fig. 6 a), showing flow-banding as recognized by differences in color of the various parts inside (×3/2).

Fig. 32 b. Microphotograph of the part marked by a circle in the same thin section (×10). Flow-structure is exihibited by a parallel disposition of the crystals. Ejecta of 1940. Locality: Oyama.

Fig. 33. Section of a square bomb (Fig. 5), showing a flow-structure as recognized by differences in color of its various parts (natural size).

Fig. 34. Cross section of a twin bomb (Fig. 12 c), showing a zonal structure as recognized by differences in color of the core and the crust. The left and right parts of the core correspond respectively to the two halves of the twin.

Fig. 35. Basal section of a compact, disk-shaped bomb, showing a zonal structure as recognized by differences in color of the core and the crust (×3/2).

Fig. 36 a. Basal section of a compact flat-ellipsoidal bomb, showing an intricate flow-structure as recognized by differences in color of its various parts (×3/2).

[Figs. 35, 36 a: Ejecta of 1874. Locality: Bôzu-yama.]

Fig. 36 b. Microphotograph of the part marked by a circle in the same thin section, showing flow-banding (×30).

Fig. 37. Longitudinal thin section of a long spindle-shaped bomb, showing flow-banding (×3/2).

Fig. 38. Thin cross section of a compact, spindle-shaped bomb, showing zonal structure as recognized by difference in color of the core and the shells (×3/2).

Fig. 39 a. Cross thin section of half of disk-shaped bomb, showing zonal structure as recognized by differences in color of the core and the shells (×3/2).

Fig. 39 b. Microphotograph of the part marked by a circle in the same thin section (×10).

(Figs. 38–39 b:) Ejecta of 1940. Locality: Oyama.

Fig. 40 a. Thin cross section of a spindle-shaped bomb, showing a zonal structure as recognized by linear arrangement of vesicles as well as by differences in color of the core and the shells (×3/2). Ejecta of 1940. Lacality: Oyama.

Fig. 40 b. Microphotograph of the part marked by a circle in the same thin section, showing flow-arrangement of the crystals (×10).

Fig. 40 c. Microphotograph of a part marked by a double circle in the same thin section, showing flow-arrangement of both crystals and vesicles (×25).

36. 三宅島產火山彈の形態及び構造に就いて

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筆者は先に富士火山產玄武岩火山彈の形態及び構造を研究し，それ等の本源が火山彈として抛出される前の噴火口內熔岩の流狀構造に求められることを推論した．本文では更に三宅島產火山彈の形態及び構造を觀察した結果を揭げ，此の場合にも同樣の推論を成し得る幾多の事實のあることを述べた．

三宅島は富士山，大島，八丈島等と共に玄武岩質火山彈を時に多量に產出する火山の一つであつて，特に同島山頂の中央火口丘（雄山）の火口附近，北東岸赤場曉附近，北腹坊主山等に多くの火山彈が見出され，また昭和15年噴火の際には，北東山腹に生じた新火口及び山頂に生じた新中央火口丘から多くの火山彈が抛出された．之等の火山彈は噴火口附近に特に多く，且つ他の同期噴出物の比較的上位に多く堆積し，一噴火の末期近くに噴火口附近に限つて多く抛出された事を示してゐる．例へば坊主山では，明治7年噴出の火山彈がその山頂附近に多量に見出され，同山の北東麓から北東海岸に亙つて堆積してゐる同年噴出の岩滓質砂礫層中には殆ど見出されない．之等の火山彈及び砂礫は同年噴出の熔岩流に先立つて抛出されたものであるが，兩者は噴出口を異にするのであつて，前者は坊主山頂上附近に形跡を留めてゐる裂罅狀火口から抛出されたのである．また昭和15年噴火の際に赤場曉灣內に生じた瓢箪山に於いても，その噴火口を中心として半徑約600 m の圓周地域內の地表に多くの火山彈が堆積してゐるが，同山東部の新海蝕崖で觀察される樣に，同山の內部を構成する物質卽ち此較的早期の噴出物は熔出流と岩滓質砂礫とであつて，火山彈を多く雜へてゐない．

三宅島で採集された100個餘の新舊火山彈は形態的特徵の上から次の12型に分類される．(1) 球形，(2) 圓盤形，(3) 楕圓體形，(4) 圓錐形，(5) 角盤形，(6) 紡錘形，(7) 柱形，(8) 棒形，(9) 葉片形，(10) 牛角形，(11) リボン形，及び (12) 双子形火山彈．之等の12型火山彈の形態的特徵は富士山火山彈に就いて分類された14型中の12型のそれに各々共通してゐる．たゞ後者中の2型卽ち皿型及び半球形火山彈に類するものは三宅島からの採集品中には見當らなかつた．また富士山に於いて見出された双子形火山彈は大小2個の火山彈が瓢箪形に連なつたかの如き形態を示す標品1個に過ぎなかつたが，三宅島火山彈中（特に坊主山產の明治7年火山彈）には双子形のものが屢々見出され，その中には，二つの個體が瓢箪形に連なるもの丶外に，兩個體か平列するもの，交叉するもの等がある．また不規則な形の熔岩塊の一部に火山彈の一面の形が發達してゐるものも見出される．

內部構造の上から見ると，三宅島火山彈は大體4種類に分かたれる．卽ち，その4種は (1) 核心に包裹物を有する火山彈，(2) 肉眼的の紐帶狀構造を示す火山彈，(3) 核心に空隙を有する火山彈，及び (4) 肉眼的に一樣に緻密質の火山彈である．

第一種火山彈の核心を成す包裹物としては，灰長石の單獨結晶，灰長石と橄欖石との集塊，舊熔岩片，火山の基盤岩の破片等が見出される．斯る包裹物を取圍む皮殼卽ち火山彈熔岩中の柱狀結晶（斜長石及び輝石）は包裹物を取卷いて流理構造を示す．而して，此の結晶の流狀配列は包裹物に接近する部分よりも火山彈の表面に近い部分に於いて一層整ひ，同表面の外郭線に略一致してゐる．

第二種火山彈はその表面から中心まで一續きの熔岩によつて構成されてゐるが，比較的緻密質の部分と多孔質の部分とが外形に應じて累帶構造を成してゐる．卽ちその核心部は緻密質又は多孔質で，それを取卷いて緻密質及び多孔質部が交互に相重なる．而して二つの累帶がその境の空隙によつて分離してゐる部分が屢々見られる．火山彈の皮殼は斯る部分に沿つて剝がれ易い．累帶構造を成す部分の各帶に含まれる柱狀結晶は累帶の方向に一致する流理構造を示し，また小氣泡は屢々同方向に連なり且つ引延ばされてゐる．

第三種火山彈の核心を成す空隙を取卷く熔岩も亦屢々累帶構造を示し，その中の柱狀結晶は流理構造を示す．長形の火山彈の或ものには中心以外にも比較的大きい空泡が在り，之等の空泡は火山彈の長軸方向に平行に引延ばされ夫々の圓筒を形成してゐることがある．然し核心部から外殼まで一樣に多數の氣孔が發達する樣な多孔質の火山彈は見出されない．

第四種火山彈には，緻密な核心を有する帶殼狀火山彈が地表に落下して後に皮殼を剝取られたものもある．一般に此の種の火山彈は肉眼的に一樣に略緻密であるが，その斷面は部分的に濃淡の色の差異に依つて累帶構造或は流理構造を示す事が多い．顯微鏡下では之等の構造が一層明瞭に認められる．卽ち斷面が肉眼的に略一樣に緻密で部分的の色の差異の認められない火山彈でも，その薄片は顯微鏡下では勿論，肉眼的にも黑色部と淡灰色部との累帶，層狀或は流理構造等を示す．顯微鏡下では，黑色部は石基中の斜長石及び輝石粒の間隙を鐵鑛粒を含む不透明物質に依つて塡められ，淡灰色部は石基結晶の間隙に比較的多量の褐色玻璃を殘してゐる．累帶構造を示す薄片では，その核心は黑色部によつて，その周圍の皮殼は一重の淡灰色部或は兩部の累帶によつて代表される．核心の黑色部には柱狀結晶の流理構造なく，周圍の皮殼部には同構造がよく發達してゐる．二つの個體が平行に連接する双子火山彈の横斷面の薄片では，各個體の核心に當たる部分に夫々の黑色部が在り，相互にS字狀に連なる．また此の種の火山彈では，顯微鏡的の小氣孔が累帶或は流理構造に一致して數列に連なつてゐる事が少くない．

以上に述べた三宅島火山彈の產狀，形態，及び構造に就いて觀察し得た事實を綜合すると次の事が云はれる．

火山彈が噴火口の附近に限つて多く分布し，且つ他の噴出物に對して比較的上位に多い事實はその拋出が一噴火期の末期に於いて噴火勢力の減退しつゝある間に多く行はれることを示す．從つて火山彈の形成は熔岩片が空中に拋出されてから後の條件に左右されるのでなくて，主として火口內熔岩の活動狀態，卽ち內的條件に支配されるものと考へられる．若し火山彈が單に火口から熔岩片としての飛出し方や空中を飛行中の運動の仕方に支配されるものとすれば，噴火時期の前後を問はず形成されるはずであるが，噴火の最盛期に拋出されるものは主として岩滓狀砂礫であつて，一樣に岩滓狀多孔質の熔岩片は火山彈としては見出されない．卽ち火口內熔岩が比較的多量の火山瓦斯に飽和或は過飽和してゐる間の噴火では火山彈は形成され難いものと考へられる．

火山彈がその形態的特徵によつて種々の型に分たれ，普通一般に火山彈と呼ばれる紡錘形のそれが單にその中の特別の一型に過ぎない事實は火山彈の形成が空中飛行中に於ける或特定の運動に因つては行はれ難い事を示すものである．例へば，空中飛行中に於ける火山彈の廻轉が紡錘形火山彈の形成を說明し得る程著しいものでない事は昭和 15 年噴火の際に實見し得た所である．

火山彈の內部の緻密部と多孔部，或は結晶部と多玻璃部との累帶或は層狀構造，柱狀結晶の流理構造，一方向に長く引延された氣孔或は氣孔の列等が火山彈の空中飛行中或は地上落下後に生ずるものとしては到底說明されないであらう．之等の存在する事實は火山彈拋出當時の火口內熔岩が既に斯る構造を有し，また氣孔を生ずる火山瓦斯に比較的乏しく且つ粘稠度を增してゐた事


Fig. 1.

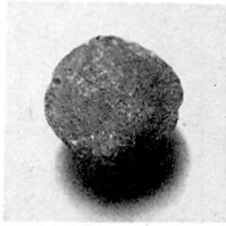
Fig. 2.


Fig. 3.


Fig. 4.


Fig. 5.


Fig. 6 a.


Fig. 6 b.

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Fig. 6 c.


Fig. 6 d.

Volcanic Bombs from Miyake-sima.


Fig. 7.

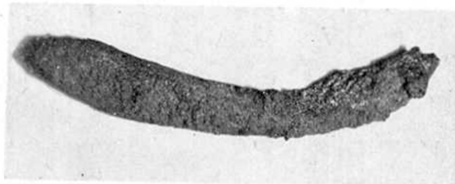
Fig. 8.


Fig. 9.

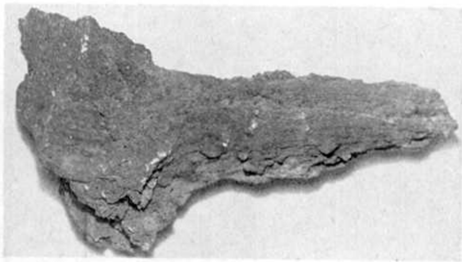
Fig. 10.


Fig. 11.


Fig. 12 a.


Fig. 12 b.

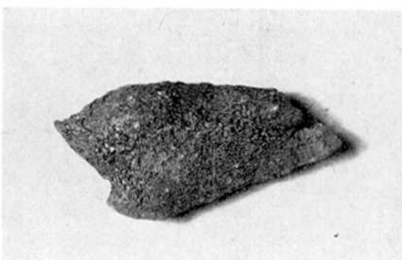
Fig. 12 c.


Fig. 12 d.

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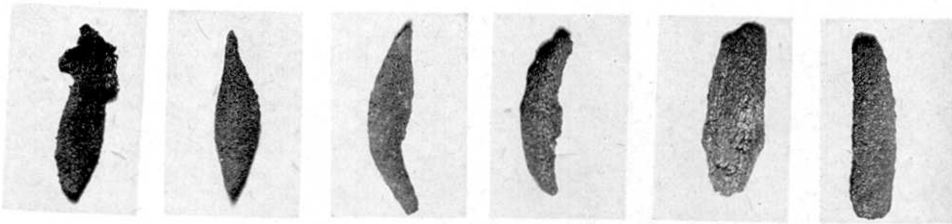

a b c d e f

Fig. 13.

Fig. 14.

Fig. 15 a.

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Fig. 15 b.

Fig. 15 c.

Volcanic Bombs from Miyake-sima.

Fig. 16.

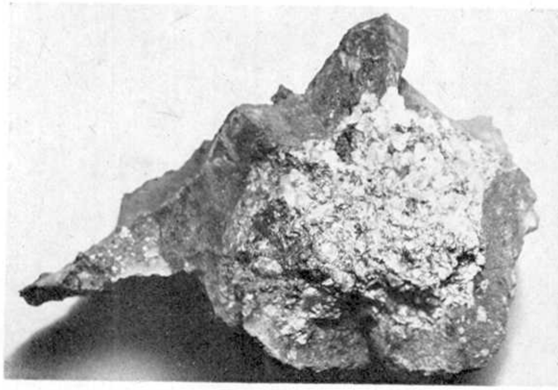

Fig. 17.

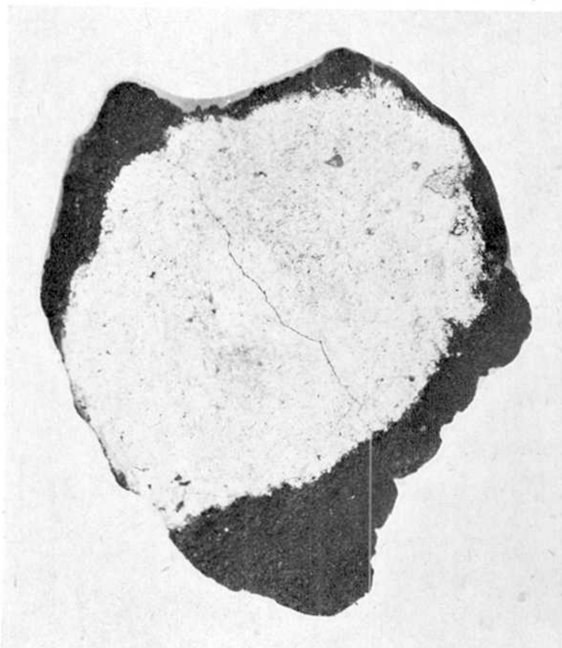

Fig. 18.

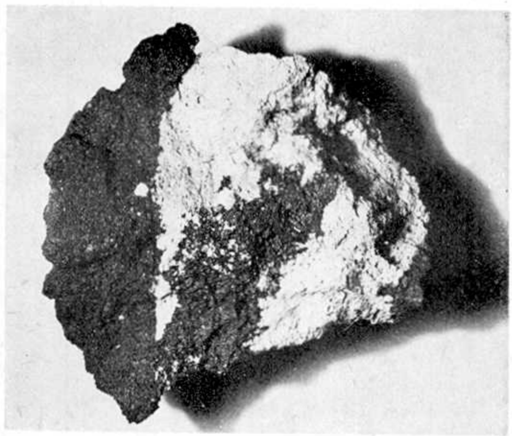

Fig. 19.

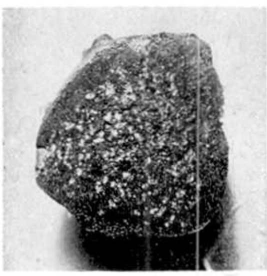

Fig. 20.

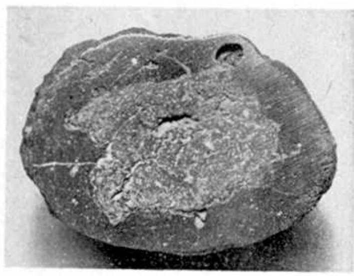

Fig. 21 a.

Volcanic Bombs from Miyake-sima.

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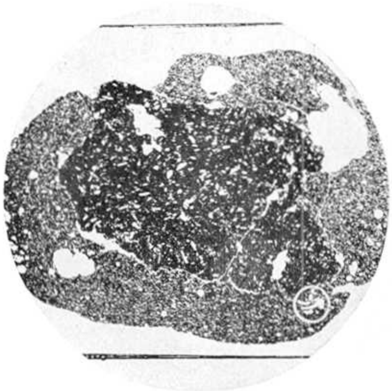

Fig. 21 b.

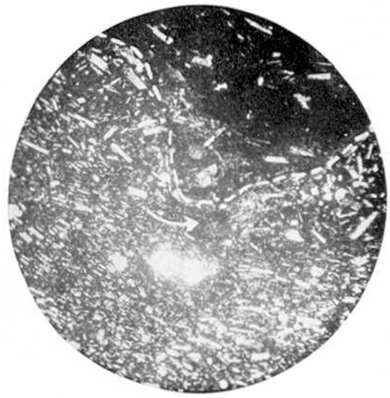

Fig. 21 c.

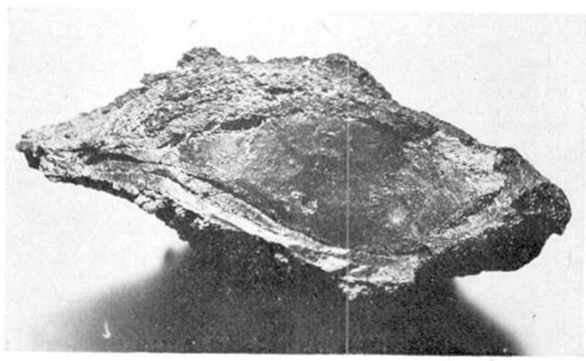

Fig. 22.

Fig. 23.

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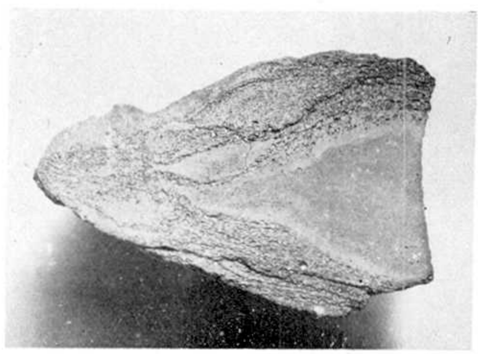

Fig. 24.

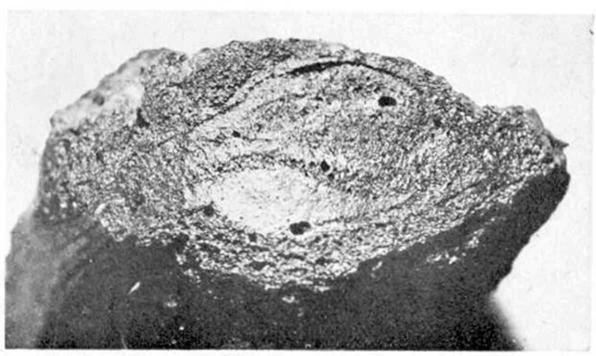

Fig. 25.

Volcanic Bombs from Miyake-sima.

Fig. 26.

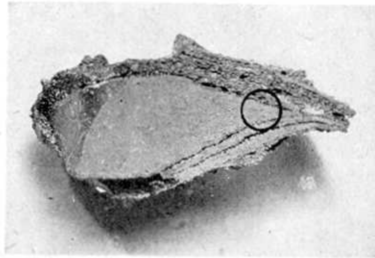

Fig. 27 a.

Fig. 27 b.

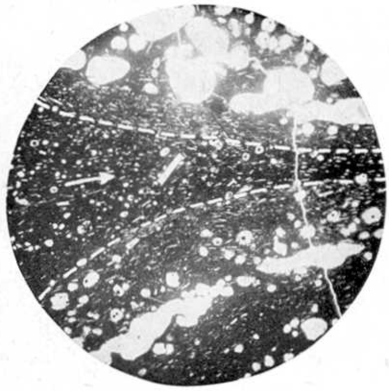

Fig. 27 c.

Fig. 28.

Fig. 29.

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Fig. 30.

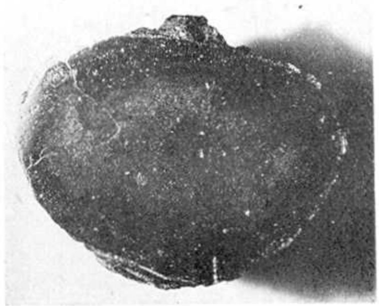

Fig. 31.

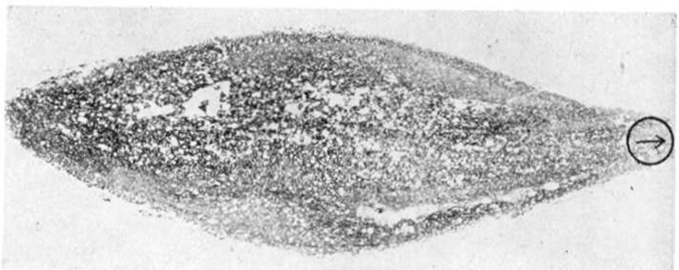

Fig. 32 a.

Fig. 33.

Fig. 32 b.

Volcanic Bombs from Miyake-sima.

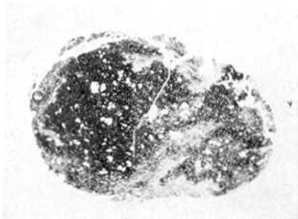

Fig. 34.

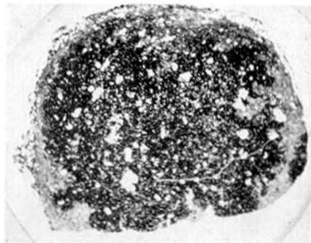

Fig. 35.

Fig. 36 a.

Fig. 36 b.

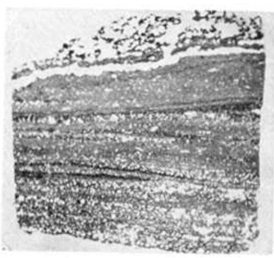

Fig. 37.

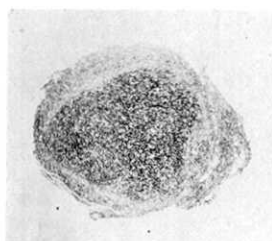

Fig. 38.

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Fig. 39 a.

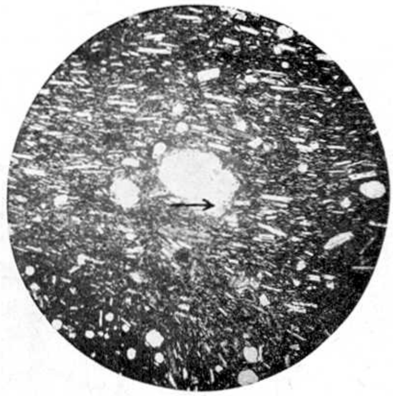

Fig. 39 b.

Fig. 40 a.

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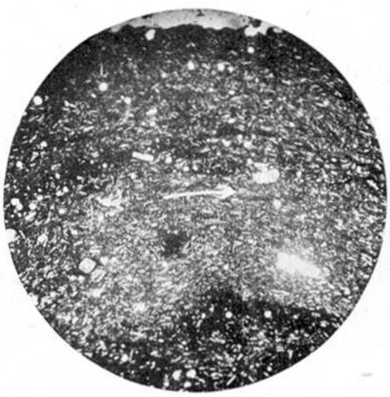

Fig. 40 b.

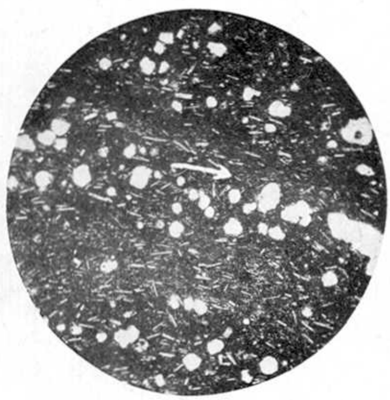

Fig. 40 c.

Volcanic Bombs from Miyake-sima.

を示すものと考へられる．従つてまた累帯構造や流理構造などが火山彈の外形に常に整合的である事實は火山彈の外形がその内部構造に全く無關係に生じたものでない事を示す．若し火山彈の外形が噴火に際して火口から熔岩片の飛出し方或はその後の空中飛行中の運動に支配されるとすれば，その内部構造と外形とが不整合的關係を示すものが存在するはずであるが斯る例は見出されない．故に火山彈の外形はその内部構造に支配されて生ずるものと考へられる．

熔岩内に緻密部と多孔部，或は多結晶部と多玻璃部との層狀或はレンズ狀構造，結晶の流理構造等の存在する事實は噴出の際比較的粘稠性が大であつたと思はれる熔岩流に於いて屢々見られる．火山彈が噴火口附近に多い事實は，勢力の比較的弱い噴火によつて火口内熔岩の極く地表に近い部分からそれが拋出された事を示すものであらう．地表近くの熔岩は深所のそれに比較すれば多少大なる粘稠性を有し，瓦斯泡の分量，結晶度等に關して多少不均質と成る．斯る熔岩は流動方向に從つて不均質な部分の層狀或はレンズ狀構造を生じ，包裹物を有すれば，それを取圍んで流線狀構造を生じ，何れの場合にもその中の柱狀結晶は同方向に流狀に配列され，また瓦斯泡は同方向に配列され且つ引延ばされ易いであらう．從つて斯る熔岩中に爆發が起れば，同熔岩は比較的分離し易い層狀或はレンズ狀構造の境界面或は瓦斯泡の配列面を境として片々に分たれ，その内部構造に相應する種々の形態の火山彈と成り，ただ火口内熔岩より分離する際及び空中を飛行中に多少引延ばされ，捻られ，或は曲げられる等の變形を受けるものと考へられる．

要するに火山彈の外形のみの起源の説明方法は色々あるにしても，その形態と内部構造との密接な關係を説明し得るものが一層事實に近いのであつて，その意味で上述の解釋は H. Reck (1915) や G. Ponte (1934) の考へに一致する點が少くない．