

Atmospheric Pollution by Iceland Volcano Lava Dispersion - the Brussels Case

Zvi Yehoshua OFFER¹, Peter VANDERSTRAETEN², Leon BRENIG³, Daniele CARATI³, Yves LÉNELLE², Annick MEURRENS², Eli ZAADY^{4*}

¹ BGU, Department of Solar Energy and Environmental Physics, The Jacob Blaustein Institute For Desert Research, Ben-Gurion University, Beer-Sheva. Israel.

² IBGE-BIM. Department of Environmental Management, Brussels Institute for Environment, Belgium.

³ ULB. Department of Statistical Physics, Université Libre de Bruxelles. Belgium.

^{4*} Corresponding author, Agriculture Research Organization, Department of Natural Resources, Gilat Research Center, Mobil Post 2, 85280, Israel, email: zaadye@volcani.agri.gov.il, Tel: +972 8 9928658, Fax: +972 8 9921242

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Abstract

In April 2010 the Icelandic Eyjafjallajökull stratovolcano emitted large clouds of volcanic ashes that provoked chaotic situations for the air traffic of the Northern hemisphere. The impact of the resulting atmospheric pollution may have widespread effects on the health of the populations living in the affected regions. For this reason, the study of the airborne particles brought by the ash clouds must cover not only their concentrations expressed in $\mu\text{g}/\text{m}^3$, but also their size, shape and chemical composition. Our results revealed that during the eruption days, some periods with a higher concentration of the coarse particles (between 2.5 and 10 μm) were observed. The sphericity (R1) and roughness (R2) parameters showed specific characteristics of the particles, suggesting long distance of their origin. Furthermore, an increase up to 4 times more in the At% of the elements K, Al, Ca, Na and Si, which characterize the felsic lava, was observed during the eruption period.

Keywords: *Iceland eruption, felsic lava, long distance transport, airborne particles, granulometry, micromorphology and chemistry*

Rezumat. Poluarea atmosferică datorată dispersiei lavei vulcanului islandez – cazul orașului Bruxelles

În aprilie 2010, stratovulcanul islandez Eyjafjallajökull a aruncat nori mari de cenușă vulcanică care au generat situații haotice pentru traficul aerian din emisfera nordică. În urma acestui fenomen, impactul poluării atmosferice poate avea foarte multe efecte asupra sănătății populației care trăiește în regiunile afectate. Din acest motiv, studiul particulelor aeriene aduse de către norii de cenușă trebuie să cuprindă nu numai concentrațiile lor exprimate în $\mu\text{g}/\text{m}^3$, dar și dimensiunea, forma și compoziția lor chimică. Rezultatele au arătat că în zilele erupției au fost înregistrate unele perioade cu concentrații mai mari ale particulelor macrogranulare (între 2,5 și 10 μg). Sfericitatea (R1) și rugozitatea (R2) au indicat caracteristici specifice ale particulelor, sugerând distanța mare față de locul de origine. Mai mult, în timpul erupției s-a înregistrat o creștere de până la 4 ori a elementelor K, AL, Ca, Na și Si, caracteristice lavei riolitice.

Cuvinte-cheie: *erupția islandeză, lava riolitică, transport pe distanțe mari, particule aeropurtate, granulometrie, micromorfologie și chimie*

Introduction

Along the mid-oceanic ridges, two tectonic plates diverge from one another. New oceanic crust is formed by hot molten rock slowly cooling and solidifying. The crust is very thin along the mid-oceanic ridges due to the pull of the tectonic plates. Iceland is a region of frequent volcanic activity, due to its location astride the Mid-Atlantic Ridge, where

the North American and Eurasian Plates are moving apart, and also over the Iceland hotspot, which greatly enhances the volcanic activity. It is estimated that a third of all the basaltic lava erupted throughout the world in recorded history has been produced by Icelandic eruptions. The release of pressure due to the thinning of the crust leads to adiabatic expansion, and the partial mixing of the mantle causing volcanism and creating new oceanic

crust (Kristjansson et al. 1975; Mattsson and Hoskuldsson 2003).

The Icelandic Eyjafjallajökull stratovolcano entered a new eruption phase in April 2010. The volcano has periodically emitted large clouds of volcanic ashes that provoked chaotic situations for the air traffic of the Northern hemisphere. As a consequence of the volcanic eruption in Iceland, on April 14, combined with the advection of air masses from the North, the air traffic over large areas of Western Europe was suspended, for security reasons, from the afternoon of Thursday April 15th.

Lava is molten rock expelled by a volcano during an eruption. This molten rock is formed in the interior of some planets, including Earth, and some of their satellites. When first erupted from a volcanic vent, lava is a liquid at temperatures ranging from 700°C to 1,200°C (1,300°F to 2,200°F). Up to 100,000 times as viscous as water, lava can flow great distances before cooling and solidifying, due to its thixotropic and shear thinning properties.

The densest minerals, ferro-magnesian silicates, form at the highest temperatures, whereas less dense minerals form when the magma cools down. Mineral types forming in molten rock often grow unrestricted to a very large size, and can have a fine crystal form. There are seven basic types of lava, which reflect the main types of volcanic rock which the lava is composed of: Basalt, Andesite, Dacite, Rhyolite, Carbonatite, Natrocabonatites, Komatite. Igneous rocks, which form lava flows when erupted, can be classified into three chemical types; felsic, intermediate, and mafic. Felsic (or silicic) lava Felsic or silicic. Most Silicic lava flows are extremely

viscous, and typically fragment as they extrude, producing blocky autobreccias.

The study of the airborne particles brought by the ash clouds should cover not only their concentrations expressed in $\mu\text{g}/\text{m}^3$, but also their size, shape and chemical composition. Apart from the damage to the jet engines, an estimation of the impact of the resulting atmospheric pollution on the health of the populations living in the regions affected by the volcanic clouds can only be based on this kind of information.

The objective of the present report is to provide data about the concentration, the micromorphology and the chemical components of the airborne particles brought by the ash clouds emitted during this exceptional volcanic phenomenon and found in the air of the Brussels urban region.

Methods and Materials

For this study we used specific methods and instrumentation that are adapted for the investigation of the proposed objectives.

The Brussels telemetric network for air pollution consists of 11 measuring sites, situated in different urban environments: traffic, residential, industrial and urban background. The PM10 mass concentration is measured in six measuring sites: Molenbeek (R001), Berchem (B011), Uccle (R012), Brussels naval port (N043), Meudon park (MREU1) and at the Brussels Environmental Institute in Woluwe (WOL1) (Fig. 1).

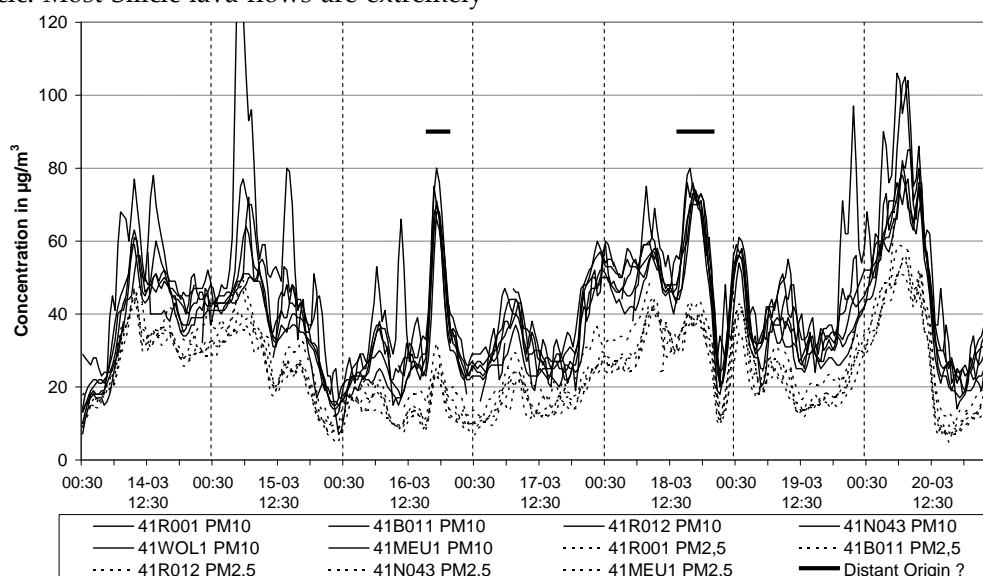


Fig. 1: Evolution "PM10-Fdms" and PM2,5-F" dms at Brussels Measuring Sites (Period: Wednesday 14 – Tuesday 20 April 2010)

With the exception for the WOL1 site, the mass concentration for PM_{2.5} is measured along with PM₁₀ in five of the six PM₁₀ measuring sites. All PM mass concentration instruments are continuous TEOM 1400Ab analyzers (*Tapered Element Oscillating Microbalance*), equipped with FDMS 8500 system (*Filter Dynamics Measurement System*). Thus, the dynamic evolution of the mass concentration can be followed, while the mass concentration results on a 24-hour basis are relatively close to those of the gravimetric reference method. At the Brussels Institute for Environmental Management (WOL1), the particulate number concentration, expressed as the number of particulates per liter air, is also measured for 31 different classes, ranging from 0.25 μm to 32 μm, by means of a Grimm Laser light scattering spectrometer, model 365.

At two of the PM₁₀ measuring sites (Uccle and Woluwe), and at the local university (ULB) particles were also collected on filters by use of low volume samplers, in order to investigate for their physical and chemical properties.

The analysis of the particles was performed by taking into consideration the fact that particles smaller than 2.5-3μm, constitute a health hazard by their simple presence, regardless of their mineralogical and chemical composition (Buringh and Opperhuizen 2002; Harrison et al. 2001; Ruuskanen 2001). In addition, the chemical compositions of the particles were analyzed by Scanning Electron Microscopy (SEM), X-Ray diffraction and light polarizing microscopy. Estimation of particle size distribution for a large number of particles was based on their planar projection in a JSM 5410 JEOL scanning electron microscope (Franck and Herbarth 2002).

Our estimation of the particle size distribution is a result of particle projection on a plane. The value of the particle area, A [in square micrometer], is defined as the surface of the particle enclosed within the projected border, P (the perimeter in micrometer). This must be compared to the classical size parameter that is the diameter (D) of the smallest circle enclosing the whole plane projection of the particle (Alshibli et al. 2004; Vanderstaeten et al. 2008). Using SEM, a series of parameters were measured on a large number of particles: the projected surface (A, in square micrometer), the projected perimeter (P, in micrometer) and the projected long and short axis (L₁ and L₂, in micrometer). From these values, two dimensionless

ratio parameters, R1 and R2, were computed for a large number of particles (Zaady et al. 2009), characterizing the roughness and the elongation of the particles.

The first parameter, R1 [in micrometer], is defined as $R1=4\pi A/P^2$. This parameter characterizes the irregularity of the contour of the particle, i.e. the roughness of the particle surface, as compared to the smoothness of a perfectly spherical surface (Alshibli et al. 2004; Vanderstraeten et al. 2008). This quantity equals the value of 1 when the projection of the particle on the surface analyzed by the microscope is a perfect circle (Zaady et al. 2009). The second parameter R2 refers to the elongation of the particle and corresponds to the projected major axis, L₁, divided by the minor axis, L₂, of the smallest ellipse enclosing the planar projection of the particle.

The nature of the filter sampling is such that the particles that are captured must have a linear size between 1μm and 10μm. Particles larger than 10μm almost systematically rebound from the filter, whilst most of the particles smaller than 1 μm pass through it without being captured.

Statistical analysis - The statistical analysis concerns the particles collected on filter at three measuring stations Uccle, Woluwe and ULB located in the Brussels urban area, in order to characterize the difference in area and shape of atmospheric particles collected on the 16th, 17th and 18th of April 2010. One-way ANOVA, with Tukey test (Sokal and Rohlf 1995) was used to test differences in parameter means between the sites and days. Differences were considered statistically significant when $P<0.05$. Our comprehensive approach allowed us to calculate the particle size distribution, their roughness and sphericity and compare between the data regarding the changes in the chemical element compositions throughout the whole year, during normal period as expressed by non agriculture period (April) and during the eruption period (Vanderstraeten et al. 2007; Zaady et al. 2008).

Results

Following the eruption on April 14, 2010, the PM₁₀ and PM_{2.5} mass concentration measured at the surface in Brussels did not exhibit any unusual concentration level (Fig. 2). The PM₁₀ levels were normally higher than those of the PM_{2.5} and the differences observed between the PM₁₀ levels, measured at different sites for most of the time,

express the typical local influences. However, on Friday, April 16th between 16:00 and 19:00 h UT and on Sunday, April 18th between 14:00 and 19:00 h UT, the PM10 mass concentrations at the different

measuring sites were quite similar and the differences between the PM10 and the PM2.5 levels were much more pronounced than during the rest of the considered period.

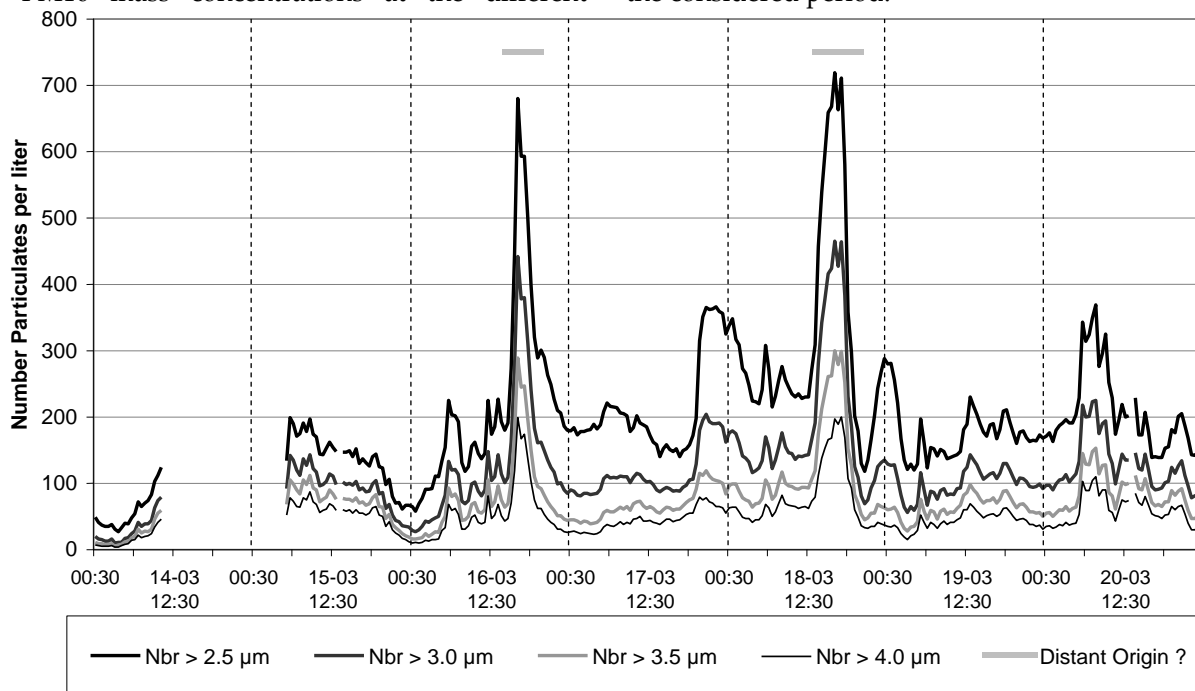


Fig. 2: Number of Particulates “> 2.5 μm” “> 3.0 μm” “> 3.5 μm” “> 4.0 μm” (Period: Wednesday 14 – Tuesday 20 April 2010)

During the two periods (between the eruption period and the regular airborne particle dynamics in Brussels Capital Region), the particulate number concentrations for the coarser fractions peak, as illustrated by Figure 3, representing the particulate number concentration for some classes: “>2.5 μm”, “>3.0 μm”, “>3.5 μm” and “> 4.0 μm”. In both figures (2 and 3), the two periods are indicated by small horizontal lines just above the top of the peaking concentration. The peak measured on April 20th could also be partially due to the eruption, but not exclusively, since important differences in the concentration level are observed between the PM10 concentrations at different stations.

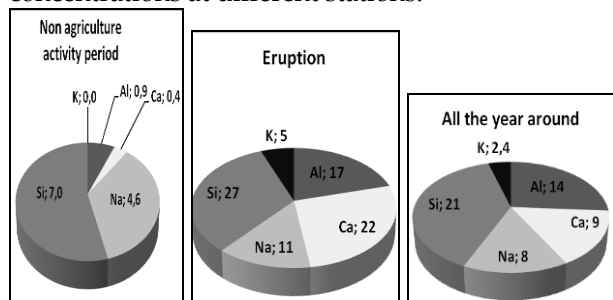


Fig. 3: Comparison between the atmospheric chemistry composition during the whole year, during non agriculture period and during the eruption period

Comparison between the atmospheric chemistry composition during the year, during non agriculture period and during the eruption period showed an increase of up to 4 fold in the At% of the elements K, Al, Ca, Na and Si (Fig. 3) for the eruption period.

The R1 (sphericity) on the three main days of the eruption period was three times higher than that found throughout the whole year and the non agriculture period, while the R2 (roughness) was lower by a factor 2 during the eruption period compared to the other two periods (Table 1).

Table 1 The micromorphological characteristics (R1 and R2) of the airborne particles during the 16, 17 and 18 April 2010 in Brussels

Period of measurement	Sphericity R1=(Long/Short)	Roughness R2=(4*A/P ²)
During the whole year	0.46±0.2	1.33±0.4
Non agriculture period	0.42±0.1	1.29±0.3
Eruption	1.46±0.4	0.72±0.1

Discussion

Measurements to obtain PM10 concentrations by means of R&P TEOM 1400Ab continuous instruments were performed at six different sites in the Brussels Capital Region. Three of these sites are representative for the general activities in the city (traffic, domestic heating, business and commercial activities), a fourth one is situated in an industrial area (city naval port) with a lot of traffic and two additional sites are situated in typical city residential environments. The granulometry was measured at the Woluwe site (WOL1), while the micromorphology and the chemistry were measured only in the sites with the filter sampling system; Uccle (R012), Brussels University (ULB) and the Brussels Environmental Institute (WOL1).

The observations obtained, especially those on April 16 and 18, support the idea that a common and distant source, situated outside the Brussels urban area, is responsible for the amount of the coarser particulates (PM 2.5 to 10). Nevertheless, as for the concentration of airborne particles, very high PM10 concentrations in the past have been reported during agriculture activity periods (the harvesting and sowing of wheat, corn and barley) (Vanderstraeten et al. 2007; Zaady et al. 2008) and by advection of Sahara sand. Similar to that, during the eruption period PM10 particles were predominant to PM2.5.

Our main results concerning the airborne particle micromorphology and chemistry showed a possible temporal correlation between the eruption period and the regular airborne particle dynamics in Brussels Capital Region (Zaady et al. 2010). These results are complemented by a previous study, which compared the non agricultural work periods (April) with the whole year round (Fig. 3). At least for two short periods the principal origin of the airborne particles is likely to be found in combustion processes (volcanic eruption). The high thickness and strength of the airborne particles, of the eruption period, were the result of their chemistry, which are high in silica, aluminum, potassium, sodium, and calcium, suggesting that their origin were from the Icelandic Eyjafjallajökull felsic stratovolcano. These chemical elements form a polymerized liquid rich in feldspar and quartz, which thus has a higher viscosity than other magma types (intermediate, mafic and ultramafic).

Conclusion

- During the eruption period high concentrations of large particles of PM10 were found.
- An increase of up to 4 fold in the At% of the elements K, Al, Ca, Na and Si, which characterize the felsic lava, was observed during the eruption period.
- The R1 (sphericity) and R2 (roughness) parameters showed specific characteristics of the particles suggesting a long distance from their origin.

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