Prevention of Catastrophic Volcanic Eruptions

***Fujii[1] Y, Kodama[1] J, Fukuda[1] D and Dassanayake[2] ABN**

[1]Faculty of Engineering, Hokkaido University, Japan
[2]Faculty of Engineering, University of Moratuwa, Sri Lanka
*Corresponding author – fujii6299@frontier.hokudai.ac.jp

Abstract

Giant volcanic eruptions emit sulphate aerosols as well as volcanic ash. Needless to say that volcanic ash causes significant damage to the environment and human at large. However, the aerosols are even worse. They reach the Stratosphere and stay there for months to years reflecting insolation. As a result, air temperature at the Earth's surfaces drops. Even a slight temperature drop may cause severe food shortage. Yellowstone supervolcano, for example, can even make human in the Northern Hemisphere extinct in several hundred thousand years. Therefore, gradual energy release by supercritical geothermal power generation was proposed to prevent such catastrophic eruptions. The necessary technical innovation is drilling into the depth. However, after the innovation, the power generation itself would be profitable. The risk is unpredicted induction of unwanted catastrophic eruptions.

Keywords: Electro pulse drilling, Human extinction, Silica carbide composite, Supercritical geothermal power generation, Yellowstone supervolcano

1. Introduction

Giant volcanic eruptions emit sulphate aerosols as well as volcanic ash. Needless to say that volcanic ash causes significant damage to the human society. However, the aerosols are even worse. They reach the Stratosphere and stay there for months to years reflecting insolation. As a result, air temperature at the Earth's surfaces drops. Even a slight temperature drop may cause severe food shortage. As described later, Yellowstone supervolcano, for example, can even make human in the Northern Hemisphere extinct in several hundred thousand years.

Imminent prediction methods for catastrophic volcanic eruptions have never been established so far although there are a few cases which include the prediction of the eruption of Mt. Usu, Japan in 2000 [1, 2] by the dedicated researchers with exceptional efforts.

Even if a prediction method was established, the method could not significantly reduce infrastructure damages although it could slightly reduce the number of fatalities. On the other hand, prevention of eruptions, if developed, could significantly reduce not only the number of fatalities but also infrastructure damages.

This paper introduces examples of the past catastrophic eruptions. Further a method is proposed to prevent future catastrophic eruptions. The authors also try to clarify necessary technical developments, cost, risk and problems. Our research group already proposed a method to prevent giant earthquakes

at subduction zones [3] and will present a method to prevent large earthquakes beneath big cities [4].
The objective of this paper is not merely to show the details of the prevention method, but to show what we can do is not only just reinforce infrastructures and look at catastrophic volcanic eruption disasters but also we could even prevent them. Deliberate investigation on the procedure, risk, costs etc., should be done in future.
The volcanic explosivity index (*VEI*) defined as

$$VEI = \log(V_E) - 4 \quad (1)$$

where V_E is the volume of the ejecta in m^3 [5] will be used to represent the magnitude of an eruption.

2. Examples of Catastrophic Eruptions

The biggest known eruption on the Earth would be, that occurred in Gondwana 132 Ma (*VEI* 8.9) on the boundary of South America and Africa (Brazil, Namibia and Botswana) just before they were split.
The biggest known eruption after human existence was Mount Toba (*VEI* 8.4) 74,000 BP in Indonesia [6]. It was estimated that this eruption decreased the human population to just 15,000 inducing the very limited diversity of human gene (Toba Catastrophe Theory). Also it is supposed that human began wearing clothes because of the cold climate based on the analysis of lice gene.
The biggest known eruption in Japan is Kikai Caldera (*VEI* 7) 7,300 BP [7] which destroyed the Jomon Culture in the South Kyushu.
The biggest known eruption in the 19th century is Tambora, Indonesia (*VEI* 7) in 1815 [8] which caused air temperature drop in the Northern Hemisphere. The cooling induced the famine in the US and it is said that the famine was one of the driving forces of the Big West. It is estimated that 10,000 people were directly killed and 50,000-90,000 people were indirectly killed by the later famines and diseases.
The biggest known eruption in the 20th century is Pinatubo, The Philippines (*VEI* 6) in 1991 [9] which caused air temperature drop of 1 K in the Northern Hemisphere and induced severe food shortage in Japan in 1993.

3. The case of Yellowstone supervolcano

3.1 Eruption probability

Yellowstone supervolcano, for example, was erupted ca. 2.1 Ma with 2,450 km^3 ejecta, 1.3 Ma and 0.63 Ma with 1,000 km^3 ejecta [10]. The data was not enough but the average interval and standard deviation of the eruptions were calculated as 735±92 thousand years. Let's assume that the next catastrophic eruption will occur 735±92 thousand years after the previous eruption, namely, 105±92 thousand years from now and calculate probability of eruption till specific years after now assuming the normal distribution. Cumulative distribution Φ at x for the normal distribution with average $\bar{x}$ and standard deviation σ can be represented as

$$\Phi = \frac{1}{2}\left(1 + \operatorname{erf}\frac{x - \bar{x}}{\sqrt{2\sigma^2}}\right) \quad (2)$$

(Fig. 1) where erf is the error function. The probability p at t_1 that a catastrophic eruption occurs before t_2 can be calculated as

$$p = \frac{\Phi(t_2) - \Phi(t_1)}{1 - \Phi(t_1)} \quad (3)$$

Even the probability for an imminent eruption is not zero and it reaches almost 100% in several hundred thousand years (Fig. 2).

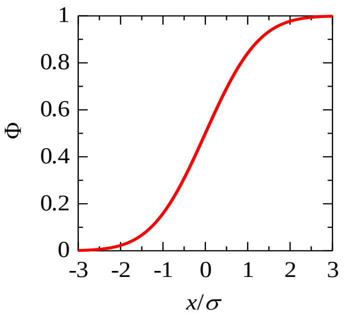

Figure 1 - Cumulative distribution for the normal distribution with the average of 0 and standard deviation of *σ*

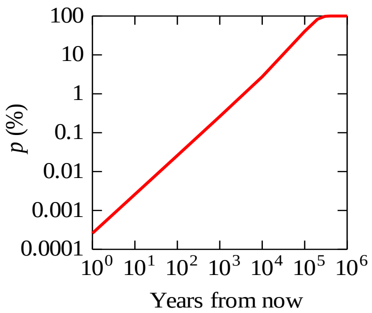

Figure 2 - Probability of a catastrophic eruption at Yellowstone supervolcano

3.2 The Effects of an Eruption

If the Yellowstone volcano erupts, volcanic ash will vastly distribute [11], 90% people within 1000 km from the volcano will be choked to death and the air temperature in the Northern Hemisphere will drop by 10 K for several tens of years due to the sulphate aerosols from the volcano which obstruct sunlight to reach the ground surface [12].
No crops can be raised and most people will starve to death. In short, people in the Northern Hemisphere will certainly be made extinct in several hundred thousand years if we do nothing. Civilization may remain because people in the Southern Hemisphere could survive, and will move to the Northern Hemisphere.

3.3 The Prevention Method

Let us propose to prevent such catastrophic eruptions by gradually relieving energy for eruptions by the supercritical geothermal power generation (Fig. 3).

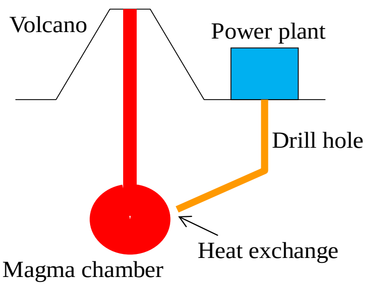

Figure 3 - Schematic figure showing the concept of gradual energy release by the supercritical geothermal power generation

In the supercritical geothermal power generation [13, 14], boreholes are drilled to the vicinity of a magma chamber. Heat is exchanged at the borehole end by vaporization of a fluid with a low melting point, the latent heat is recovered at the surface and electric power is generated at the surface (the binary technique) so that corrosive volcanic gases would not be led to the ground. Pressure of the magma chamber will decrease as temperature drops.
Problems in this system are durability of drilling rods and drilling bit due to the high temperature and low pH near magma chambers. They will be solved by silica carbide composite [15] and electro pulse drilling technique [16]. The former is a very hard material with high corrosion and heat

resistance. The later uses high voltage electric pulse to crash rocks so that it does not wear due to high temperature. The eruption energy of Krakatoa 1883 is estimated to be 200 MT [17], namely 840 × 10^{15} J. *VEI* of Krakatoa is estimated to be 6. Therefore, assuming that the eruption energy is proportional to ejecta volume, *VEI* can be converted to eruption energy E_R (J) by

$$E_{\mathrm{R}} = 840 \times 10^{VEI+9} \quad (4)$$

VEI of Yellowstone eruptions for the eruptions of 2.1 Ma, 1.3 Ma and 0.63 Ma are 8.4, unknown and 8.0. Dividing the eruption energy by the average interval of 0.735 Ma, the average power can be calculated as 9.1 MW and 3.6 MW for the first and the third known eruptions, respectively. Adapting a safe side estimation, it can be said that only 10 MW supercritical power generation is enough to prevent the catastrophic eruptions of Yellowstone. The output of a moderate scale nuclear power plant is 1 GW and even several GW is expected for the supercritical geothermal power plants. The 10 MW power plants is much smaller than them and no serious technical problems related to the output scale are predicted.

The most cost consuming part is drilling in geothermal power plants. For example, the magma chamber of Yellowstone supervolcano is ca. 8 km deep and the drilling cost is expected to be too expensive. However, the cost of the electro pulse drilling is 800 kilo EUR based on 100 EUR/m [16]. Assuming that a drilling hole can be used for 30 years, the drilling cost is just 0.0041 EUR/kWh. This is cheap enough compared to the typical selling price of ca. 0.1 EUR/kWh in Japan. Therefore the power plant can be profitable even considering other various costs. This means that there would be no problems of cost.

On the other hand, human in the Northern Hemisphere will be made extinct if a catastrophic eruption occurs at Yellowstone. The economic loss would be almost equal to the world GDP (74 trillion USD in 2015) at the eruption year. Assuming that the world economy will gradually recover to the previous level for the following 100 years, total economic loss would be 74 x 100 / 2 = 3700 (trillion USD). Dividing the total economic loss by the average eruption interval, the annual economic loss would be ca. 5 billion USD/y.

There would be risks that those drillings stimulate volcanoes and induce unpredicted catastrophic eruptions. This issue should be, of course, deliberately investigated before the method is adapted in practice.

4. Concluding Remarks

Gradual energy release by supercritical geothermal power generation was proposed to prevent catastrophic eruptions. The necessary technical innovation is drilling into the depth. However, after the innovation, the power generation itself would be profitable. The risk is unpredicted induction of unwanted catastrophic eruptions.

Prediction of eruptions may decrease the number of fatalities but cannot decrease damages of infrastructures. On the other hand, prevention of eruptions makes fatality and infrastructure to completely zero. Therefore the prevention is much better than prediction.

References

[1] Jones, T.E., (2016). Evolving Approaches to Volcanic Tourism

Crisis Management: An Investigation of Long-term Recovery Models at Toya-Usu Geopark, *J. Hospitality & Tourism Management*, 28, pp. 31-40, doi:10.1016/j.jhtm.2016.04.005.

[2] Yamagishi, H., Watanabe, T., & Yamazaki, F., (2004). Sequence of Faulting and Deformation during the 2000 Eruptions of the Usu Volcano, Hokkaido Japan, Interpretation and Image Analyses of Aerial Photographs, *Geomorphology*, 57, pp. 353-365, doi:10.1016/S0169-555X(03)00165-X.

[3] Fujii, Y., Yamada, M., Fukuda, D., & Kodama, J., (2017). Prevention of Giant Earthquakes by Underground Nuclear Explosions, *Proc. MMIJ Spring Meeting*, 3411-17-07, Tsudanuma, Japan, Mar. 29.

[4] Fujii, Y., Fukuda, D., & Kodama, J., (2017 in press). Prevention of Large Earthquakes beneath Big Cities, *Proc. MMIJ Fall Meeting*, Sapporo, Japan, Sep. 26-28.

[5] Newhall, C. G., & Self, S., (1982). The Volcanic Explosivity Index (VEI) - An Estimate of Explosive Magnitude for Historical Volcanism, *J. Geophys. Res. Oceans*, 87(2), pp. 1231-1238.

[6] Oppenheimer, C., (2002). Limited Global Change due to the Largest Known Quaternary Eruption, Toba, Approximate to 74 kyr BP? *Quaternary Science Reviews*, 21(14/15), pp. 1593-1609.

[7] Maeno, F., & Taniguchi, H., (2007). Spatiotemporal Evolution of a Marine Caldera Forming Eruption, Generating a Low-aspect ratio Pyroclastic Flow, 7.3 ka, Kikai Caldera, Japan: Implication from Near-vent Eruptive Deposits, *J. Volcanology and Geotherm. Res.*, 167(1-4), pp. 212-238.

[8] Stothers, R. B., (1984). The Great Tambora Eruption in 1815 and Its Aftermath, *Science*, 224(4654), pp. 1191-1198.

[9] McCormic, M. P., Thomason, L. W., & Trepte, C. R., (1995). Atmospheric Effects of the Mt-Pinatubo Eruption, *Nature*, 373(6513), pp. 399-404.

[10] https://en.wikipedia.org/wiki/Yellowstone_Caldera, Visted 29th June 2017.

[11] Mastin, L. G., Eaton, A. R., & Lowenstern, J. B., (2014). Modeling Ash Fall Distribution from a Yellowstone Supereruption, *Geochemistry, Geophysics, Geosystems*, 15(8), pp. 3459-3475. doi: 10.1002/2014GC005469.

[12] http://www.epochtimes.jp/jp/2010/08/html/d23986.html, Visted 29th June 2017.

[13] Elders, W.A., Friðleifsson, G.Ó., & Albertsson, A., (2014). Drilling into Magma and the Implications of the Iceland Deep Drilling Project (IDDP) for High-temperature Geothermal Systems Worldwide, *Geothermics*, 49, pp. 111-118, doi; 10.1016/j.geothermics.2013.05.001.

[14] Watanabe, N., Numakura, T., Sakaguchi, K., Saishu, H., Okamoto, A., Ingerbritsen, S. E., & Tsuchiya, N., (2017). Potentially Exploitable Supercritical Geothermal Resources in the Ductile Crust, *Nature Geoscience*, Online 23 Jan. 2017, doi: 10.1038/NGEO2879.

[15] Nakazato, N., Kohyama, A., & Kohno, Y., (2013). Effects of Pressure during Preform Densification on SiC/SiC Composites, *Open Journal of Non-metallic Materials*, 2013, 3. doi;10.4236/ojinm.2013.3.31003.

[16] Schiegg, H. O., Rodland, A., Zhu, G., & Yuen, D. A., (2015). Electro-Pulse-Boring (EPB): Novel Super-Deep Drilling Technology for Low Cost Electricity, *Journal of Earth Science*, 26(1), pp. 037-046.

[17] MacNeill, A. R., (1989). *Dynamics of Dinosaurs and Other Extinct Giants*. Columbia University Press.