Electrical charging of volcanic ash

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***Abstract*—The existence of volcanic lightning and alteration of the atmospheric potential gradient in the vicinity of near-vent volcanic plumes provides strong evidence for the charging of volcanic ash. More subtle electrical effects are also visible in balloon soundings of distal volcanic plumes. Near the vent, some proposed charging mechanisms are fractoemission, triboelectrification, and the so-called "dirty thunderstorm" mechanism, which is where ash and convective clouds interact electrically to enhance charging. Distant from the vent, a self-charging mechanism, probably triboelectrification, has been suggested to explain the sustained low levels of charge observed. Recent research linked the self-charging of volcanic ash to the properties of the particle size distribution, observing that a highly polydisperse ash distribution would charge more effectively than a monodisperse one. Natural radioactivity in some volcanic ash could also contribute to self-charging of volcanic plumes. Here we present laboratory measurements of particle size distributions, triboelectrification and radioactivity in ash samples from the Grímsvötn and Eyjafjallajökull volcanic eruptions in 2011 and 2010 respectively, and discuss the implications of our findings.**

I. INTRODUCTION

Volcanic ash charges electrically, producing some of the most spectacular displays of lightning in nature. Factors affecting the electrical charging of ash from two different Icelandic volcanic eruptions (Eyjafjallajökull in 2010 and Grímsvötn in 2011) are presented in this paper. The Eyjafjallajökull eruption caused a well-documented flight ban over most of Europe for several days. Volcanic lightning was detected close to the vent [1], and the charge in the centre of the plume was ~0.5pCm^{-3} over Scotland, over 1200km from the source [2]. This indicates a self-charging mechanism must be involved, as charge present at the vent would have decayed within a timescale of a few hundred seconds, and the distribution of charge within the plume is inconsistent with that expected from the fair weather current in the global electric circuit. The 2011 Grímsvötn eruption caused less disruption to air traffic but generated a spectacular lightning display [3]. The reasons for variations in volcanic lightning and ash charging are not well understood, and have been investigated here using ash samples from the two eruptions. Ash from the 2010 Eyjafjallajhave eruption was collected at Selheimaheiði, 22 km from the crater, and ash from the 2011 Grímsvötn eruption was collected 70 km from the crater.

Laboratory tests investigating the charge transferred to a conducting plate from falling ash are described in section II. Gamma ray spectroscopy measurements of ash from the two volcanoes are reported in section III.

II. Measurements of Triboelectric Charging

A series of experiments were carried out where samples of volcanic ash were released to fall through a cylinder onto a screened metal plate located close to the bottom of the cylinder. The charge associated with the ash fall was measured by connecting the metal plate to an electrometer, which recorded the voltage on the plate. The apparatus consisted of a 1m long cylindrical Perspex tube, 0.25m in diameter, the top of which was sealed with an inverted funnel connected to a loading trap and shutter (made of cardboard to minimise charge generation from the apparatus). The voltage on the bottom plate was measured with a Keithley 6512 electrometer and logged to a PC via an IEEE-488 interface. Approximately 50g of ash (baked to remove adsorbed water) was loaded into the trap and the shutter released to enable ash to fall under gravity to the bottom of the tube. The tube was mounted on a support frame so that after each ash drop it was rotated to reload the ash [4],[5].

A. Results

Eleven ash drops were obtained with the Eyjafjallajökull ash and six for the Grímsvötn ash, with typical results shown in Figure 2. The difference in polarity and magnitude of the voltage generated on the bottom plate between the two ash samples is clear.

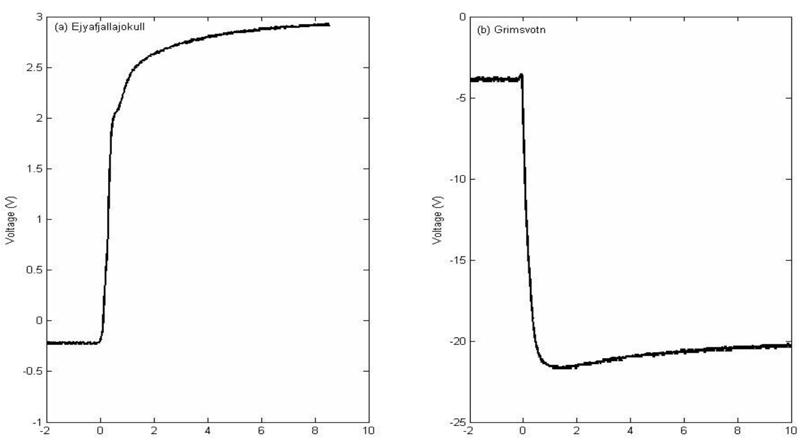

Fig 1. Typical results from ash drops. (a) shows a potential change of + 3.15V for the

ash from Eyjafjallajökull, (b) the Grímsvötn ash produces a potential change of -18V.

These results indicate that the ash from Grímsvötn has a greater propensity to charge than that from Eyjafjallajökull. The sign of self-charging observed in the Eyjafjallajökull sample is consistent with in-plume observations [2]. Further experimental work [6] found that the efficiency of triboelectric charging was related to the polydispersity of the particle size range, so that broad distributions charged more than, for example, highly bimodal distributions. This implies that all volcanic ash plumes will become charged, with implications for detection, plume lifetime and the associated aircraft hazards [6].

The reasons why the Grímsvötn ash charged more effectively, and negatively, than Eyjafjallajökull ash are not well understood. Part of the explanation may be related to the size distribution of the ash particles, shown in Figure 2.

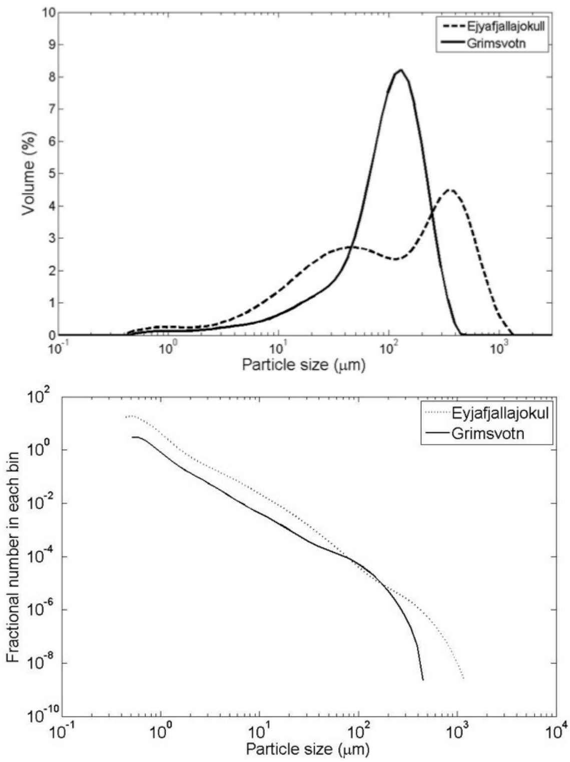

Fig 2. Size distributions of the ash samples used. (top) Volumetric size distribution, measured with a Malvern Mastersizer 2000. (bottom) Estimated number size distribution, calculated from the volumetric size distribution. Although spherical particles were assumed for simplicity, different packing fractions (0.5 for Eyjafjallajökull and 0.2 for Grímsvötn) were chosen to best represent the ash samples used.

Theoretical work [7] explained empirical observations that small particles charge negatively and larger ones positively through redistribution of surface electrons between different particles. Subsequent experiments [6] showed that the span (an index of the polydispersity of a particle distribution) controlled the triboelectric charging for Grímsvötn ash. The span for the Grímsvötn sample was 1.919, whereas the Eyjafjallajökull sample has a span of 1.987, indicating that between two different samples, span alone is not adequate to explain why the Grímsvötn ash charges more readily. Microscopic analysis of the ash particles after sieving into different size fractions indicated that the composition of each sample varied with size, so it is likely that the differing materials making up the sample triboelectrically interact, in addition to charge transfer between identical particles of different sizes. Whilst models have been developed to investigate the triboelectric charging of granular systems of identical material [7], realistic modeling of volcanic plume charging would need to allow for both a net charge to exist in the system (rather than the simpler approach of assuming charge conservation), and to include triboelectric charge transfer as a function of both size and material.

III. CHARGING FROM NATURAL RADIOACTIVITY

As a volcanic eruption is essentially an injection of a large quantity of pulverized subsurface rock into the atmosphere, the decay of uranium (U), thoron (Th) and potassium (K) radioisotopes naturally occurring in the rock offers another self-charging mechanism. As well as leaving a residual charge on the radioactive particle, alpha and beta particles are ionising and the ions created can attach to other particles to charge them [8]. Natural radioactivity levels in the ash are low compared to the surface background, since the samples did not enhance the count rate of a Geiger counter. To investigate any possible self-charging aloft from radioactivity, ash samples were placed in a Canberra 7229N gamma ray spectrometer, and data normalised for mass of the sample and against background. The results indicated a range of peaks associated with the decay of ^{238}U, ^{232}Th and ^{40}K, as shown in Figure 3. Not all peaks were identified, and some peaks were indistinguishable between the two samples. The Eyjafjallajökull ash was more radioactive than Grímsvötn ash, and on the basis of our measurements, contained a factor of 1.6 more Th and 1.8 more U, whereas the K concentrations were indistinguishable between the two samples. No data is available on the relative U and Th concentrations in the volcanic ash, but K_2O concentrations in the Eyjafjallajökull ash were a factor of 4 greater than in Grímsvötn ash [9].

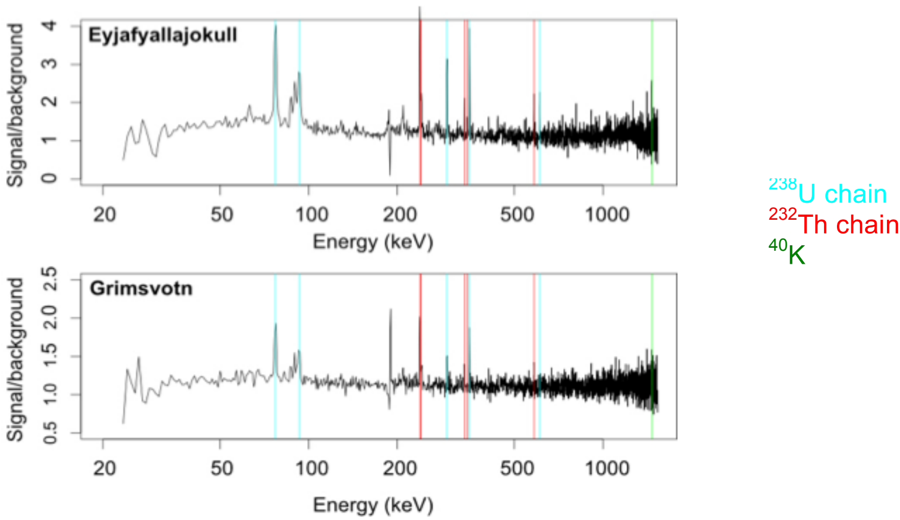

Fig 3. Gamma ray spectra, normalized against background and for mass, of ash samples from the two volcanic eruptions. Gamma peaks associated with particular natural decay chains are indicated in colour (cyan for ^{238}U, red for ^{232}Th and green for ^{40}K)

As the Eyjafjallajökull ash was more radioactive than Grímsvötn, further gamma ray spectrometry measurements were carried out on the ash samples after sieving into different size fractions, to determine if the radioactivity resided in a particular part of the size spectrum. Gamma ray peaks corresponding to decays of ^{214}Bi and ^{40}K were identified on particles > 180 μm. Alpha spectrometry measurements were also carried out using a Canberra 7401 alpha spectrometer, but no alpha decays were observed. Many other decays from natural radioisotopes are expected to produce gamma rays with energies above the upper detection threshold of our spectrometers. However, since ^{214}Bi is part of the ^{238}U decay chain, it can be assumed that other isotopes in the decay chain must be present, even if they were not detected during our experiments. The average number of charges produced per ash particle can be estimated from standard information on the decay chain to be approximately 1000 on particles >180 μm, whereas in-plume observations [2] only measured charge on particles <10 μm. Therefore radioactivity is unlikely to have contributed to the measured self-charging of the Eyjafjallajökull plume, though it would have a proportionally greater effect nearer the vent when there are more large particles in the plume.

IV. Conclusions

Laboratory measurements of the self-charging and radioactivity in volcanic ash samples from two recent Icelandic eruptions have been carried out and the following conclusions can be drawn.

1. Ash from Grímsvötn becomes more triboelectrically charged than ash from Eyjafjallajökull. This is consistent with the efficient generation of lightning by Grímsvötn, although it must be noted that meteorological factors and plume height are also relevant to the formation of volcanic lightning [3].

2. When comparing ash samples from different volcanoes, the polydispersity alone is not adequate to explain the observed triboelectric charging; compositional differences should also be taken into account.
3. Ash from Eyjafjallajökull is more radioactive than ash from Grímsvötn, presumably due to different levels of U, Th and K in the underlying rock.
4. Radioactive emissions were only observed on particles exceeding 180μm, which is probably related to the ash composition. Radioactivity could therefore contribute to self-charging nearer the vent when larger particles have not been lost from the plume.
5. Previous observations of positive charge in the distal plume [2] are best explained by triboelectric charging, since there was no radioactivity on particles of the size seen in the plume. Additionally, laboratory experiments on triboelectric charging found that Eyjafjallajökull ash became preferentially positively charged, as observed.

Our results are also consistent with recent work indicating that charged volcanic ash can scavenge anthropogenic radioactive aerosols, which may also explain slightly enhanced radioactivity levels in the plume [10]. Further work is needed to evaluate our measurements in the light of this data.

REFERENCES

[1] A.J. Bennett, P. Odams, D. Edwards and P. Arason, "Monitoring of lightning from the April-May 2010 Eyjafjallajökull volcanic eruption using a very low frequency lightning location network", Env. Res. Letts. 5, 4, 044013, 2010
[2] R.G. Harrison, K.A. Nicoll, Z. Ulanowski,, and T.A. Mather, "Self-charging of the Eyjafjallajökull volcanic ash plume", Env. Res. Letts., 5(2), 024004, 2010
[3] P. Arason, G. N. Petersen and H. Björnsson, "Estimation of eruption site location using volcanic lightning", Icelandic Met Office Report VÍ 2013-006, 2013
[4] C.E. Krauss, M. Horanyi, and S. Robertson, "Experimental evidence for electrostatic discharging of dust near the surface of Mars". New J. Phys. **5**, 70.1–70.9, 2003
[5] K.L. Aplin, T. Goodman, K.L. Herpoldt and C.J. Davis, "Laboratory analogues of Martian electrostatic discharges", Planet. Space Sci., 69, 100-104 doi: 10.1016/j.pss.2012.04.002, 2012
[6] I.M.P. Houghton, K.L. Aplin and K.A. Nicoll, "Triboelectric charging of volcanic ash from the 2011 Grímsvötn eruption", Phys Rev Letts, 111, 118501, doi:10.1103/PhysRevLett.111.118501, 2013
[7] D.J. Lacks and A. Levandovsky, "Effect of particle size distribution on the polarity of triboelectric charging in granular insulator systems", J. Electrostatics, 65, 2, 107-112, 2007
[8] C.F. Clement and R.G. Harrison, "The charging of radioactive aerosols", J. Aerosol Sci., 23, 5, 481-504, 1992
[9] N. Oskarsson and G. Sverrisdóttir, "Chemical composition and texture of ash from the Grímsvötn 2011 eruption", unpublished report, Iceland University Institute of Earth Sciences, 2011
[10] J.P. Corcho Alvarado, P. Steinmann, P. Estier, F. Bochud, M. Haldimann and P. Froidevaux, "Anthropogenic radionuclides in atmospheric air over Switzerland during the last few decades", Nature Comms. 5, 3030 doi:10.1038/ncomms4030, 2014