Investigation on the Lava Tube Cave Located under the Hornito of Mihara-yama in Izu-Oshima Island, Tokyo, Japan

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Abstract

A lava tube cave recently found under the hornito of Mihara-yama in Izu-Oshima island, located in the Pacific Ocean at 120km south of Tokyo, was surveyed and investigated by the Vulcano-Speleological Society. This lava cave was formed inside of 1951 eruption lava flow deposited at the edge of inner crater of Mihara-yama. The lava tube cave consists of a flat region and a sloped region whose total length is about 40m. Inside of the lava tube cave, general characteristics such as lava stalactites and lava benches can be found. Two important lava characteristics, yield strength and surface tension, were obtained from the observation of this lava tube cave. By using a simple model of steady state flow in circular pipe for analysis based on Bingham characteristics of lava flow in the tube (T.Honda,2001) and from the height and slope angle of the lava tube on the sloped region, the yield strength of the lava can be obtained as 50000 dyne/cm^2. This value is very near to the value calculated as 43000 dyne/cm2 by G.Hulme(1974) for 1951 eruption lava flow configuration observed by T.Minakami(1951). From the pitch of lava stalactites on the roof surface (3 to 4cm), the surface tension of lava was determined as 600 to 1000 dyne/cm. This value agrees well with the extrapolated value obtained by I.Yokoyama (1970) in the melting lava surface tension measurement experiments in Laboratory.

Introduction

The hornito with lava tube cave is located on Izu-oshima island south of Tokyo in the Pacific Ocean. Izu-oshima island, located on the volcanic front of the izu-Ogasawara (Bonin) arc, consists of Mihara-yama which has large outer crater and small inner crater. This hornito and lava cave were formed inside of 1951 eruption lava flow deposited at the edge of inner crater of Mihara-yama. Its lava flow with temperature of 1200~1150 degree is basaltic, with silica content of 52~53%[1].

The existence of the hornito of Mihara-yama has been well known since the eruption of 1951 of Mihara-yama. The formation process was also remotely well observed by volcanic researchers at that time and precisely described in the scientific papers[1,2,3]. However, since the eruption, any research inside of the lava tube cave under the hornito has not been tried though the accessibility is

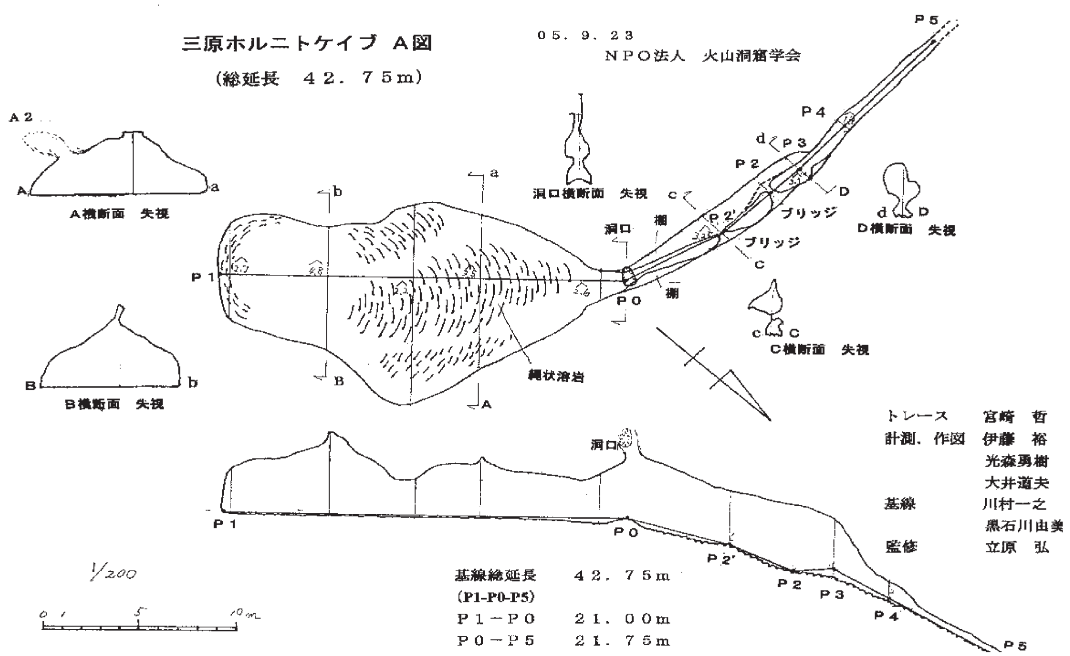

Figure 1. Horizontal and vertical cross section of the lava tube cave under the hornito. (Right side is crater side, left side is outer sloped crater wall side).

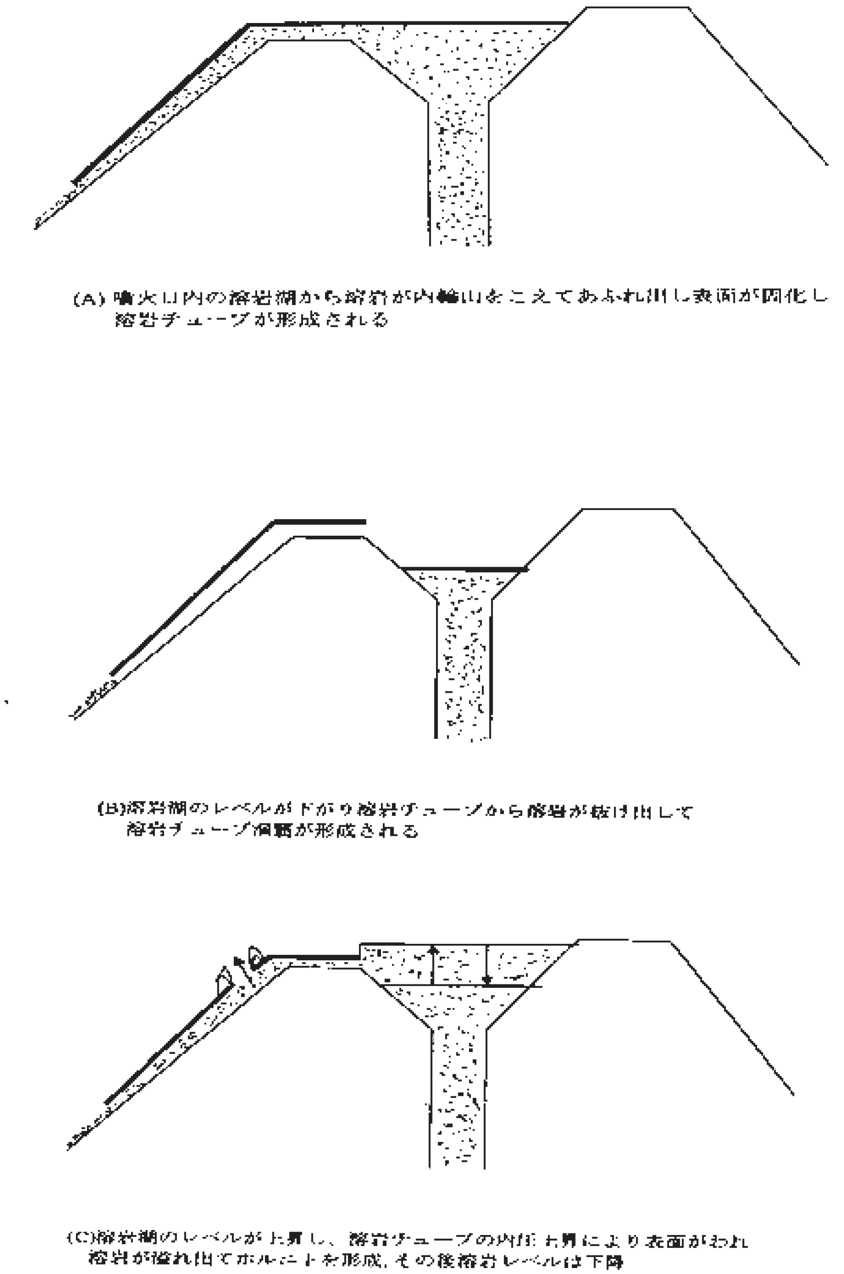

Figure 2. Simplified model of formation process of the lava tube cave and hornito: (A) The lava supplied from the underground will get over the edge of the crater, and flow down though the slope to the foot. (B) The cooled surface of lava flow becomes solid and inner fluid lava will drain out when the supply of the lava from the crater is terminated. (C) The eventual level change of lava will exercise the additional pressure on the solid inner surface, the surface will break and inner fluid lava will eject and accumulate around the hole.

very good. Recently in 2005 and 2006, members of Vulcano-Speleological Society of Japan investigated the hornito and the lava tube cave.

Configuration and formation process

General configuration of the lava tube cave is shown in Fig.1. The lava tube cave consists of a flat region on the edge of the inner crater and a sloped region in the outer slope. The total length of the cave is about 40m.

Formation process of the lava tube cave and hornito is schematically shown in Fig.2. The lava supplied from the underground will get over the edge of the crater, and flow down though the slope to the foot. The cooled surface of lava flow becomes solid and inner fluid lava will drain out when the supply of the lava from the crater is terminated. Thus the lava tube cave will be formed. The formation of hornito seems be only parasitic. When the solid surface has partially a vulnerable part and the eventual level change of lava will exercise the additional pressure on the solid inner surface, the surface will break and inner fluid lava will eject and accumulate around the hole. Based on this model, we can obtain the important physical property of lava: yield strength.

Discharge mechanism, modeling, assumption and analysis

In modeling the discharge mechanism of this type of lava tube, we used an inclined circular tube model for the sloping section of the cave. Regarding the inclined circular pipe, the discharge mechanism of lava tube caves already has been established, based on Bingham characteristics of intratubal lava flow[4,5,6]. A simple model of steady state isothermal laminar flow in inclined circular pipes was used for analyses. Flow characteristics were studied as a function of parameters such as tube radius, viscosity, yield strength of lava and slope inclination. A critical condition

Table 1. Relation between slope angle and height of the lava tube cave of sloped configuration area.

Location of lava cave in the sloped area	Slope angle(α)	Height(2R)
Upper reaches	15 degree	~3.5m
Intermediate reaches	25 degree	~2.5m
Lower reaches	30 degree	~1m

Table 2. Yield strength obtained from the critical condition.

Name of volcano	SiO_2 fraction of lava	Obtained yield strength	References
Mihara-yama	52~53%*	$5x10^4$dyne/cm^2 $4.3x10^4$dyne/cm^2[7]	*T.Minakamil (1951)[1]
Mt.Fuji	49.09~51.3%*	2.5~$5.0x10^4$dyne/cm^2[6]	*H.Tsuya(1971)[8]

was determined for the discharge parameters in which the yield strength plays a dominant role. The equation $(\varrho g \sin\alpha)R/2=f_B$ is the limiting condition to determine if the fluid in the tube can be drained out. Here, α is angle of slope or inclination of tube, ϱ density of the fluid, g gravity acceleration, R radius of the tube, r_B radius of the flowing position where Bingham yield stress takes f_B.

For given and known relation between slope angle and diameter (height) of the tube, this critical condition can give the yield strength f_B. This critical condition means that when the yield strength of Bingham fluid is higher than the shear stress at the wall, there is no flow of fluid, as a consequence, no drainage of fluid from the tube.

From Table 1, $f_B=5x10^4$ dyne/cm^2 can be obtained for the lava of Mihara-yama.

The deduced yield strength from lava of the caves was found to be in good accordance with yield strength ($4.3x10^4$ dyne/cm^2) as estimated by other methods[7].

In summary, obtained basaltic yield stress from slope angle and height of some lava caves(see Table-2)are also reasonable values as compared with the yield stress obtained for Mt.Fuji[6].

Observation of inside surface

Inside of the lava tube cave, lava stalactites are positioned periodically on the surface of the ceiling wall as shown in Fig.3. From the periodical pitch of the stalactites, we can obtain the surface tension of the lava. The pitch will be critical wave length of the occurrence of instability of thin liquid film attached on the surface of the ceiling of the lava tube cave. The pitch is shown as $2\pi(\sigma/g\varrho_L)^{1/2}$, where σ is surface tension of liquid ϱ_L is density of liquid, g is gravity acceleration.

From the pitch of lava stalactites on the roof surface (3 to 4cm), the surface tension of lava was determined as 600 to 1000 dyne/cm. This value agrees well with the extrapolated value obtained by I. Yokoyama et al.[9] in the melting lava surface tension measurement experiments in Laboratory.

Conclusions

The lava tube cave under the hornito of Mihara-yama, though this is a small scale lava tube cave, is a typical lava tube cave which can be explained by discharge mechanism of lava by gravity under the solidified surface of lava flow.

As a results of this study, Bingham fluid model seems to be well applied for an explanation of formation process of lava tube cave. Obtained yield strength has a well accordance with the results obtained by other method. As for surface tension, it seems to be obtained by simple model of instability of liquid film attached on the roof surface. The estimated surface tension agree with the experimental results by melting the lava in the Laboratory.

Figure 3. Lava stalactite on the ceiling wall surface in the lava tube cave.

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