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Geochimica et Cosmochimica Acta 190 (2016) 156–174

Geochimica et Cosmochimica Acta

www.elsevier.com/locate/gca

Potentials and problems of building detailed dust records using peat archives: An example from Store Mosse (the "Great Bog"), Sweden

Malin E. Kylander [a,b,*], Antonio Martínez-Cortizas [c], Richard Bindler [d], Sarah L. Greenwood [a,b], Carl-Magnus Mörth [a,b], Sebastien Rauch [e]

[a] Department of Geological Sciences, Stockholm University, SE-10691 Stockholm, Sweden
[b] The Bolin Centre for Climate Research, Stockholm University, SE-10691 Stockholm, Sweden
[c] Departamento de Edafología y Química Agrícola, Facultad de Biología, Universidad de Santiago de Compostela, Campus Sur E-15706, Santiago de Compostela, Spain
[d] Department of Ecology and Environmental Sciences, Umeå University, SE-901 87 Umeå, Sweden
[e] Water Environment Technology, Chalmers University of Technology, 41296 Göteborg, Sweden

Received 28 September 2015; accepted in revised form 21 June 2016; available online 29 June 2016

Abstract

Mineral dust deposition is a process often overlooked in northern mid-latitudes, despite its potential effects on ecosystems. These areas are often peat-rich, providing ample material for the reconstruction of past changes in atmospheric deposition. The highly organic (up to 99% in some cases) matrix of atmospherically fed mires, however, makes studying the actual dust particles (grain size, mineralogy) challenging. Here we explore some of the potentials and problems of using geochemical data from conservative, lithogenic elements (Al, Ga, Rb, Sc, Y, Zr, Th, Ti and REE) to build detailed dust records by using an example from the 8900-yr peat sequence from Store Mosse (the "Great Bog"), which is the largest mire complex in the boreo-nemoral region of southern Sweden. The four dust events recorded at this site were elementally distinct, suggesting different dominant mineral hosts. The oldest and longest event (6385–5300 cal yr BP) sees a clear signal of clay input but with increasing contributions of mica, feldspar and middle-REE-rich phosphate minerals over time. These clays are likely transported from a long-distance source (<100 km). While dust deposition was reduced during the second event (5300–4370 cal yr BP), this is the most distinct in terms of its source character with $[Eu/Eu^*]_{UCC}$ revealing the input of plagioclase feldspar from a local source, possibly active during this stormier period. The third (2380–2200 cal yr BP) and fourth (1275–1080 cal yr BP) events are much shorter in duration and the presence of clays and heavy minerals is inferred. Elemental mass accumulation rates reflect these changes in mineralogy where the relative importance of the four dust events varies by element. The broad changes in major mineral hosts, grain size, source location and approximated net dust deposition rates observed in the earlier dust events of longer duration agree well with paleoclimatic changes observed in northern Europe. The two most recent dust events are much shorter in duration, which in combination with evidence of their local and regional character, may explain why they have not been seen elsewhere.

Keywords: Mineral dust; Peat; Geochemistry; Sweden; Paleoclimate; Holocene

* Corresponding author at: Department of Geological Sciences, Stockholm University, SE-10691 Stockholm, Sweden. Fax: +46 (0)8 674 7897.
E-mail address: malin.kylander@geo.su.se (M.E. Kylander).

http://dx.doi.org/10.1016/j.gca.2016.06.028
0016-7037/

1. INTRODUCTION

Mineral dusts play a complex role in the Earth's climate system both directly, through absorption and scattering of incoming solar radiation, and indirectly through its role in atmospheric photochemistry, cloud formation processes and the transport of nutrients to marine and terrestrial ecosystems (Kohfeld and Harrison, 2001). We can better understand these processes by looking at dust in the different climatic settings of the past as recorded in paleoclimatic archives. Long-term records of dust deposition can provide data on (i) net dust deposition rates, (ii) source changes, (iii) grain size, and (iv) mineralogy. In the past such studies have focused primarily on marine sediment and ice core records from the poles. The main terrestrial archive to date has been loess, which is restricted in distribution and subject to material reworking and dating challenges (Kohfeld and Harrison, 2001). Given that three quarters of the estimated 2000 Tg of dust entering the atmosphere each year is deposited on land (Shao et al., 2011), there is a need to expand the spatial coverage of terrestrial dust archives. Ombrotrophic bogs have a wide spatial distribution (Gore, 1993) and provide continuous, high-resolution, datable records of atmospheric deposition. Peat-rich temperate regions at higher latitudes are often overlooked by the dust community, despite the fact that dust production and emission processes are on-going, especially in previously and currently glaciated areas (Bullard, 2013). Glaciers and ice sheets are powerful agents of erosion and weathering, leaving in their wake significant amounts of potential dust in the form of unconsolidated material with a range of size fractions.

A first insight into Holocene dust variability in the previously glaciated landscape of Scandinavia comes from Store Mosse (the "Great Bog"), the largest mire complex in the boreo-nemoral region of southern Sweden (77 km^2) (Fig. 2). Kylander et al. (2013) presented bulk density, net peat accumulation rates, colourimetric humification, ash content, $[Eu/Eu^*]_{Profile}$ data and a Principal Component Analysis (PCA) of a suite of 28 major and trace elements. From these data it was possible to characterize peatland development and align major botanical transitions from the studied sequence with past works (Svensson, 1988; Malmer et al., 1997). While the fen to bog transition was identified at 6030 cal yr BP, the low ash contents (<2%) found above the basal section (8500 to 8330 cal yr BP) suggest that the southern area of the bog was exclusively atmospherically fed (i.e., ombrotrophic) much earlier. The PCA helped to identify four main processes controlling the geochemistry at Store Mosse. Principal Component 1 (PC1) grouped Al, K, Sc, U, Th, Y and the rare earth elements (REE) and was interpreted to signal detrital input via atmospheric dust deposition while PC2 and PC3 grouped mobile (Ca, Mn, Fe) and pollution-sourced (Pb, Zn) elements, respectively. PC4 was mainly linked to Zr and was tentatively interpreted to represent the input of larger grain sizes. By comparing and contrasting changes in PC1 with indicators of the local hydrologic balance (humification, bulk density and net peat accumulation rates), Kylander et al. (2013) reconstructed past changes in effective humidity at Store Mosse. These were found to broadly agree with records of effective humidity in southern Sweden and the main paleoclimatic interpretations are summarized in Fig. 1.

While this study established a general paleoclimatic framework for Store Mosse, key information on past changes in dust deposition was not presented. Kylander et al. (2013) did not (i) quantify net dust deposition rates but rather used variations in PC1 to identify three periods of relatively higher dust deposition. The quantification of net dust deposition rates in peat paleodust records has been based on the calculation of mass accumulation rates (MAR) ($g\,m^{-2}\,yr^{-1}$) of conservative lithogenic elements such as Al, Sc, Ti, Y or the REE (e.g., Sapkota et al., 2007). Conversion of this into net dust deposition rates requires the selection of a representative "dust" element from an appropriate reference such as the upper continental crust (UCC) (e.g., Fagel et al., 2014). The underlying assumption is that some component of the dust remains in constant proportion to the total dust flux through time. (ii) Source tracing of deposited dusts in peat records has been accomplished through trace element and isotopic source tracing tools (e.g., Kylander et al., 2005; Kylander et al., 2007; Le Roux et al., 2012; Vanneste et al., 2015). While one period of distinct source change was identified by Kylander et al. (2013) using $[Eu/Eu^*]$ data, no further characterization of this period was made. Neither (iii) grain size nor (iv) mineralogical data are routinely analysed in atmospheric records from peat bogs. This is because to date there are no completely effective and non-destructive (to the mineral component) methods established for the removal of such large amounts of organic matter. Dry ashing procedures (often at 450 °C) alter less crystalline minerals with physical and chemical alterations starting at temperatures as low as 40 °C (Kaiser and Guggenberger 2003) while chemical procedures (e.g., H_2O_2) are inadequate for removing such excessive amounts of organic material. High-resolution analyses also limit the amount of available material to be analyzed, which restricts the number of separate, destructive analyses that can be performed.

In theory, the elemental variations seen in dust records can provide us with grain size and mineralogical information. This is because elemental variations are controlled by the mineralogy of the deposited dusts, which is in turn controlled by the source(s) and its/their distance(s) from the peat deposit. The composition of the dust supplied by a given source area is governed by the local bedrock and the particular environmental conditions at that site. As an example of the latter, dust derived from sites that have experienced a greater degree of weathering will contain more secondary minerals such as clay minerals, and thus the minerals hosting major and trace elements will change over time as weathering proceeds within the source-area regolith. The distance from a dust source to the site of deposition plays a role through physical fractionation (i.e., particle sorting). Minerals such as quartz and feldspar tend to be concentrated in the coarser fractions (>2 μm) in dust and loess deposits, while the finer fractions (<2 μm) are enriched in mica and clays; these smaller particles can experience longer transport distances than larger particles (Tsoar and Pye, 1987; Gallet et al., 1996; Yang et al., 2006; Ferrat et al., 2011; Pye, 2013). Physical