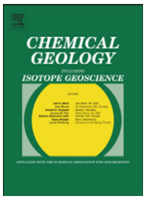
Chemical Geology 442 (2016) 54–61

Contents lists available at ScienceDirect

Chemical Geology

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



Elemental and isotopic composition of surface soils from key Saharan dust sources

A. Gross [a,*,1], D. Palchan [a,2], M.D. Krom [b,c], A. Angert [a]

[a] The Institute of Earth Sciences, The Hebrew University of Jerusalem, Israel
[b] Department of Marine Biology, Haifa University, Israel
[c] School of Earth and Environment, Leeds University, Leeds, UK

ARTICLE INFO

Article history:
Received 8 February 2016
Received in revised form 7 June 2016
Accepted 1 September 2016
Available online 6 September 2016

Keywords:
Dust
Sahara
$\delta^{18}O_P$ isotopes
Sr isotopes
Phosphorus
Potential source area

ABSTRACT

Saharan dust contains significant amount of P, an important macronutrient to all living organisms, which has been shown to exert large effects on nearby and remote ecosystems located across the dust transport pathways. The biological effect of Saharan dust depends on the amount and nature of the P speciation of the dust. However, thus far relatively small numbers of samples from potential source areas (PSA) has been analyzed. Here we report the P speciation (resin-P, HCl-P, Fe-bound-P and organic-P), the $\delta^{18}O_P$ values, the elemental composition, and the $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ of the fine fraction and bulk soil from 5 important PSAs across Northern Africa. We found the HCl-P concentrations between different source areas were relatively constrained but that these concentrations were higher in the fine fraction, which here is used a surrogate for dust. The $\delta^{18}O_P$ values for soils from sand dunes varied from 15.0 to 21.4‰, which is in the range of phosphate minerals from sedimentary origin. The $\delta^{18}O_P$ values of soils from dry lakes were significantly higher (24.0–28.5‰), probably since their P is derived from fossilized plankton that lived in the lake as it dried up. The $^{87}Sr/^{86}Sr$ and εNd values ranged from 0.7219 to 0.7276 and −12.7 to −14.0 in eastern samples and from 0.7146 to 0.7185 and −11.9 to −13.4 in western samples, suggesting a different source for the siliciclastic material of eastern and western samples. Our analysis indicates that the $\delta^{18}O_P$ values are decoupled from the Sr and Nd isotopic systems. Together, the new chemical and isotope data are specific for different PSAs and thus are used for source apportionment purposes. Such data can be used to provide more accurate estimates of the flux of potentially bioavailable P to marine and terrestrial ecosystems. These estimates can be used in global climate models to determine the magnitude and distribution of P control on carbon uptake.

1. Introduction

The Saharan desert is the largest dust source on earth and contributes more than 50% of the global mineral dust load (Goudie and Middleton, 2001; Schutz et al., 1981). Once lifted from the Saharan soils, the dust can spread southward to the Sahel and central Western Africa, northward across the Mediterranean towards Europe (Thevenon et al., 2010), eastward towards the Middle East (Ganor, 1991; Israelevich et al., 2003) and westward across the Atlantic Ocean reaching as far as the Amazon Basin (Prospero et al., 1981; Swap et al., 1992). Because of the large spread of Saharan dust its transport pathways, active sources and chemical composition have been intensively studied ((Scheuvens et al., 2013) and references within).

The Saharan desert covers a large area, and as a result it cannot be referred to as a uniform dust source. Within the Sahara desert, several potential source areas (PSA) have been identified which emit most of the dust burden ((Scheuvens et al., 2013) and references within). Many of these active sources are shown in Fig. 1 (adapted with permission from Scheuvens et al. (2013)) and include Northern Algeria and the “Zone of Chotts” in Tunisia (PSA 1, green), the foothills of the Atlas mountains and Western Mauritania (PSA 2, light blue), Southern Algeria and Northern Mali, near the Ahaggar massif (PSA 3, dark blue), Central Libya (PSA 4, purple), the Bodèlè depression in Western Chad (PSA 5, brown) and Central Egypt and Northern Sudan (PSA 6, red). It has been suggested that the most active sources within these large areas are associated with depressions and dry lakes (Ashpole and Washington, 2013; Prospero et al., 2002). However recent studies reveled the active dust sources are more diverse and include alluvial fans, dry wadis, sand dunes and anthropogenic surfaces (Bullard et al.,

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[*] Corresponding author at: 141 Mulford Hall, University of California, Berkeley, CA, 94720, United States.

E-mail address: avner.gross@gmail.com (A. Gross).

[1] Currently at the Department of Environmental Science, Policy & Management, University of California, Berkeley, CA, USA.

[2] Both authors contributed equally to this paper.

http://dx.doi.org/10.1016/j.chemgeo.2016.09.001
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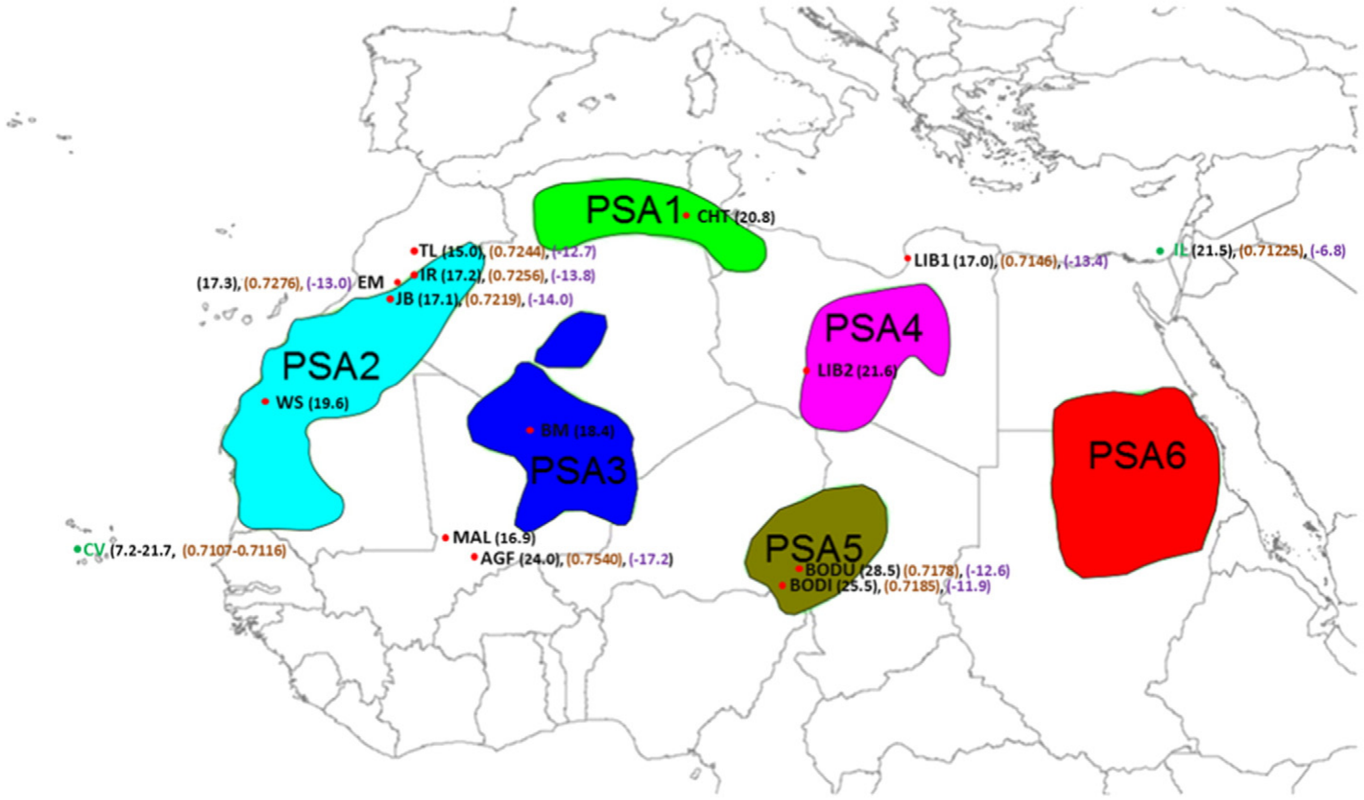

Fig. 1. Map of North Africa (adapted with permission from Scheuvens et al. (2013)) showing potential source areas (PSA1 to 6, different colors), locations of soil and dust sampling sites (red and green dots, respectively) and the spatial distribution of $\delta^{18}O_P$ values (black), $^{87}Sr/^{86}Sr$ values (brown) and εNd(0) values (gray). The isotopic values for the dust samples were taken from Gross et al. (2015a) and Palchan et al. (2013).

2011; Crouvi et al., 2012; Ginoux et al., 2012; Schepanski et al., 2013; Schepanski et al., 2009).

The most important source of atmospheric P is desert dust, which has been estimated to account for 83% (1.15 Tg P a^{-1}) of the total global source of atmospheric phosphorus (Mahowald et al., 2008). In particular Saharan dust is considered one of the major external suppliers of phosphorus (P) to the Atlantic Ocean (Mills et al., 2004; Okin et al., 2011), to the Mediterranean Sea (Krom et al., 2004) and to America's tropical forests (Gross et al., 2015b; Okin et al., 2004; Swap et al., 1992). The total amount of P in atmospheric dust and its potential bioavailability depends on P mineralogy in the source soils and the subsequent atmospheric processes, which occur during transit to final deposition in the ocean or on land (Nenes et al., 2011; Stockdale, Submitted (PNAS)). Bioavailable P in the ocean is the phase which rapidly dissolves in surface seawater before the refractory minerals drop out of the photic zone. Here this was determined as the P fraction that is extracted by anion exchange resin (resin P phase (Gross et al., 2015a, 2013; Qian and Schoenau, 2002)). In addition, during atmospheric transport, acidic processes in the atmosphere dissolve some fraction of the less bioavailable P fractions such as P that is bound to calcium minerals as apatite or P that is bound to iron minerals (Stockdale, Submitted (PNAS)). Thus, the P phase that is released by 1 M HCl extraction represents the potentially bioavailable P in the ocean. On land, the resin P fraction is considered immediately bioavailable to organisms (Cooperband et al., 1999) while the HCl P fraction is likely to become available in longer time scales and thus represents the potentially bioavailable P. At present, the degree of bioavailability of organic P to marine or terrestrial ecosystems is still unknown.

Yang et al. (2013), developed a global estimate of P in source soils based mainly on the soil map of Dürr et al. (2005) and estimates of the effect of desert weathering on the rocks, derived from data obtained in the deserts of SW USA. However, North African dust sources are still poorly characterized. In order to characterize the P speciation of dust that derives from the various PSAs in the Sahara and to predict its biogeochemical effect on nearby or remote ecosystems, data on the P mineralogy of the soils in the source area is required. Furthermore measurement of relevant different isotopic systems and elemental content of the soils in the source area can be used to characterize the area within the Sahara desert that is the source of a given sample of dust.

Our aim in this study was to create a data set that includes isotopic values and bulk concentrations of major and trace elements in a series of soils sampled from the major dust source areas (PSAs) in North Africa. Our measurements include the isotopic composition of oxygen in phosphate ($\delta^{18}O_P$), which can be used to trace Saharan dust-P sources (Gross et al., 2015a, b) and the isotopic ratios of Sr and Nd which have been widely used as fingerprints for particle sources (e.g. Box et al., 2011; Grousset and Biscaye, 2005; Grousset et al., 1992). Our elemental analysis is focused on phosphorus (P) because Saharan dust has been shown to be enriched in P (Gross et al., 2015a, b; Scheuvens et al., 2013) which is crucial for the productivity and carbon uptake of marine and terrestrial ecosystems located across the dust transport pathway (Carbo et al., 2005; Mills et al., 2004; Okin et al., 2004; Swap et al., 1992). Since dust is derived primarily from the soil finest particles, we also examined the elemental and isotopic composition in fine particles (PM_{10} and PM_{20}) separated from a selected number of soils, as a surrogate for mineral dust (Lafon et al., 2006; Shi et al., 2011b). Overall, the data set presented in this study partly complements older studies and can be used in future studies to identify the source of the Saharan dust, and by characterizing its P speciation, to predict the flux of potentially bioavailable P to globally important marine and terrestrial ecosystems.