RELATION BETWEEN THE VOLCANIC ACTIVITY OF Mt. HACHIJO-FUJI AND VOLCANIC CAVES ON HACHIJOJIMA ISLAND, THE SEVEN IZU ISLANDS, JAPAN

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ABSTRACT

Volcanic caves which cannot be explained by conventional formation mechanisms were discovered at the summit of Mt. Hachijo-Fuji on Hachijojima Island for the first time. The namesof the caves are Hachijo-Fuji Fuketsu and Hachijo Dome FissureCaves. The purpose of this paper is to propound a formation mechanism of Hachijo-Fuji Fuketsu as an example of a volcanic tectonic cave on the basis of a slide of a bed in the craterrim, and that of Hachijo Dome Fissure Caves as an example of alava dome fissure cave on the basis of a residual thermal stressin the lava dome.

Hachijo-Fuji Fuketsu is formed along the head of the slide because fissures are formed in the bed owing to collaspes of thecrater rim, and the resultant slide develops the fissures intoHachijo-Fuji Fuketsu with the width of the fissures widening.

Hachijo Dome Fissure Caves are formed in the form of a fissure in the plane of the maximum residual thermal stress in the lava dome with viscoelastic properties because quick cooling of the wall of a pit crater with the atmosphere causes the fissure to be formed through deformation of the lava dome due to the residual thermal stresses.

1. INTRODUCTION

Members of Japan Volcanospeleological Soiety have been investigating volcanic caves on Hachijojima Island, one of the Seven Izu Islands, Japan since the existence of Hachijo Fuketsu N°.1 was confirmed in 1979.

Hachijo-Fuji Fuketsu and Hachijo Dome Fissure Cave A were discovered in 1990 and in 1992 respectively. However, it has turned out that the formation of these volcanic caves cannot be explained by coventional formation mechanisms of volcanic caves.

The purpose of this paper is to propound formation mechanisms of a volcanic tectonic cave and a lava dome fissure cave. The formation mechanisms are proposed on the basis of my on-the-spot surveys. Hachijo-Fuji Fuketsu is a volcanic tectonic cave. Hachijo Dome Fissure Caves are instances of a lava dome fissure cave.

The term a volcanic tectonic cave" is defined as the volcanic cave formed because of a slide of a bed in an unsteady crater rim as a result of the sliding of a bed. The term a lava dome fissure cave" is defined as the volcanic cave formed in the form of a fissure in a lava dome with viscoelastic properties because of a residual thermal stress.

Before turning to the main argument, this paper describes an outline of the Seven Izu Islands, a summary of the geology and topography of Hachijojima Island and Mt. Hachijo-Fuji, andthe volcanic caves on Hachijojima Island.

2. THE SEVEN IZU ISLANDS

The Seven Izu Islands is composed of Oshima, Toshima, Niijima, Kozushima, Miyakejima, and Hachijojima islands (Fig.1).

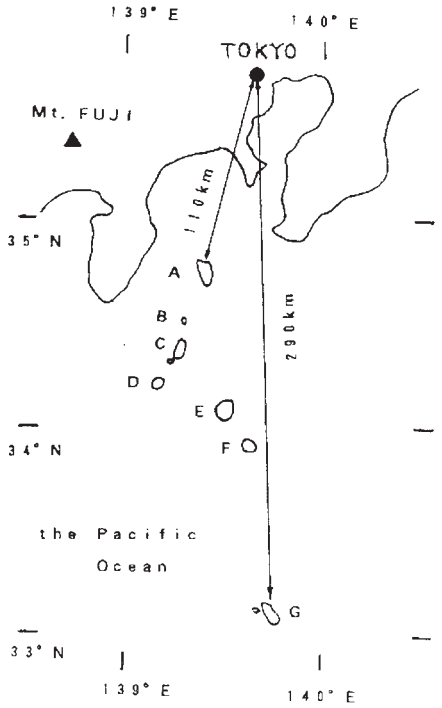

Fig.1.- The locations and the names of the Seven Izu Islans. A: Oshima Island, B: Toshima Island, C: Niijima Island, D: Kozushima Island, E: Miyakejima Island, F: Mikurajima Island, G: Hachijojima Island.

The Seven Izu Islamds is situated in the western part of the Pacific Ocean, between latitude 33 degrees to 35 degrees north and longitude 139 degrees to 140 degrees east.

To take two typical examples, Oshima Island is situated about 110km south of Tokyo, the nation's capital. Hachijojima Island is situated about 290 km south of Tokyo.

The Islands are located on the eastern border of the Philippene Sea Plate. The origin of island-arc type volcanos is related to the subduction of the Pacific Plate underneath the Philippene Sea Plate. Some island-arc type volcanoes have developed into the SevenIzu Islands (Yuasa, 1991).

Table 1 shows the relation of the geology of the Seven Izu Islands and the volcanic caves. Oshima, Toshima, Miyakejima islands are made up principally of basalt and andesite (Isshiki, 1959). Volcanic caves have been discovered except Toshima Island because we have not yet made investigations into volcanic caves on Toshima Island.

There is no volcanic cave on Niijima Island and Kozushima Island because they are made up principally of rhyolite.

3. HACHIJOJIMA ISLAND

As I mentioned above, Hachijojima Island is the southernmost island of the Seven Izu Islands. It has the shape of a pear with maximum 8 km in width and 14 km in length. The area of this island is about 69 square kilometers (Fig. 2)

Hachijojima Island consists of Mt. Hachijo-Fuji and Mt. Miharayama. Mt. Hachijo-Fuji is the highest volcano in the Seven Izu Islands. It is 854.3 meters high. The heiht of Mt.Miharayama is 700.9 meters.

Mt. Miharayama is made up of a caldera stratovolcano (region 2 in Figure 2) and a small conical volcano (region 3 in Figure 2) (Isshiki, 1984). The volcanic activity started tens thousands of years ago and ended 3000 years ago or 2000 years ago. The caldera was created about twenty thousand years ago. The volcanic body of Mt. Miharayama has been dissected considerably (Nomura, 1986).

The large degree of dissection must have destroyed the volcanic caves on Mt. Miharayama because most volcanic caves tend to exist near the surface of the earth.

Mt. Hachijo-Fuji is a main stratovolcano (region 1 in Figure 2) (Isshiki, 1984). The volcanic activity started 3000 years ago or 2000 years ago and ended in 1707. Mt. Hachijo-Fuji is scarcely dissected (Nomura, 1986).

As for the geology of the two volcanos, Mt. Miharayama is made up principally of Andisitic

lavas, basaltic lavas and phyloclastic rocks. Mt. Hachijo-Fuji, on the other hand, is made up principally of basaltic lavas and scoria (Nomura, 1986). Considering the difference in the degree of dissection between the two volcanoes and that in the geology between the two volcanoes,it is reasonable that the volcanic caves are concentrated not in Mt. Miharayama but in Mt. Hachijo-Fuji (Fig.2). The circles in Figure 2 designate the locations of the volcanic caves.

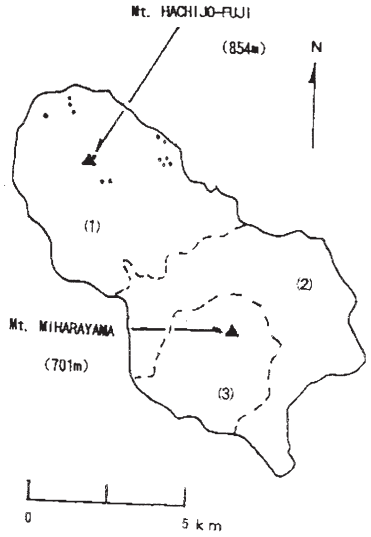

Fig.2.- Topographic map of Hachijojima Island. The closed circles designate the locations of volcanic caves. The region 1) is a main stratovolcano. The region 2) is a caldera stratovolcano (Older caldera stratovolcano). The region 3) is a small conical volcano (Younger caldera strato-volcano). (Modified after Isshiki, 1984.)

4. MT. HACHIJO-FUJI

Mt. Hachijo-Fuji is an almost perfectly conical stratovolcano just like Mt. Fuji in the Mainland of Japan (Fig. 3).

Fig.3.- A complete view of Mt. Hachijo-Fuji from Mt. Miharayama. Mt. Hachijo-Fuji is an almost perfectly conical stratovolcano just like Mt. Fuji in the Mainland of Japan.

Fig.4.- Topographic map of Mt. Hachijo-Fuji. Mt. Hachijo-Fuji occupies the northwestern part of Hachijojima Island. The broken line represents a boundary between the region of Mt. Hachijo-Fuji and that of Mt. Miharayama. (Modified after Isshiki, 1959.)

The small island to the left is a volcanic island named Hachijo-Kojima. It is located at 7.5 km northwest of Hachijojima Island. It is considered that this island was created in the first stage of Mt. Miharayama formation (The board of Education of Hachijo-Cho, 1973).

Mt. Hachijo-Fuji has parastic volcanoes in the southwest part of its foot. These volcanoes have nothing to do with the volcanic caves on Hachijo Island because no cave exists on the parasitic volcanoes (Fig. 4).

Mt. Hachijo-Fuji has a summit crater named Oana. It's about 400 meters in diameter, and about 50 meters in depth. The volcanic tectinic cave exists on the rim of the summit crater (Fig. 5).

Moreover, Mt. Hachijo-Fuji has a lava dome in the summit crater. There are five lava dome fissure caves with twelve entrances in the lava dome.

Furthmore, Mt. Hachijo-Fuji has a pit crater named Koana in the summit crater. It is about 180 meters in diameter, and about 95 meters in depth. The formation of this pit crater caused the lava dome fissure caves to be created in the lava dome. The details will be described later.

It is recorded in documets that the eruptions of Mt. Hachijo-Fuji was in 1394 ≈1427, 1487, 1518≈1523, 1605 and 1707. However, it is not described whether the eruptions were summit eruptions or lateral eruptions. Moreover, it is not clear where lava flows poured from because lava explorations have been begun only partly on Hachijojima Island (Nomura, 1986).

The last eruption of Mt. Fuji is also in 1707. The relation between these eruptions has not been apparent yet.

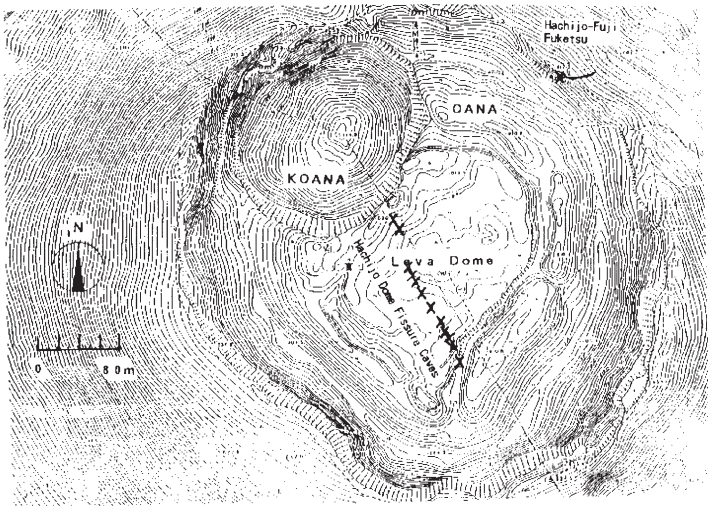

Fig.5.- The locations of Hachijo-Fuji Fuketsu and Hachijo Dome Fissure Caves in the summit crater ofMt. Hachijo-Fuji. Koana is the name of the pit crater. Oana is the name of the summit crater. The crosses designate the entrances of Hachijo-Fuji Fuketsu and Hachijo Dome Fissure Caves.(After Hacjijo-cho, Tokyo.)

5. VOLCANIC CAVES ON HACHIJOJIMA ISLAND

Table 2 is a list of volcanic caves on Hachijojima Island. These volcanic caves can be roughly classified into four groups: a lava cave, a rift cave, a volcanic tectonic cave and a lava dome fissure cave.

There are nine lava caves. Hachijo Fuketsu N.º 1 is the second longest lava cave in Japan. The longest lava cave is Mitsuike-Ana at the foot of Mt. Fuji. It is 2202 meters long.

Hachijo Fuketsu N.º 2 is missing. Why should we cannot find it out in spite of three times searches ?

Hachijo Fuketsu N.º 5, Gokuraku-Ana, Hachijo Dome Fissure Cave C and E are unsurveyed caves.

There are four rift caves. Part of Nazumado Rift Cave is a lava cave, which is 80 meters long. Rift cave part of this cave is more than 6 meters high. We cannot climb up any higher because of a narrow passage.

There is the volcanic tectonic cave named Hachijo-Fuji Fuketsu. There are the five lava dome fissure caves named Hachijo dome fissure cave A, B, C, D and E. Hachijo dome fissure cave A is the deepest volcanic cave in Japan. It is 77m in depth. There are 19 volcanic caves altogether.

I would like to focus attention on the formation mechanisms of the volcanic tectonic cave and the lava dome fissure caves because they were discovered for the first time in Japan.

6. VOLCANIC TECTONIC CAVE

6.1 Features of the Outside of Hachijo-Fuji Fuketsu

In view of the important features of the crater rim of Mt. Hachijo-Fuji, let us then consider the formation mechanism of Hachijo-Fuji Fuketsu.

The cross on the topographic map (Fig.5) designates the locations of two entrances of Hachijo-Fuji Fuketsu. These entrances open on the upper part of a very steep crater wall, namely a free face. The mark of the topographic map under the cross presents a rock precipice. A talus slope can be observed at the foot of the crater wall, and hence it is considered that retreats of the crater wall due to a rockfall caused the entrances to open on the free face.

Part of the crater rim with the entrances is higher than parts of the crater rim on both sides of the entrances. As is analogized from the numerous examples of collapses of crater rims on stratovolcanoes (Ollier, 1991), collapses of the crater rim due to volcanic activity of Mt. Hachijo-Fuji resulted in the formation of the lower parts of the crater rim.

Judging from these features, it can be considered that the higher part of the crater rim with the entrances was left behind as an unsteady rock precipice during the volcanic activity.

As is evident from Figure 5, Hachijo-Fuji Fuketsu is located along the brink of the unsteady rock precipice. Moreover, the cave is below the slope of the higher part of the crater rim. These features indicate that the unsteady rock precipice was pulled downward by gravity, and hence it is considered that tensile stresses toward the center of the crater and the lower part of the crater rim have been set up in the higher part of the crater rim.

6.2 Features of the Inside of Hachijo-Fuji Fuketsu

The angle of inclination of the cave is about 27 degrees, and that of the slope of the crater rim over the cave is about 25 degrees (Fig.6). These features show that Hachijo-Fuji Fuketsu is formed near the surface of the crater rim because Entrance 2 is about 4 meters below the surface.

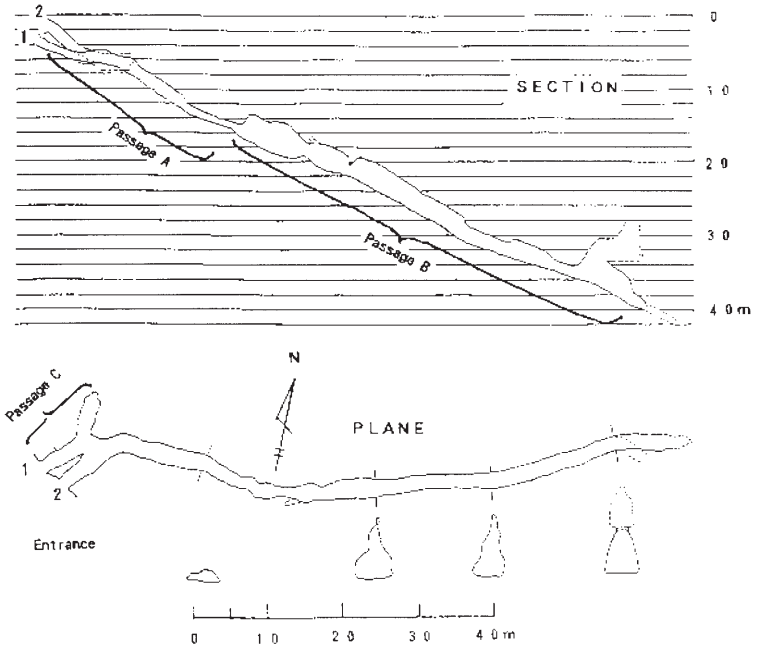

Fig.6.- Map of Hachijo-Fuji Fuketsu Hachijo-Fuji Fuketsu. The cave iscomposed of Passage A, passage B and Passage C. Patr of Passage C was excavated. Entrance 1 was opened artificially.

It is reported from a seismic prospecting that the internal structure of Mt. Hachijo-Fuji is symmetrical about the central axis of the crater (Tokyo Metropolitan Government Office, 1992). It is likely from this feature that the stratification structure of Mt. Hachojo-Fuji promotes sliding by the collapses of the crater rim described in section 6.1 because stratification planes act as shear surfaces along which a slide bed moves downward (Fujita,1990).

The floor in Passage A is buried under lots of pyroclastic materials, such as lappili, volcanic blocks and lavas, while the floor in Passage B is somewhat buried. Moreover, there is scarcely a variation in the height of a ceiling in Passage A in comparison with a variation in Passage B. These features indicate that Passage A was affected in interior conditions by the volcanic activity after Entrance 2 was opened by the retreats.

6.3 Formation Mechanism of Hachijo-Fuji Fuketsu

It is not necessary to consider Entrance 1 and Passage C because Entrance 1 was opened artificially and Passage C was excavated for part of a military base during World WarII. This section concentrates on a formation mechanism of Passage A and Passage B.

From the observational studies described above, the formation mechanism can be developed as follows:

1) the crater rim of Mt. Hachijo-Fuji is formed (Fig.7 a),
2) the crater rim is collapsed by the volcanic activity, and consequently, the higher part of the crater rim and the lower part of that are formed,
3) the higher part is bent downward by gravity, and hence fissures are formed mainly in the weak part of the bed 2 (Fig.7b),
4) the slide occurs under the crater rim because the bed 2 is divided into two parts on the fissure plane by gravity,
5) the slide widens the fissures, so that it develops them into Hachijo-Fuji Fuketsu (the volcanic tectonic cave) along the head of the slide (Fig.7c),
6) Entrance 2 is opened by the retreats of the crater wall.

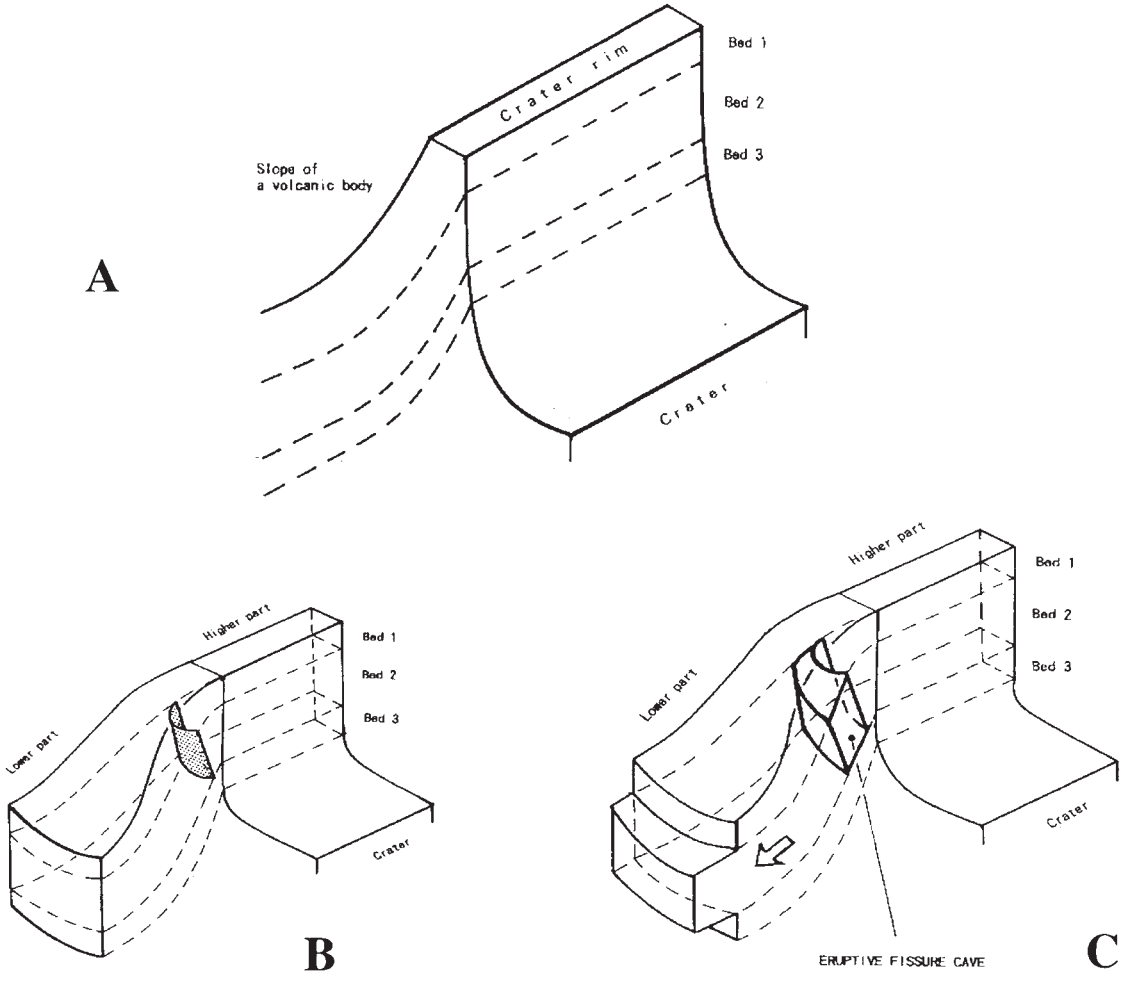

Fig. 7.- Diagram illustrating the formation of Hachijo-Fuji Fuketsu. A) The crater rim is formed during the volcanic activity. B) Fissures are formed in the weak part of the stratum 2 after the collapses of the crater rim. The shaped portion designates the zone of the fissures. C) The slide develops the fissures into Hachijo-Fuji Fuketsu (the volcanic tectonic cave) along the head of the slide. The arrow represents the direction of the slide.

7. LAVA DOME FISSURE CAVE

Turning now to the formation mechanism of the lava dome fissure caves, namely Hachijo Dome Fissure Caves.

7.1 Features of the Outside of Hachijo Dome Fissure Caves

The fist point to note is that tha entrances are approximately on a straight line (Fig. 5).

The second point to note is that there is neither a strike-slip feature by a lateral fault nor a tectonic scarp by a dip-slip fault on the lava dome.

Thirdly, it is difficult to consider that the northeast-southwest movement of the lava dome accompanied with a tensile stress caused the lava dome fisurre caves to form in the lava dome because the relative height value of the lava dome, 25 m, is much smaller than the depth value of the lava dome fissure cave, 77 m maximum, so that the movement of the lava dome cannot have had direct effects upon the lower part of the lava dome fissure caves.

These features indicate that Hachijo Dome Fissure Caves were formed not by the tectonic agency, but by the agency of the thermal stress induced by the formation of the pit crater.

There is a ring-shaped trench on the lava dome (Fig. 8). It is believed that the trench formed when the lava of the lava dome went back to the volcanic vent to some extent, and then the fringe of the lava dome cooled with the vent was pulled toward the center of the lava dome. The trench formed earlier than the pit crater formed because the northwestern part of the trench is cut by the pit crater as in Figure 5.

Fig. 8.- Looking southeastward toward the summit of Hachijo-Fuji. The ring-shaped trench can be seen on the lava dome. (Photo by Gakken Hachijo Visitor Center).

7.2 Features of the Inside of Hachijo Dome Fissure Caves Figure 9 shows the section of Hachijo Dome Fissure Cave B, C, and D. However,it has not yet perfected as a section. Up to now it has been verified that the entrances, N.° 2, N.° 3, N.° 4, N.° 5 and N.° 6 are connected by the lower part of the cave B. Similarly, the entrances, N.°7 and N.° 8 are connected by the lower part of the cave C. Besides, the entrances, N.° 9 and N.° 10 are connected by the lower part of the cave D (Kondo, personal communications).

As in Figure 9, the several entrances are wide to an explorer, but the width of the caves is reduced at a halfway point and at the bottom of the caves. Each passage is very narrow (Kondo and Hirose, personal communications). Figure 10 shows a very wide bottom at a depth of 66 meters in the Cave A. This is the exception.

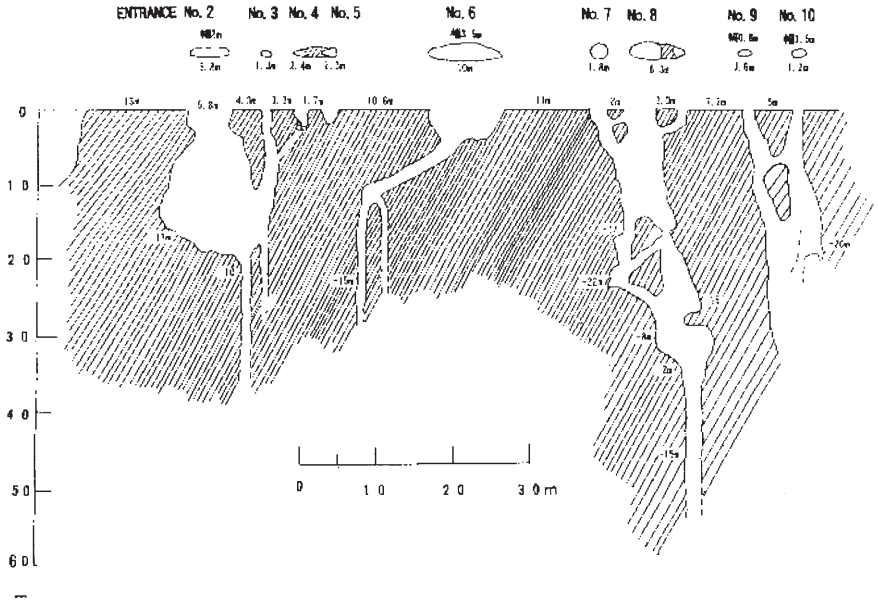

Fig. 9.- Section of Hachijo Dome Fissure Caves (From T. Hirose, 1993).

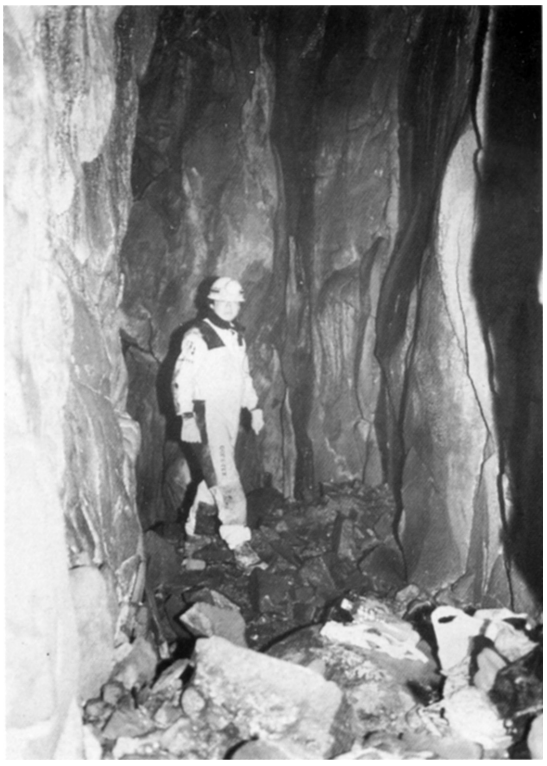

Fig. 10.- A very wide bottom in Hachijo Dome Fissure Cave A. (Photo by S. Kondo).

It has been reported that the same level lines of lava lining are observed in each of the lava dome fissure caves (Kondo, personal communication). It indicates that all entrances were connected by the lower part of the caves when a lava rose to the same lava level lines.

Several observations in the last few paragraphs have shown that the vertical cave system of very narrow width consists of Hachijo Dome Fissure Caves.

7.3 Formation Mechanism of Hachijo Dome Fissure Caves

In this section, I make the assumption that the lava dome can be regarded as a viscoelastic body before and after the formation of the pit crater.

It was reported by Miyano et al. in 1983 that a residual compressive stress is set up near the surface of a viscoelastic body and a residual tensile stress is set up in the central part of that when the surface of the body is cooled quickly (Fig. 11(a).

It was also reported by Sudo in 1988 that a hollow cylinder is deformed by quick cooling of the internal surface of the cylinder, it changes to a barrel in shape as a result as shown in Figure 11(b).

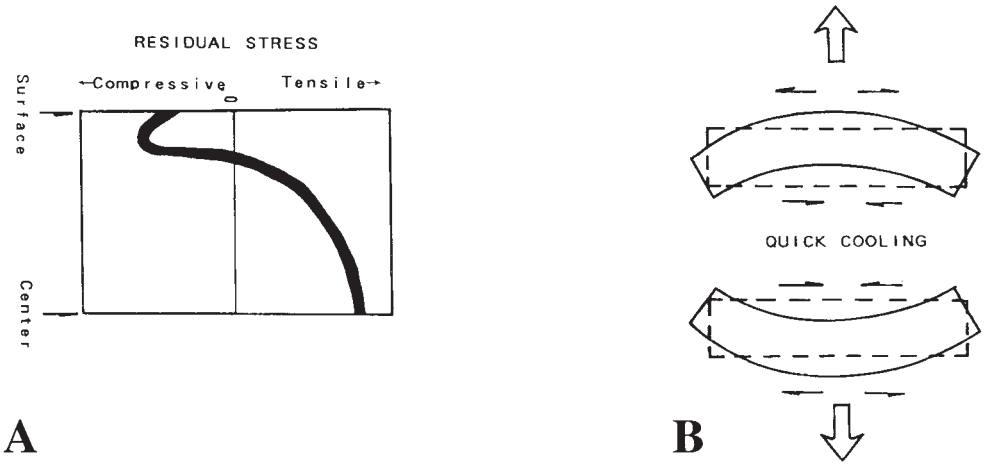

Fig. 11.- Principles for the formation mechanism of the Lava Dome Fissure Caves. **A**) Distribution of a residual stress. **B**) Deformation of a cylinder. The big arrow represent the direction of the deformation of the cylinder. The small arrows represent the direction of the residual compressive stresses (→ ←) and the residual tensile stresses (← →). (A: from K. Miyano et al., 1983; B: from H Sudo, 1988).

Here, let us regard the lava dome as a hollow cylinder, although the pit crater is inscribed in the crater.

Thermal conductivity of a lava is so low that a time lag of cooling (temperature difference) takes place between the side wall of the pit crater and the fringe of the lava dome when the distance between the two places is long on a horizontal plane.

Let us apply the ideas in Figure 11 to Hachijo Dome Fissure Caves. The pit crater was formed in the lava dome, and consequently quick cooling of the wall of the pit crater with the atmosphere caused a residual compressive stress to set up near the surface of the pit crater, and, at the same time, caused a residual tensile stress to set up on the fringe of the lava dome, and hence the forces are applied horizontally, for example, in the direction of the arrow 1 and the arrow 2 in Figure 12.

Consequently, the fissure will be formed in the lava dome because of the deformation of the lava dome when the horizontal compressive stress induced by the forces reaches the fracture strength of the lava dome. What has to be noticed is that as the distance between the two places mentioned above gets shorter, a residual stress will grow weaker, for instance, in the direction of the arrow 2 in Figure 12. This is because a time lag of cooling gets shorter.

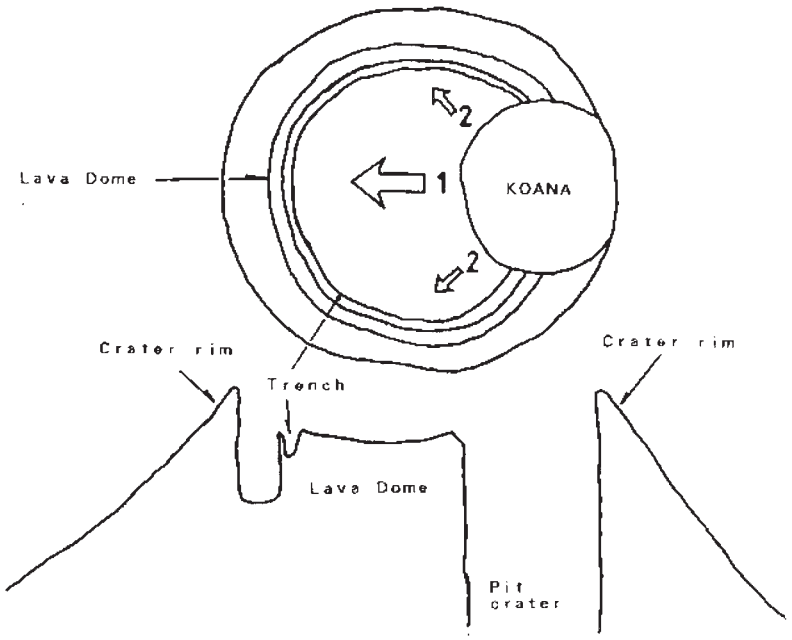

Fig. 12.- Diagram illustrating the formation of Hachijo Dome Fissure Caves. They were formed in the direction of arrow 1.

It follows from what has been said that Hachijo dome fissure caves were formed in the plane of the maximum residual stress in the lava dome. In short, the lava dome fissure caves are the cavities where the fissure is not filled by lava blocks, and so on.

8. DISCUSSION

It remaims an unsettled question how Hachijo-Fuji Fuketsu (the volcanic tectonic cave) is formed near the surface of the crater rim.

The interior surface of Passage B just like shark-tooth-shaped lavacicles indicates that the bed 1 in Figure 13 was a viscoelastic body maintained at a high temperature. Consequently, the bed 1 will not break by the agency of stress relaxation unless the bed is bent rapidly. On the other hand, the elastic bed 2 and the other elastic beds will break in the absence of stress relaxation when the bending stress reaches the rupture strength of the beds. Before the slide starts, the beds are steady, but as soon as the shear surfaces develop among each bed because of the inclination of the crater rim, the only restraining force is the friction of movement. The tendency to slide decreases with increasing bed thickness bacause the sliding frictional forces are in proportion to the forces perpendicular to the shear surfaces as in Figure 13.

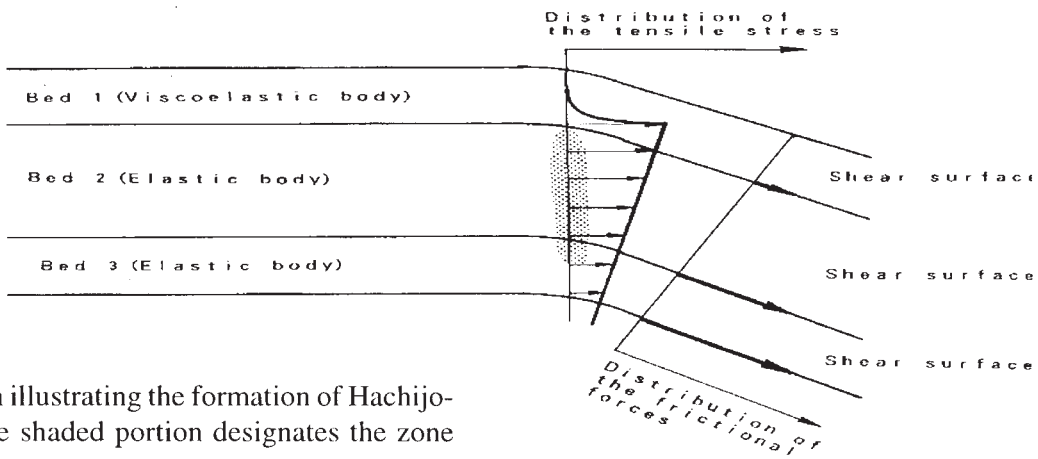

Fig. 13.- Diagram illustrating the formation of Hachijo-Fuji Fuketsu. The shaded portion designates the zone of the fissures.

Judging from Figure 13, the bed 2 is the most suitable bed for the slide because the tensile stress due to the bending is strongest in the bed 2, so that the fissures will be formed mainly in the bed 2. Moreover, the slidung frictional force is weakest in the bed 2. Consequently, the bed 2 near the surface of the crater rim can slide down most easily in the beds.

Let us leave Hachijo-Fuji Fuketsu and turn to Hachijo Dome Fissure Caves. An example to support the formation mechanism of Hachijo Dome Fissure Caves (the lava dome fissure caves) is a Kondo's personal communication that each of the cave widths in the middle of the depth shows a tendancy to widen in comparison with each of the cave widths at the entrances and the bottoms just as Fig.11(b) shows. In this formation mechanism, it is very important that the deformation of the lava dome takes place as described in section 7.3. However, the possibility of the cave formation gets smaller when the diameter of the lava dome becomes larger because the viscoelastic property of the lava dome weakens the effect of the deformation on the analogy of a shock absorber.

9. CONCLUSION

In the first half of this paper, the relation of the geology and the number of the volcanic caves on the Seven Izu Islands are described. This relation shows whether volcanic caves exist or not, but cannot clarify the reason why many volcanic caves exist on Hachijojima Island.

The formation mechanism of Hachijo-Fuji Fuketsu is proposed as an example of a volcanic tectonic cave. This mechanism is an accurate reflection of the stratification structure of Mt. Hachijo-Fuji. Considering from the the formation mechanism, a volcanic tectonic cave is a uncommon volcanic cave which has a kind of a slide collapse structure.

The formation mechanism of Hachijo Dome Fissure Caves is proposed as an example of a lava dome fissure cave. This is the first time that a concept of a residual thermal stress has been introduced into the formation mechanism of the volcanic caves. The notable feature of this mechanism is that the movement of matter, such as a lava and pyloclastic materials except volcanic gases, does not take place in the lava dome fissure caves when the lava dome fissure cave is formed.

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N.°	CAVE NAME	LENGTH (DEPTH)	NOTE
1	Hachijo Fuketsu N.° 1	1404 m	
2	Hachijo Fuketsu N.° 2		(missing)
3	Hachijo Fuketsu N.° 3	84 m	
4	Hachijo Fuketsu N.° 4	76 m	
5	Hachijo Fuketsu N.° 5		(unsurveyed)
6	Gokuraku Ana		(unsurveyed)
7	Sin—Gokuraku Ana	676 m	
8	20 Bokku Fuketsu	35 m	
9	21 Bokku Fuketsu	45 m	
10	Eigo Rift Cave N.° 1	(- 31 m)	
11	Eigo Rift Cave N.° 2	(- 12 m)	
12	Eigo Rift Cave N.° 3	80 m (+ > 8 m)	
13	Nazumado Rift Cave		
14	Hachijo—Fuji Fuketsu	103 m	
15	Hachijo Dome Fissure Cave A	(-77 m)	Entrance N.° 1
16	Hachijo Dome Fissure Cave B	(-78 m)	Entrance N.° 2 ≈ N.° 6
17	Hachijo Dome Fissure Cave C		Entrance N.° 7 ≈ N.° 8 (unsurveyed)
18	Hachijo Dome Fissure Cave D	(-70 m)	Entrance N.° 9 ≈ N.° 10
19	Hachijo Dome Fissure Cave E		Entrance N.° 11 ≈ N.° 12 (unsurveyed)

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