Earth-Science Reviews 116 (2013) 170–194

Contents lists available at SciVerse ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

# Bulk composition of northern African dust and its source sediments — A compilation

Dirk Scheuvens [a,b,*], Lothar Schütz [b], Konrad Kandler [a,b], Martin Ebert [a], Stephan Weinbruch [a]

[a] Institut für Angewandte Geowissenschaften, Technische Universität Darmstadt, Schnittspahnstraße 9, 64287 Darmstadt, Germany
[b] Institut für Physik der Atmosphäre, Johannes-Gutenberg-Universität Mainz, Becherweg 21, 55128 Mainz, Germany

ARTICLE INFO

*Article history:*
Received 22 November 2011
Accepted 19 August 2012
Available online 29 August 2012

*Keywords:*
Mineral dust
Bulk composition
Source area
Northern Africa

ABSTRACT

This paper presents a review of bulk compositional data of northern African dust and its potential source sediments and includes elemental, isotope and mineralogical data. Northern African dust represents about one half of the total global atmospheric mineral dust burden, and its uplift, transport and deposition have strong impacts on climate and various terrestrial and marine ecosystems. The chemical data set shows, that an 'average northern African dust' exhibits comparable Si, Fe and Mn contents with respect to the average composition of the upper continental crust, is slightly depleted in the alkali metals K and Na, and enriched in Ti and P. However, the complete data set yields clear evidence that northern African dust and its source sediments are compositionally heterogeneous on a regional scale and that this heterogeneity can be used to differentiate between major potential source areas on the basis of so-called source markers. An evaluation of these compositional fingerprints shows that the following parameters and especially their combination are effective in the discrimination of the most active source areas in northern Africa: ratio of (Ca + Mg)/Fe [wt.%], calcite (or carbonate) content, palygorskite occurrence and abundance, illite/kaolinite ratio, $\varepsilon_{Nd}(0)$ value, and $^{87}Sr/^{86}Sr$ ratio. For example, the data set corroborates previous ideas, which assign carbonate-, illite- and palygorskite-rich mineral dusts to north(west)ern source regions. Because most of the above listed source markers do not change substantially during transport, even far-traveled dusts may be assigned to specific potential source areas in northern Africa. Some limitations of the presented data set are also discussed. Our compilation reveals some substantial gaps in the knowledge of the composition of source sediments and mineral dusts from important potential source areas that should be filled in the future.

The here compiled data set can be used as a reference frame, when incorporating the composition of source sediments (e.g., mineralogy) into global or regional dust transport models and can be compared with source analysis by remote sensing or back-trajectory analysis. However, source apportionment studies supported by our data set will not only be useful for actual dust samples, but will also be helpful for the understanding of paleo-wind directions and hence paleo-climatological conditions through the investigation of Quaternary eolian sediments deposited in and around northern Africa.



**Contents**



* Corresponding author at: Institut für Angewandte Geowissenschaften, Technische Universität Darmstadt, Schnittspahnstraße 9, 64287 Darmstadt, Germany. Tel.: +49 6151 163271; fax: +49 6151 164021.
*E-mail addresses:* dscheuvens@geo.tu-darmstadt.de (D. Scheuvens), schuetz@uni-mainz.de (L. Schütz), kzk@gmx.de (K. Kandler), mebert@geo.tu-darmstadt.de (M. Ebert), weinbruch@geo.tu-darmstadt.de (S. Weinbruch).


http://dx.doi.org/10.1016/j.earscirev.2012.08.005

## 1. Introduction

In recent years, it is more and more recognized that the uplift, transport and deposition of mineral dust have severe impacts on the atmospheric, pedological and marine compartments, and directly influences living organisms including mankind.

Studies of the last decades showed, that the input of mineral matter into the atmosphere has large impacts on the earth's radiative balance through absorption and scattering of the incoming solar and outgoing terrestrial radiations (direct forcing effect). Mineral dust also provides effective cloud condensation nuclei (CCN) and ice nuclei (IN) in the atmosphere (indirect forcing effect), thus influencing the formation, growth and life-time of clouds (see Arimoto, 2001; Sokolik, et al., 2001; Andreae and Rosenfeld, 2008). For the African continent it was shown that the input of mineral dust into the atmosphere could suppress precipitation in southern West Africa (Huang et al., 2009), leads to cooling of the Atlantic sea surface (Wong et al., 2008) and modulates the genesis of hurricanes over the Atlantic ocean (Sun et al., 2008). Mineral dust also provides reactive surfaces for trace gases and hence alters chemical reactions in the atmosphere (Dentener et al., 1996). Especially calcium-rich mineral dusts may partly neutralize acidic precipitation (Loÿe-Pilot et al., 1986; Rodà et al., 1993).

The removal of mineral matter and especially of clay minerals in the source region generally causes a significant degradation of soils, whereas re-sedimentation after transport often results in a supply of nutrients (e.g., Fe, P) to terrestrial ecosystems and an increase in fertility in the area of dust settlement (e.g., Amazon forest, Swap et al., 1992). In oceanic regions, the deposition of mineral dust might be responsible for the demise of coral reefs (Shinn et al., 2000). On the other hand, trace elements as Fe and P that are added to the oceanic ecosystems influence marine biogeochemical processes by supplying nutrients for phytoplankton or cyanobacteria, which in turn will alter the carbon and nitrogen cycle (e.g., Waeles et al., 2007).

Additionally, the transport of mineral dust directly affects different types of organisms, because it might be coupled with the carriage of pathogens over large distances (Kellogg and Griffin, 2006). In addition, after long-range transport the amount of $PM_{2.5}$ (mass concentration of particles with an aerodynamic diameter equal or smaller than 2.5 µm) in mineral dust is comparatively high and hence may affect human's and animals' health through inhalation and transport to the sensitive alveolar regions in the lungs (Prospero et al., 2008; de Longueville et al., 2010). Of special concern is the transport of northern African dust to Europe because it leads to exceedances of the $PM_{10}$ limit values of the European Union in southern Europe (e.g., Querol et al., 2009). Dust uplift and transport may also be responsible for a degradation of visibility (e.g., Ozer et al., 2006), an abrasion damage to crops and technical products (vehicles etc.) and fouling of machinery in and near the source regions. Deflation and uplift of material in the source areas can also undermine infrastructural units as roads, railways, etc.

In paleoclimatology, the analysis of the amount of eolian dust in oceanic sediments or in ice cores may have some important implications for the dust loading, the distribution of aridity and the direction of wind systems in the past (Rea, 1994; Maher et al., 2010).

All the above listed influences of mineral dust on the global system underline the importance to investigate the transport patterns, the grain-size distribution and the composition of eolian dust. In this review paper we will focus on the bulk elemental, mineralogical, and isotopic composition of northern African ('Saharan') dust and its source sediments.

Northern Africa is the largest source on earth for mineral dust, supplying up to $0.8 \times 10^9$ t per year of material to the atmosphere (see compilations in Goudie and Middleton, 2001; Laurent et al., 2008), representing circa 20 to 70% of the total global mineral dust burden of $1.0–3.0 \times 10^9$ t per year (Laurent et al., 2008).

Sources of Saharan dust are not evenly distributed over northern Africa. Several studies suggest that there exist various regions, which are far more productive than others (e.g., Middleton and Goudie, 2001; Prospero et al., 2002; Engelstaedter et al., 2006; Schepanski et al., 2009). These so-called potential (or preferential) source areas (PSAs) were determined by vastly differing methods including surface dust and visibility observations at meteorological stations, analysis of back trajectories, and global or regional atmospheric circulation models. More recently, remote sensing data as the Total Ozone Mapping Spectrometer Aerosol Index (TOMS AI) and the Infrared Difference Dust Index (IDDI) were applied to characterize the position of source regions more precisely. Last but not least, so-called 'compositional fingerprints' such as mineral tracers were used to identify several PSAs.

A compilation of available data for Saharan dust sources yields different main areas of dust entrainment and uplift (Fig. 1a, b). According to the TOMS AI (Middleton and Goudie, 2001; Israelevich et al., 2002; Prospero et al., 2002; Washington et al., 2003; Laurent et al., 2008) major potential source areas in northern Africa are located in western Chad (e.g., the Bodélé depression) and within a large area in western Africa that stretches from southern Algeria over Mali to Mauritania. Additional source regions were detected in Western Sahara, at the Algerian–Tunisian boundary, in central and eastern Libya, and in northern Sudan. Further important areas of dust mobilization based on different methods are proposed for example by Bertrand et al. (1974), D'Almeida (1986), Caquineau et al. (2002), Goudie and Middleton (2006) and Laurent et al. (2008). Other authors (e.g., Prospero et al., 2002) emphasized the role of topographical lows ("dust pans") as important regions for dust uptake and the good correlation of the model of Tegen (2003) and TOMS AI data is rather convincing. Comparing the proposed source regions with the distribution of sand dunes in the Sahara (see for example Prigent et al., 1999), it is obvious that the huge sand seas of northern Africa are not important areas of dust entrainment due to the large grain-sizes of their sediments which prevents uplift to altitudes suitable for long-range transport. Considering all the above listed studies and especially incorporating the excellent data set of Schepanski et al. (2009) who used Meteosat Second Generation (MSG) Spinning Enhanced Visible and Infrared Imager (SEVIRI) IDDI images to determine major dust areas, we propose the following six regions as the most important PSAs in northern Africa (Formenti et al., 2011; Fig. 1c. A detailed description of the geographic features of the various source regions in northern Africa is given by Prospero et al. (2002).

PSA 1: Tunisia and northern Algeria including the 'zone of chotts'
PSA 2: Foothills of Atlas mountains (PSA 2a) and western coastal region (PSA 2b; Western Sahara, western Mauritania)
PSA 3: Southern Algeria and northern Mali
PSA 4: Central Libya