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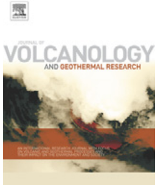

Sweet chestnut (*Castanea sativa*) leaves as a bio-indicator of volcanic gas, aerosol and ash deposition onto the flanks of Mt Etna in 2005–2007

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ABSTRACT

Sweet chestnut leaves (*Castanea sativa*) collected from the flanks of Mt Etna volcano in 2005–2007 were analysed by inductively-coupled plasma mass spectrometry to investigate the spatial and temporal variability of element concentrations. The aim of this work was to determine whether these leaves are a bio-indicator for volcanic gas, aerosol and ash deposition and to gain new insights into the environmental effects of quiescent and eruptive volcanic plumes. Results show a positive correlation between sample variability in the concentration of elements in *Castanea sativa* and enrichment factors of elements in the plume. The spatial and temporal variability of chalcophilic elements (As, Cd, Cu, Mo, Tl, Zn) is consistent with prevailing winds transporting eruptive plumes to the south-east of the summit, resulting in enhanced plume deposition onto the flanks of the volcano. Similar spatial and temporal variability was found for the halide-forming elements (Cs, K, Rb) and intermediate elements (Al, Co, Mn). The spatial variability of chalcophilic, intermediate and halide-forming elements during quiescent periods was diminished (relative to eruptive periods) and could not be explained by plume deposition. In contrast, the concentrations of lithophilic elements (Ba, Ca, Mg, Sr) did not show any clear spatial variability even during eruptive periods. Comparisons between enrichment factors for elements in *Castanea sativa* and literature values for enrichment factors of the volcanic plume, groundwater and lichen were made. Whilst *Castanea sativa* offers insights into the spatial and temporal variability of deposition, the species may not be a bio-indicator for plume composition due to biological fractionation.

1. Introduction

1.1. Overview

Recent field studies have led to significant advances in the understanding of the composition and processing of volcanic emissions at source, including major gas species (e.g., Horrocks et al., 2003; McGonigle et al., 2004; Martin et al., 2006; Aiuppa et al., 2007), trace gases (e.g., Aiuppa et al., 2005; Bobrowski et al., 2007; Bagnato et al., 2007; Witt et al., 2008) and particulates (e.g., Mather et al., 2003; Martin et al., 2008). Amongst other things, this work allows estimates to be made of the global volcanic outputs of a range of species, which is important for understanding geochemical mass budgets and exchanges between reservoirs. However, these studies have not, in general, considered the fate of volcanic emissions in the environment and the mechanisms by which these emissions interact with the Earth's surface through the processes of plume dispersion and deposition. An understanding of these processes is vital for any assessment of the environmental and human impacts of volcanic emissions.

Previous attempts to assess plume dispersion and deposition have included: (1) computational dispersion models (e.g., Pareschi et al., 2001), (2) chemical analysis of passive air samplers (diffusion tubes), deposition plates and precipitation samplers (e.g., Delmelle et al., 2001, 2002; Edmonds et al., 2003; Aiuppa et al., 2003a, 2004, 2006) and (3) chemical analysis of lichens, plants and soils (e.g., Notcutt and Davies, 1989; Varrica et al., 2000; Delmelle et al., 2003; Watt et al., 2007; Bellomo et al., 2007). Dispersion models have been applied with some success to small volcanic islands (e.g., Vulcano Island, Sicily) and can simulate the local-scale dispersion of volcanic emissions from multiple sources over complex topography (Pareschi et al., 2001). This approach is less successful on larger scales (e.g., Mt Etna, Sicily) due to uncertainties in the wind field, the requisite resolution of the digital elevation model and changes in the chemical

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speciation of the plume, which may affect depositional properties (e.g. Aiuppa et al., 2007). Diffusion tubes and precipitation samplers offer estimates of wet and dry rates of deposition but the density of monitoring network (and thus, the spatial resolution of the technique) is often limited by financial and practical constraints. A complementary approach is the use of environmental samples (e.g., leaves, bark, tree cores, soils) as a bio-indicator of the environmental conditions that exist in a given locale (Kabata-Pendias, 2001). A "good" bio-indicator must have abundant coverage throughout the study area over an extended period of time and a measurable response (e.g., accumulation of a certain element) to environmental conditions (Wittig, 1993). Subject to these criteria, a bio-indicator may be used to retroactively investigate environmental conditions across large areas, over periods of weeks and months (e.g., deciduous tree leaves and grasses) to years (e.g., lichens and mosses) at high spatial resolution. The leaves of plants act as passive and active "collectors" for airborne pollutants (e.g., gas, aerosols, dusts) and are more sensitive to air quality than other plant organs (e.g., roots) (Landolt et al., 1989; Caselles, 1998; Kabata-Pendias, 2001). Several studies have analysed leaves to assess the spatial and/or temporal variability of anthropogenic pollution (e.g., Pikzak et al., 2003; Rossini-Oliva and Valdés, 2004; Kapusta et al., 2006; Kuang et al., 2007 and others) but few studies exist where these methodologies have been applied to investigate the dispersion and deposition of volcanic gas, aerosols and ash. However, recent and preliminary studies have suggested that sweet chestnut (*Castanea sativa*) leaves are a bio-indicator for volcanic F and trace metal deposition on the flanks of Mt Etna (Bellomo et al., 2007; Watt et al., 2007).

1.2. Uptake of elements into plants

The uptake of elements from the environment by plants may occur via the roots, foliage and stem (Lepp, 1975). Elements may be subsequently redistributed by transport processes within the plant. The dominant uptake route for most elements is through the soil although above-ground plant organs may accumulate airborne pollutants (Kabata-Pendias, 2001). The main factors affecting the concentration of elements in the soil solution (and bio-availability) are soil temperature, acidity and redox state (i.e., these factors determine the stability of aqueous ions), the grain size distribution (i.e., fine grains have a high surface area to volume ratio promoting the release of elements into the soil solution), the abundance of organic (e.g., humic and fulvic acids) and inorganic (e.g., clays, oxides and hydroxides; these components are often most abundant in the fine fraction) binding agents and the solubility of the resulting complexes, and biological activity (Kabata-Pendias, 2001). The concentration of elements in the soil solution is also modified by the balance of inputs to (i.e., dry and wet deposition at the surface) and outputs from (i.e., release to groundwater) the soil profile. The uptake of elements by plants is further influenced by physical factors, such as the flow rate and contact time between plant roots and soil solution, and biological factors which may result in fractionation between elements. The mechanisms for foliar uptake of elements are varied but may involve the leaf cuticle, the stomata or both. Transport across the leaf cuticle increases with leaf-surface wetness (promoting dissolution; Percy and Baker, 1988), permeability of the waxy cuticle (which increases with pH; Percy and Baker, 1988) and the atmospheric supply of elements to the leaf surface.

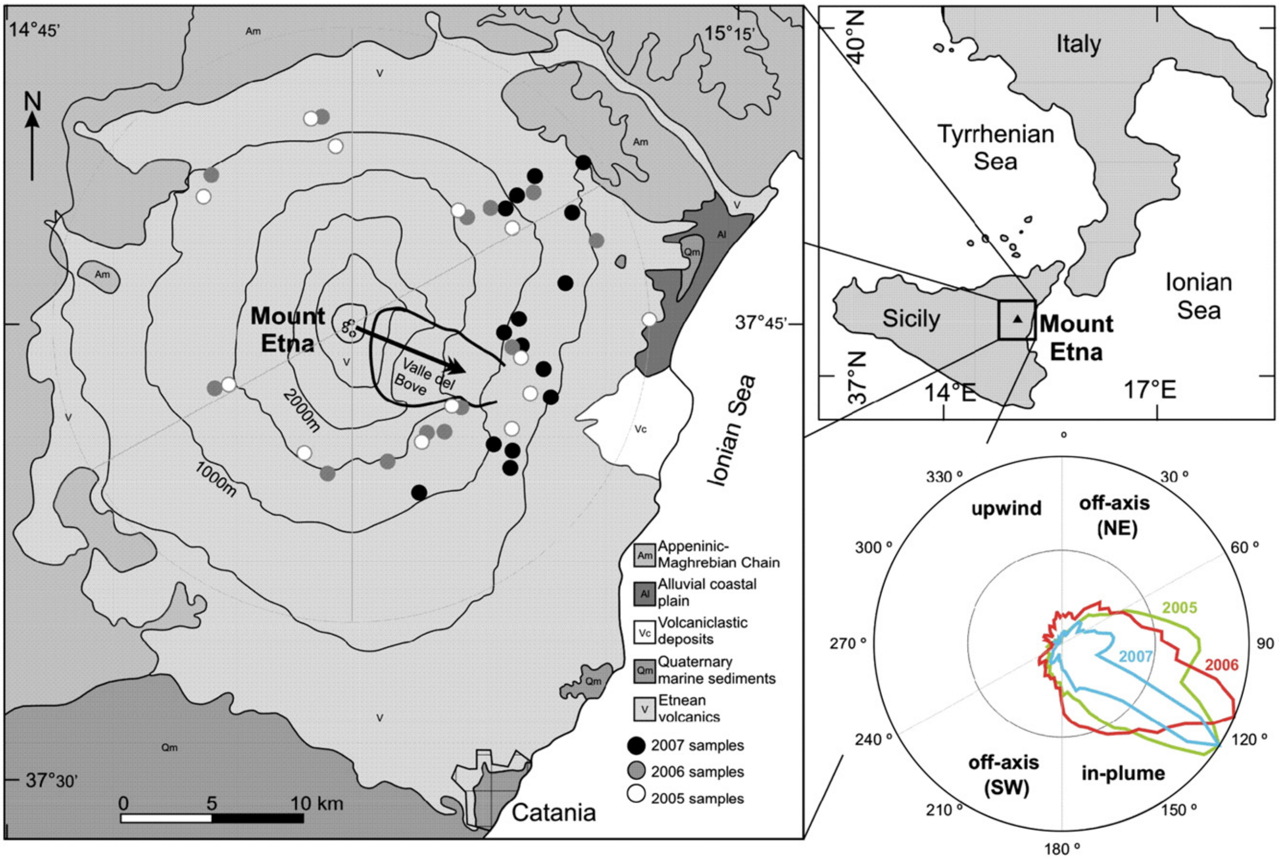

Fig. 1. Location map of Mt Etna, Sicily. Sample locations are shown on the main map. Wind direction results for 2005–2007 are shown in the lower right hand corner of the figure (adapted from Watt et al., 2007).