Testing the reliability of terrestrial tephra layers as records of past volcanic eruptions (Ref IAP2-18-89)

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In partnership with Newcastle University

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Key Words

Tephra, Preservation, Iceland, Isopachs, volcanic hazards

Overview

Deposits of tephra (airborne fragments of volcanic rock produced during explosive eruptions) can cover thousands of km² and constitute significant natural hazards. Terrestrial tephra deposits are often preserved as layers in the soil. These layers are used to reconstruct the frequency of past volcanic activity, and to infer the characteristics of the eruption that produced them, e.g., eruption style and magnitude (Pyle 1989). Research based on terrestrial tephra layers has greatly extended the short and rather patchy record of volcanic eruptions based on historical accounts, and made major contributions to our understanding of volcanic processes and attendant hazards. However, inferences made from the tephra record rely on the assumption that the preserved tephra layer is representative of the initial deposit. A great deal can happen to tephra after deposition, and the ways in which tephra deposits are preserved (or not) are poorly understood (Dugmore et al. 2018). Recent research indicates that the preservation of tephra on land is spatially variable (Cutler et al. 2016); almost nothing is known about variation through time. Variable preservation can obscure the signal of the eruption, hindering our understanding of past volcanism. This project addresses this problem, utilizing a mixture of field surveys in Iceland and an environmental experiment in the UK.

The overall goal of this project is to gain greater insight into the preservation of terrestrial tephra layers, in order to improve knowledge of past volcanism and to aid predictions of the hazards arising from explosive volcanic eruptions in the future. This project will address two main questions:

Q1: Is time a factor in the interpretation of tephra layers? Tephra deposits are vulnerable to re-working from the moment they are deposited. For example, fresh deposits may be eroded and re-distributed by surface processes (Panebianco et al. 2017); compaction and geochemical changes occur belowground. It is crucial to understand these processes if tephra layers are to be successfully interpreted. However, we don’t know the period over which tephra layers are transformed: identical deposits of different ages could produce very different tephra layers. It could be that very little change occurs after burial (i.e., early changes are ‘locked in’ when they are interred). Alternatively, change may occur throughout the ‘life’ of a tephra layer (Fig. 1).

Q2: How do the physical properties of a tephra layer change after deposition? Terrestrial tephra layers are often highly variable in space. Thickness can vary over small spatial scales (Cutler et al. 2016), but this variability is poorly constrained (with implications for palaeo-volcanic
reconstruction). The processes that transform tephra deposits can impact on internal tephra layer stratigraphy, a property used to infer eruption dynamics. For example, wind and water ‘winnow’ exposed tephra unevenly and can truncate/obliterate layers. The episodic growth of ice crystals has the potential to re-sort tephra deposits, moving coarser grains upwards in the layer (thereby giving the illusion of increasing eruption intensity with time). These processes have received little attention; hence, the reliability of tephra layer stratigraphy as an indicator of palaeo-volcanism is unknown.

Methodology

The project has two components: 1) a field study of extant tephra layers in Iceland, designed to infer multi-decadal change and 2) a long-term experiment, based on the experimental application of tephra, to study changes to a high degree of spatial and temporal resolution.

Component 1: Icelandic fieldwork

Iceland is an ideal location for tephra studies, as it has numerous, well-dated layers. We will assess the impact of time on tephra layer preservation (Q1), by comparing layers deposited at different times in the same location, and under similar conditions. To do this, we will survey the tephra layers produced by the 1947 AD eruption of Mt Hekla (H1947) and the 2010 AD eruption of Eyjafjallajökull (Ey2010, Fig. 2). Both eruptions occurred in spring and are sufficiently close in time for us to be confident that surface conditions (e.g., land use and vegetation cover) and climate did not differ markedly between the depositional events. The student will establish ~20–30 sampling locations where the layers a) co-occur and b) were of a similar initial depth. They will record the thickness and stratigraphy of the layers along short (~50 cm long) transects and collect samples for grain size analysis. The properties of the initial deposits will be interpolated from published accounts, using established geostatistical techniques. Scale-free metrics of thickness variability will be computed to compare the layers to each other, under the null hypothesis that the degree of variability should be the same. The tephra layers will also be compared to the original deposits to assess the degree of transformation they have undergone.

Fig. 2 – Tephra from the 2010 eruption of Eyjafjallajökull on the surface four months after the eruption. Here the deposit was about 4 cm thick.

To assess the physical transformation of a tephra deposit (Q2), we will study a single, well-described tephra layer (H1947) in different depositional settings. This will allow us to establish the influence of surface cover, grain size and initial thickness on preservation. The student will establish sampling locations across the H1947 fallout zone and survey the extant layer as outlined above. As well as constraining spatial variability and the degree of transformation undergone by the layer in different locations, multivariate statistical techniques will be deployed to investigate spatial variation in key properties, using surface cover, deposit depth, deposit grain size (for H1947) as explanatory variables, and metrics of variability as response variable.

The two field trips to Iceland will prepare the student for component 2 of the project, as they will a) provide training in field survey skills and b) allow them to locate a source of tephra for subsequent experiments.

Component 2: Experimental application of tephra

Inferring temporal change from extant layers is valuable, but the only way to fully understand the gradual transformation of tephra deposits is by high-frequency repeated observation of the period immediately after a tephra is deposited. The unpredictable nature of volcanic eruptions means that real-time observation of tephra deposition is difficult to accomplish in the field. We will address this difficulty by the experimental application of tephra. The experiment will be established on an upland in Angus. A weather station will be installed to monitor meteorological conditions (soil temperature, precipitation and wind speed/direction) for the duration of the experiment. Tephra will be sourced in Iceland from the 1104 AD eruption of Hekla, because this tephra layer is already quarried. A replicated (N=3), full-factorial design will be used for the
experiment with grain size (sand, silt) and initial thickness (2.5, 7.5 and 15 cm) as factors. We estimate ~1.5 m³ (~1100 kg) of tephra will be required with this design. A grid of 18 plots, each measuring 1 m x 1 m, will be established on flat terrain with homogeneous vegetation cover (ungrazed pasture, to simulate the impact of tephra deposition on farmland). Treatments will be randomly assigned to the plots and will be well-mixed at the outset (no stratigraphy). The student will survey layer thickness (mean and variability), grain size and stratigraphy at three-month intervals for the duration of the study (18 months, initially), as well as record change photogrammetrically. This approach will give insight into the transformation of tephra deposits immediately after deposition (when we suspect most change occurs), as well as longer term changes due to erosion, freeze-thaw and other processes.

Timeline

Year 1: Literature review, geostatistics training, experimental design and planning of tephra sample collection, Iceland fieldwork (1); training and collection of data for pilot study, tephra sample collection in Iceland and shipping back to UK.

Year 2: Set up and monitor tephra experiment. Iceland fieldwork (2); Survey H1947/Ey2010 layers in Iceland. Analysis of fieldwork survey data; analysis of lab data. analysis of the fieldwork data and 1st year of experimental data.

Year 3: Continue experiment monitoring, data analysis of fieldwork data, experiment wrap up and experiment data final analysis, begin writing up thesis.

Year 3.5 (6 months): Publication production and project dissemination.

Training & Skills

The student will be trained in the field description and recording of tephra layers, lab analysis of sediments, GIS, and advanced geospatial and multivariate statistics. This training will ensure the student graduates with excellent statistical and GIS skills, which are highly valued across a range of research areas and within industry. In addition, project-specific training will be provided by RS in tephra stratigraphy, photogrammetric survey approaches and particle size analysis. NC will provide project-specific training in experimental design and ecological survey skills. RS and NC will provide training in statistical analysis in R and mapping in QGIS. Overall the training for this project means that the student will develop a diverse range of in-demand complementary skills. The student will also attend the residential course ‘Statistics for Geoscientists’ run by the British Geological Society.

References & Further Reading


Further Information

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