Effects of concentrated and intense heavy rain on phreatic eruptions

〜Based on a case study of the phreatic eruptions of Mt. Ontake in Japan-〜

Statement

This paper is a non-peer reviewed preprint submitted to EarthArXiv

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Abstract

For humans living in an economic zone adjacent to volcanoes, the reality of unpredictable eruptions is a constant concern. This paper presents a new view on the phreatic eruption process of Mt. Ontake, Japan. The purpose of this posting is to find ways to reduce casualties from phreatic eruptions. As a background, there is the current situation that phreatic eruptions where magma does not move cannot be predicted. By analyzing the process of phreatic eruptions in which the magma does not move, future eruption prediction measures will be established. The significance of the submission is that this research is shared not only by researchers in Japan but also by researchers around the world. It is highly likely that the water necessary for the phreatic eruption was supplied by accidental heavy rains in addition to the water stored in the mountain. On the other hand, it is presumed that the lava rock surrounding the magma cooled from the outside over a long period of time. As the cooling water from heavy rain hit the heated lava rocks continuously, the lava rocks were gradually scraped away while the vaporization phenomenon continued, colliding with the hotter lava rocks and leading to a large explosion. At this time, the power of the explosion was not able to pass through the escape route, and it became a large eruption that reached the top of the mountain. The event occurred 7 minutes after it was first observed by the seismometer. As a result, it was not possible to predict the eruption, resulting in casualties.

Introduction

Mt. Ontake is located in the central part of Japan and is the second highest volcano after Mt. Fuji. Mt. Ontake, a so-called "extinct" volcano, experienced a phreatic eruption without any warning at approximately 5:00 am on October 28, 1979 [1-3,12,15,16]. Because it was early in the morning, there were no fatalities. The Eruption Prediction Liaison in Japan has selected 50 of the 111 active volcanoes, including Mt. Ontake, for 24-hour continuous observation. (Fig. 1) After 35 years, at 11:52 am on September 27, 2014, another phreatic eruption occurred without warning. (Fig.1) According to newspaper reports at the time, 58 people died and 5 went missing after being hit by mainly ballistic rocks from the eruption. The same tragedy should not be repeated. Therefore, the mechanism of the phreatic eruption process should be elucidated. Mt. Ontake has had several phreatic eruptions since its 1979 eruption. Among them, two eruptions are selected with large scales and proceeded with the research. This research was initiated to identify a way to elucidate the eruption process and prevent casualties. Most current theories are dominated by the theory that eruptions with immobile magma are difficult to predict[4, 6-13].

The paper hypothesizes that heavy rains interacted with the magma, assuming that the most likely cause of the non-moving eruption was rainwater action. Here, we show that torrential rainwater interacted with around 280°C lava rock on its way to the magma chamber and that this 7-minute event occurred in a sealed state. Therefore, the reason why the magma did not move and the large-scale phreatic eruption occurred became clear.

Methods and Result

Piña-Varas et al.[11] and Caudron et al.[9] stated that “one of the most important aspects of understanding the internal structure of a volcano is to characterize its magmatic system. The danger of that volcano is strongly related to the size and depth of the magma source." The first step is to understand the structure inside Mt. Ontake. Unlike the sky and the sea, it is difficult to assess the inner structure in detail because the ground cannot be seen. However, according to newspaper articles of the time, the strong tremors of the September 14, 1984, Western Nagano earthquake (magnitude 6.8), caused a large-scale collapse of the volcanic edifice called the “Ontake Collapse”. It is reported that this event reveals a glimpse of the cross section.

On the homepage (in Japanese) of the Nagoya University Mt. Ontake Volcano Laboratory, a cross-section of this volcanic collapse with photographs are published. According to the photograph and caption of this scene, the volcanic edifice with its mouth wide open reveals the inside of the volcanic edifice, where lava and volcanic ejecta are piled up intricately to reveal the tephra layer, pumice layer, and lava layer. Another photograph also introduces the fact that many large and small waterfalls constantly discharge water, giving it the nickname “Montain of Waterfalls”. In addition, the huge caverns and andesitic lavas show regular fissured platy joints that appear to be stacked flat slabs. At the foot of Mt. Ontake, many hot spring areas such as Kiso-ontake,, and Kaida Kogen support the tourism industry. Mt. Ontake absorbs enough rainwater on a daily basis and discharges cold water, contributing to hydroelectric power generation. In order to pursue the possibility that the main cause of phreatic eruptions is not only the stagnant water inside the volcanic edifice, but also a large amount of continuous rainfall, it was necessary to investigate the statistical table of rainfall. According to AMeDAS (Automated Meteorological Data Acquisition System) observation data published on the Japan Meteorological Agency website, the average annual precipitation is 3,694 mm, concentrated from May to September (Table 1). The rainfall just before the October 1979 and September 2014 eruptions were notable historical records.

According to newspaper articles at the time, the former was related to Typhoon No. 20, which weakened when it landed in Japan, but when it appeared, a new world record low pressure of 870 hPa was caused by heavy rain on October 20, and 110 people died nationwide. The latter was associated with Typhoons No. 11 and No. 12, which landed at the same time as the secularly stationary front, causing extensive damage in various places. It was a year that broke the number one record in various parts of Japan since the start of statistics, such as 20 places with maximum 1-hour precipitation, 20 places with maximum 24-hour precipitation, and 33 places with maximum 48-hour precipitation. Mt. Ontake experienced torrential downpours for about two weeks, with a total cumulative rainfall of 893 mm occurring during August (Table 2). In particular, attention was focused on the continuous heavy rainfall and the possibility that the short-term rainfall per hour had a pressurizing effect. These recordbreaking rainfall conditions could be the fuse leading to the eruption of Mt. Ontake, which stores a large amount of water.

Sasaki et al.[18] introduced that "the September 27, 2014 eruption was caused by water ejected directly from the crater into the lahar that erupted from the crater." Yamaoka et al.[2] , Ikehata and Maruoka [15] concluded “The absence of juvenile material in the eruptive products indicates that the eruption was phreatic. The difference in sulfur isotopic values between anhydrite and pyrite from the 2014 eruption indicates isotopic equilibration temperatures ranging from 270 to 281 °C. No significant differences in the mineral assemblages or sulfur isotopic compositions of the pyroclastic materials were observed between the 2014 and 1979 Ontake phreatic eruptions, which indicates geochemical similarity in the hydrothermal systems below the crater before each of these eruptions”.

These comments lead to the conclusion that the phreatic eruption of Mt. Ontake is an event driven primarily by the interaction of magma and water. And it shows that it was the result of working with lava rock around 270 to 280 °C. degrees, not directly with magma.

Regarding the source of the phreatic eruption, Yamaoka et al.[2] mentioned that it occurred at a very shallow location below the crater at a depth of possibly less than 1 km. In addition, Takagi et al.[4] claimed that “the event occurred immediately below the crater at a shallow depth of 1,700 m above sea level (1,000 m below the surface).

Kaneko et al.[1] and Oikawa et al.[16] stated that “the 2014 volcanic trajectory does not pass through the same place as the fumarole created in 1979, but passes through its vicinity."

Maeda et al.[5]argued that “Phreatic eruptions require shallow subsurface heat and water supplies and a closed structure where pressure can build up”. In addition, Yamaoka et al.[2] and Maeda et al.[5]analysed a very long period earthquake (VLP event) that occurred 25 seconds before the start of an eruption and found ENE–WSW-oriented fault slip at a depth of 0.3 to 1 km from the surface. They speculate that a tensile crack in the rocks opened and that hydrothermal fluid flowed through the crack towards the surface.

Ogiso et al.[17]conducted a definitive analysis of the process of the 2014 eruption of Mt. Ontake as follows. “At approximately 11:45 on 27 September, a sudden decompression event commenced at a shallow depth. The inferred descent of tremor locations just before the eruption is a key factor in our interpretation of the phreatic eruption process at Ontake. The decompression induces phase transition of the volcanic fluids with exciting volcanic tremor, leading it to flash into a gaseous phase.” These disturbances propagate downwards in the hydrothermal system. At the same time, ascending volcanic gases and water vapor open a crack just beneath the eruption crater (Maeda et al.[5]), together with upward migration of seismicity (Kato et al.[14]). The results here show that on the way to the magma chamber, the torrential rain interacts with lava at about 280°C, increasing the vaporization explosion. Seven minutes after the first volcanic earthquake was observed by seismographs, a phreatic eruption occurred in a sealed state. (Fig. 3).

Here, the structure inside the volcanic edifice, rainwater, and the process of phreatic eruptions are classified by phase and shown with schematic model. (Fig.2-a,b,c,d)

Discussions

A few questions and discussions are necessary to conclude this paper.

(1) Does a phreatic eruption always occur if there is a large amount of precipitation?

Compared to the rainfall after the 1979 and 2014 eruptions, larger rainfall events have occasionally occurred at other times but did not lead to eruptions. For example, the rainfall in 2015, 2016, 2018, 2020, and 2021 each exceeded that in 2014(Table1), but no eruptions occurred. According to the observation results of the Japan Meteorological Agency, the earthquake and fumarole of Mt. Ontake have continued since 2014. To date, no phreatic eruption has occurred. Since the pressure is released, it is thought that this process will not lead to an eruption, but this is a subject for future research.

(2) Why do the dates of rain and eruptions not match?

Mt. Ontake is a high mountain with a height of 3,067 m, and because rainwater flows through narrow crevices and fine pumice stones inside the volcano, there is a high possibility that it takes a time lag to reach the lava stone. Research on the time lag between the date of rainfall and the date of earthquake occurrence will be a future research topic.

(3) Why do phreatic eruptions occur when magma does not move?

According to Oikawa et al.[14], until the 1979 eruption, no historical record of the eruption of

Mt. Ontake had yet been found. It is assumed that the temperature of the lava rock decreased with increasing distance from the magma. Based on the analysis results that the erupted lava rock was formed at around 280 °C, it was assumed that the eruption was located at an epicenter away from the magma. Therefore, the phreatic eruption occurred without the magma moving. Further research is needed to pinpoint the location of the magma chamber.

(4) Why is it not possible to study the phreatic eruptions of other volcanoes by confining them to Mt. Ontake?

Among the volcanoes that have phreatic erupted in recent years, Mt. Ontake is the only volcano that has an AMeDAS. The number of research subjects should be increased, but unfortunately other volcanoes did not have AMeDAS installed, so they could not be research subjects.

Conclusion

The fact that the same event occurred twice on one mountain and that a common cause was discovered led to a hint. In Japan, there is an old saying that “what happens twice, happens three times”. In the future, when all the following phenomena are observed, there is a possibility of recurrence.

1) A period of more than two years without earthquakes or volcanic activity

2) Rainfall exceeding 500 mm per month, over 100 mm per day, over 20 mm per hour for several short periods of time

3) Timing of eruption prediction when seismic observations start to swarm even though there is no volcanic plume activity

This paper is the result of research on the unique conditions of Mt. Ontake. The papers by many researchers on the eruption of Mt. Ontake and the information on the internal structure of the volcano due to the “Ontake Collapse” provided a great impetus for this paper. A unique conclusion with a new perspective was made explicit.

To close, it was fortunate that the AMeDAS rain gauge was installed on Mt. Ontake. For future research on phreatic eruptions, rain gauges like AMeDAS should be installed not only in Japan but also in volcanoes around the world. An increase in the number of researchers studying the relationship between phreatic eruptions and heavy rains will contribute to society.

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Tables

Table 1. Mathly annual precipitation of Mt. Ontake （2006～2021）.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total	Av.
Jan	///	36	82	71	62	11	28	60	51	102	91	54	129	28	125	57	983	61
Feb	4	137	52	220	203	75	182	124	101	70	231	153	14	109	173	53	1,897	119
Mar	198	260	108	296	354	104	346	196	338	150	96	35	305	135	213	269	3,399	212
Apr	151	84	198	269	375	285	207	221	140	546	439	402	486	165	131	292	4,388	274
May	507	330	346	365	528	640	166	222	179	247	491	187	469	252	206	736	5,868	367
Jun	322	452	420	445	615	501	439	383	175	365	406	234	519	620	732	338	6,962	435
Jul	1,218	574	197	1,182	893	419	754	654	451	685	334	501	895	559	2,208	531	12,052	753
Aug	79	301	341	279	220	464	304	389	893	549	298	441	641	765	73	1,189	7,224	452
Sep	324	361	175	200	430	644	179	367	312	590	774	422	1,178	123	399	398	6,872	429
Oct	289	268	183	320	327	344	251	304	380	291	419	497	144	481	291	71	4,857	304
Nov	165	54	81	245	32	279	185	164	275	415	210	95	59	89	186	114	2,645	165
Dec	89	85	117	65	190	65	160	52	182	166	271	37	188	142	34	119	1,958	122
Total	3,346	2,942	2,299	3,954	4,227	3,828	3,198	3,133	3,473	4,174	4,057	3,054	5,023	3,464	4,768	4,163	59,101	3,694
Av.	279	245	192	330	352	319	267	261	289	348	338	255	419	289	397	347	4,925	

≥ 1000 mm

≥ 500 mm

Table 2. Daily precipitation 1979 and 2014.

1979

Date	August Precipitation		September Precipitation		October Precipitation	
	mm	Max (mm/h)	mm	Max (mm/h)	mm	Max (mm/h)
1	0	0	14	6	91	27
2	0	0	12	3	0	0
3	1	1	3	1	28	5
4	10	6	65	13	28	11
5	0	0	2	1	0	0
6	35	8	0	0	6	1
7	66	21	14	4	33	4
8	1	1	0	0	5	2
9	0	0	0	0	0	0
10	0	0	0	0	0	0
11	0	0	0	0	0	0
12	25	13	0	0	0	0
13	0	0	1	1	0	0
14	0	0	6	1	0	0
15	0	0	69	9	0	0
16	0	0	0	0	0	0
17	6	3	2	1	0	0
18	31	12	3	2	21	3
19	0	0	8	4	187	32
20	30	8	0	0	3	2
21	152	23	1	1	0	0
22	67	17	33	11	0	0
23	16	8	7	3	0	0
24	16	7	27	9	None	None
25	26	10	78	14	None	None
26	0	0	71	15	None	None
27	79	12	34	13	None	None
28	2	1	49	8	Eruption	
29	0	0	22	6		None
30	0	0	19	11		None
31	0	0				None
	563		540		402	
Total (81 days)			1,505 mm			

2014

Date	July Precipitation		August Precipitation		September Precipitation		
	mm	Max (mm/h)	mm	Max (mm/h)	Earthquake	mm	Max (mm/h)
1	1	1	0	0	4	21	6
2	0.5	0.5	0	0		0	0
3	23	5	23.5	7		1	1
4	27	7.5	29	9.5		42.5	10.5
5	46.5	11	21.5	8.5		59.5	14.5
6	4	1.5	22.5	10.5	1	9	3.5
7	91.5	10.5	0	0	2	6	3
8	9	2.5	20.5	7	5	0	0
9	36.5	24.5	9.5	3	10	0	0
10	51.5	6.5	185	32	52	0	0
11	1	1	29.5	8	85	8.5	6
12	0	0	39	10	10	0	0
13	82	15.5	0	0	7	0	0
14	20	7.5	34	14	8	0	0
15	0	0	85	15	27	0	0
16	31	12	146	29.5	18	0	0
17	8	8	102	16	10	0	0
18	1	0.5	11.5	4.5	24	0.0	0.0
19	5.5	1.5	6	3.5	3	0	0
20	1	1	0	0	10	0	0
21	1.5	1.5	0	0	17	0	0
22	0	0	2.5	1	3	0	0
23	0	0	18.5	7.5	10	0	0
24	0	0	7	3	9	74.5	14.5
25	0	0	12.5	3	8	89.5	16
26	0	0	76	26.5	6	0	0
27	1	1	0	0	483	Eruption	
28	0	0	1.5	1.5	131	0	0
29	0	0	1.5	1	53	0	0
30	0	0	9	3	58	0	0
31	8	8	0	0			
	450.5		893			311.5	
Total (89 days)			1655 mm				

Figure legends

Fig. 1. Map of Japanese volcanoes.

According to the website of the Japan Meteorological Agency, 50 of the 111 active volcanoes have been selected by the Eruption Prediction Liaison Committee and have established a "24-hour observation system" for disaster prevention. Equipped with observation equipment such as Seismograph, Inclinometer, Infrasound Instrument, GNSS (Global Navigation Satellite System), Remote Cameras

This material is publicly available in Japanese on the website of the Japan Meteorological Agency and can be viewed by anyone, and permission has been obtained from the Meteorological Agency for publication.

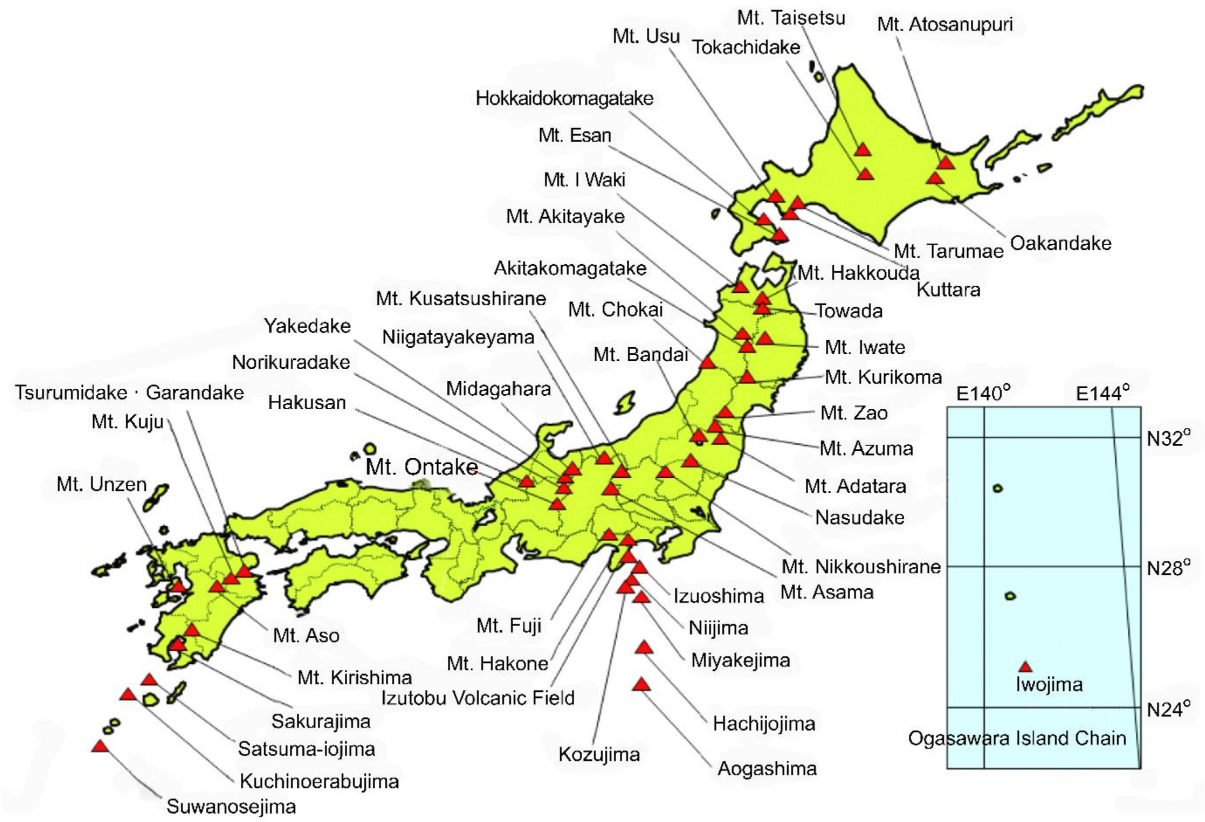


Fig. 2. Schematic diagram of the eruption process of Mt. Ontake

Stage1: 2-a Image of Mt.Ontake before the eruption

During July 2014, some of the 450.5mm of rainfall was stored inside the volcanic edifice. No plumes or earthquakes were yet observed during this period.

Blue line: cold water veins, Blue dots: cold water in voids

Red core: Magma Broun cover: Lava stone

Stage2: 2-b Image of Torrencial rain to Mt. Ontake

It was assumed that additional heavy rains before August 10, 2014 increased the momentum of the rainwater and turned it into a torrent, and the water that could not fill the gaps expanded the channel. At this point, no plumes or earthquakes have been observed yet.

Stage3: 2-c Image of the Explosion caused by vaporization of water vapor

The daily and hourly rainfall, 2014 were 185mm/d, 35mm/h on the 10th, 146mm/d, 29.5mm/h on the 16th, 76mm/d, 26th. 26.5 mm/h etc. were observed. In addition to the heavy rainfall of 893 mm in August, the short-term torrential rain exceeding 20 mm per hour approached the lava rock and turned into hot water. Due to this vaporization phenomenon, small explosions began to occur one after another after a time lag. As a result, seismic activity increased, but no volcanic plume has yet been observed.

Stage4: 2-d Image of the phreatic eruption of Mt. Ontake at 11:52 Sep. 2014

After September 6, 2014, slight seismic activity began to be observed, although rainfall was low (Table 2). At 11:41 am on September 27, 2014 there was a slight earthquake, at 11:45 the volcano began to tilt, and finally at 11:52 a very large explosion shattered the volcano. This big explosion occurred just 7 minutes after the first observation of the slope of the mountain.

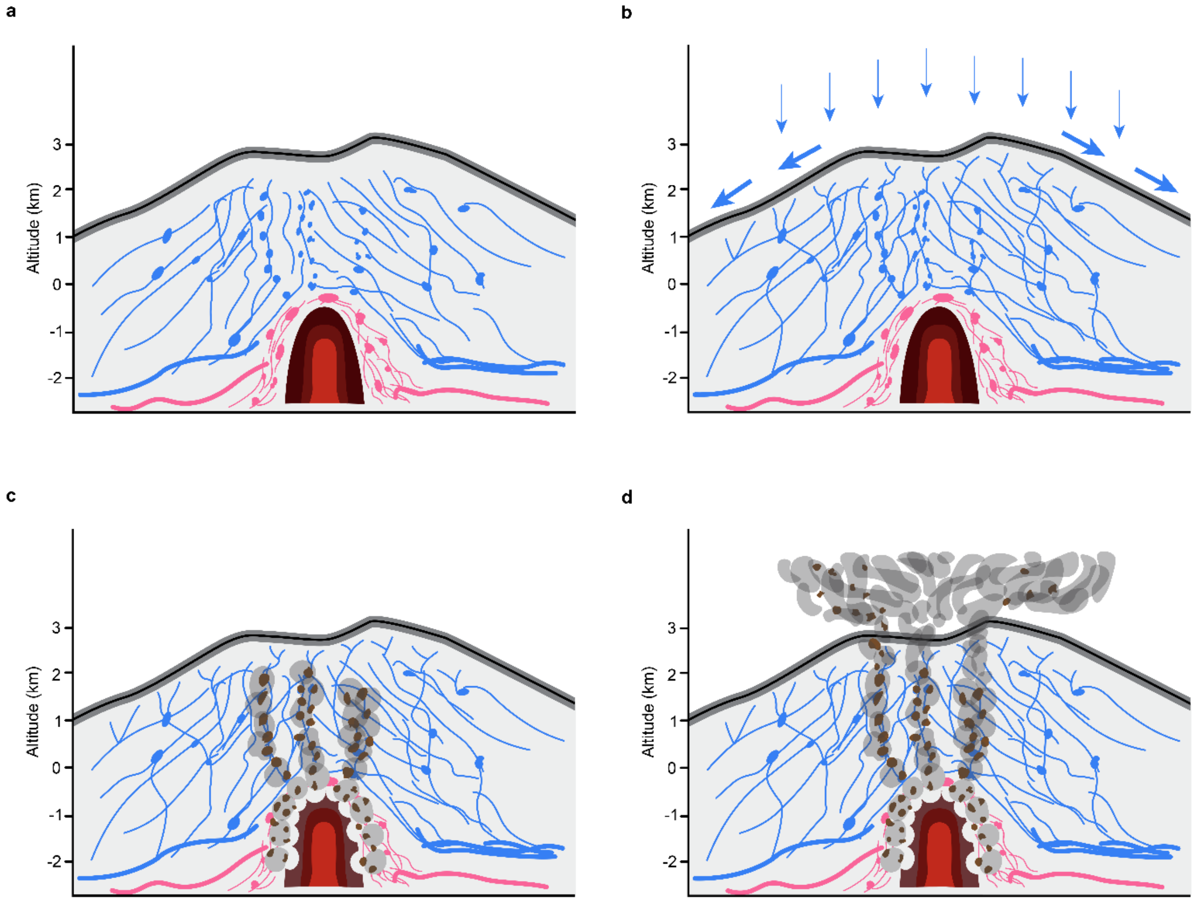
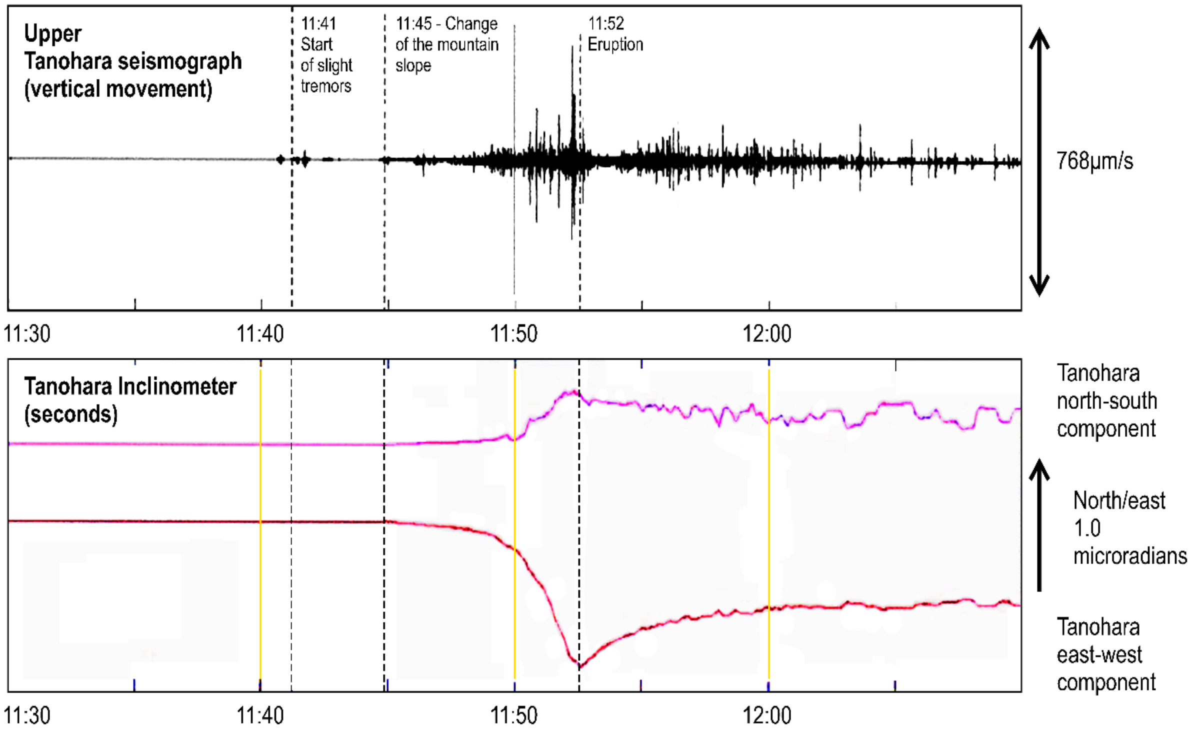


Fig. 3. Observation of seismometers and inclination during the eruption of Mount Ontake

This material is publicly available in Japanese on the website of the Japan Meteorological Agency and can be viewed by anyone.

Documents compiled by the Eruption Prediction Liaison regarding the September 2014 eruption of Mt. Ontake, and permission has been obtained from the Meteorological Agency.

https://www.data.jma.go.jp/vois/data/tokyo/STOCK/kaisetsu/CCPVE/Report/119/kaiho_119_08.pdf



Status of vibration and inclination data at the time of the Ontake volcanic event

In conjunction with volcanic tremors, we observed inflation of the northwest of the mountaionside at the Tanohara observation point, 3km southwest of the Kengamine summit. After about 7 minutes, at 11:52, we observed deflation of the southeast of the mountain. Fluctuations due to volcanic tremors etc. were also observed in the southeast.

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Author contributions

Not applicable

Competing interests

The authors have no conflicts of interest to declare.

Additional information

Not applicable

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