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A three-year time series of mineral dust deposits on the West African margin: Sedimentological and geochemical signatures and implications for interpretation of marine paleo-dust records

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ABSTRACT

Mineral dust deposits in the Northeastern Tropical Atlantic Ocean (NETAO) are an important contribution for reconstructing paleoenvironments and paleoclimates of West Africa. However, the interpretation of the changes in the sedimentological and geochemical characteristics of the dust deposits recorded in the marine sediments from the NETAO remains incomplete. In order to improve our understanding of dust proxies, in particular its mineralogical and geochemical provenance tracers, present-day dust deposition has been monitored at Mbour ($\sim$80 km south of Dakar) on the Senegalese margin. Here we report a multi-proxy investigation of a unique three-year continuous time series of mineral dust deposits collected at a weekly (or better) temporal resolution over the March 2006–March 2009 period. Mass deposition flux and mean modal grain size display marked but reverse seasonal features, with higher flux during the winter/spring seasons and coarser grain size mode in summer when flux is minimal, reflecting contrasting transport patterns throughout the year. Similarly, clay mineralogy, the illite/kaolinite ratio in particular, shows seasonal fluctuations, manifesting the latitudinal displacement of the contributing domains of provenance in response to the seasonal migration of the ITCZ position and the associated wind systems. Our three-year record also reveals the occurrence of major deposition events superimposed on the seasonal pattern, generally during the winter/spring dry seasons and most frequently during the month of March. Our study shows that these major events, which contribute a large fraction of the total annual deposition flux, all originate from the western Sahara–Sahel (a major area of emission in the region beside the Bodele Depression, stretching from the Mauritanian and Western Saharan coasts to the Hoggar Mountains). Combined with air mass tri-dimensional back-trajectories and satellite images, the mineralogical and Sr–Nd isotopic compositions of these large dust events enable us to identify several mineralogically and geochemically distinct provenance sectors within this vast western area. Unlike the background dust deposits, the $^{87}Sr/^{86}Sr$ and the ε_{Nd} isotopic signatures of the major dry events closely match that of the NETAO Late Holocene sediments, supporting the hypothesis that these events account for most of the aeolian terrigenous supply reaching the ocean floor. Although this database needs to be expanded, our results already provide useful constraints for the interpretation of the dust proxies' variations in marine sedimentary archives off Mauritania/Senegal in terms of changes in wind regimes and aridity over West Africa.

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1. Introduction

The Northeastern Tropical Atlantic Ocean (hereinafter NETAO) receives large amounts of mineral dust transported by the atmosphere from the Sahara and Sahel arid and semi-arid regions (Prospero, 1996). In the absence of significant fluvial sediment discharge on the West African margin, these dust inputs represent most of the non-biogenic material reaching the open ocean floor (Kolla et al., 1979). The long-term geological history of these aeolian deposits is well recorded in the marine sediments of the NETAO region (e.g., Matthewson et al., 1995). As dust supplies reflect dryness conditions and wind patterns over the continent, they contribute to document the long-term environmental and climatic changes that have taken place in West Africa throughout the Quaternary and beyond (Rea, 1994). Increased dust fluxes, for instance, have been interpreted as indicative of aridity intensification (Tiedemann et al., 1989; Rea, 1990). Similarly, coarser dust grain sizes have been linked to stronger winds (Sarnthein et al., 1982; Ruddiman, 1997). The ability to use dust records to monitor wind strength is particularly useful, as there is virtually no other tracer available to constrain the vigor of low-latitude atmospheric circulation in paleo-climate reconstructions and models (e.g., Mulitza et al., 2008).

Nonetheless, the interpretation of marine sediment dust records in the NETAO has been limited by the lack of information regarding dust provenance. Although the Saharan-Sahel region stretches over an area of around 2000-by-4000 km^2 area at present, and contains numerous distinct high-emission "hot spots" (Goudie and Middleton, 2001; Prospero et al., 2002; Engelstaedter and Washington, 2007a,b), it has been considered as a "single source" in most paleoclimatic studies. Valuable additional information on shifts in transport systems and the distribution of arid areas over West Africa could certainly be gained if we were able to define more precisely the origin of the dust and its variability over time in paleo-dust records. Specific mineralogical and geochemical intrinsic tracers, which reflect the geological and weathering history of the dust source area, can be analyzed and used for this purpose (Grousset et al., 1998; Bout-Roumazeilles et al., 2007; Colin et al., 2008; Meyer et al., 2011). Provenance can then be inferred by matching the dust signature with those of potential source areas (Grousset and Biscaye, 2005).

There have been several attempts to use radiogenic isotopes (Sr and Nd), for example, for identifying possible shifts in dust provenance through recent climate transitions (Grousset et al., 1998; Jullien et al., 2007; Cole et al., 2009; Stumpf et al., 2011). These studies have been hindered, however, by the fact that the signature of potential source areas is not well documented. Indeed, there is clearly insufficient data coverage over the Sahara–Sahel region, mostly due to the large number of possible dust sources spread over this vast territory (Engelstaedter and Washington, 2007b; Formenti et al., 2011). Previous provenance investigations therefore have relied on data obtained from various types of geological samples (rocks, soils, sediments etc.). How representative these samples are with respect to the dust sources is difficult to assess, however. As a result, inferences obtained from these provenance proxies up until now has been limited.

Additionally, the interpretation of dust records has been hampered by the fact that there is poor understanding also of the wind systems responsible for the dust deposited in the NETAO. One way of improving the interpretation of the paleo-dust records might be to turn to modern deposits reaching the NETAO. The main interest in monitoring current dust deposition in the NETAO region is that information on the contributing source regions and associated wind patterns can be obtained simultaneously from meteorological and remote-sensing data. The mineralogical and isotopic signature of the dust obtained in this way can therefore be traced back directly to its region of provenance within West Africa. Another advantage in collecting present-day dust as it reaches the oceanic domain is that these dust samples then also reflect the complex mixing processes that occur between multiple contributing sources during Saharan outbreaks. Such mixing would be difficult to reproduce using the present incomplete database of potential source areas.

Furthermore, it is known that the initial grain size distribution of a source area evolves during deflation, saltation and atmospheric transport, which may modify the mineralogical composition of the dust and thus its isotopic composition (e.g., Dasch, 1969; Mason, 1982; Martin and Withfield, 1983; Schütz and Sebert, 1987; Alfaro et al., 1997; Sabre et al., 1997). Consequently, even reliable data obtained from soils or sediments found in well-identified dust sources may not truly reflect the signature of the airborne fraction emitted from these areas, making it even more difficult to base provenance investigations on source data alone. Using a combination of deposition measurements and atmospheric transport data enables us to circumvent some of these problems and provide some calibration of the proxies, not only in terms of source area complex signatures (likely mixed) but also in terms of transport patterns and their seasonal timing. Although dust emission, transport and deposition patterns observed at present may not offer match past configurations one-to-one, we believe such an approach can provide new insights in the interpretation of the mineralogical and isotopic records in marine sediments.

We started sampling dust deposits at Mbour ($\sim$80 km south of Dakar) on the Senegalese margin in 2006 (Skonieczny et al., 2011), as part of the African Multidisciplinary Monsoon Analysis (AMMA) framework (Redelsperger et al., 2006). The sampling site, located near the western tip of West Africa as well as under major corridors for both winter/spring and summer dust outbreaks, is ideally situated for monitoring mineral aerosol inputs as they reach the NETAO. Here, we report a unique three-year time series of weekly mineral dust deposits at Mbour, spanning the spring 2006 to spring 2009 period. Mass fluxes, grain-size, and clay mineralogy measurements were carried out throughout the entire record. This deposition record enables us, for the first time, to document the temporal pattern of dust deposition in this region in response to the changing wind systems through the whole year.

Further, Sr and Nd isotope analyses of samples during some of the major deposition events were carried out as well, along with characterization and identification of fresh-water diatoms. Provenance information, inferred from tri-dimensional back-trajectories and satellite images, allows us to assess the efficacy of the proxies measured for identifying provenance and transport systems. Lastly, we discuss the implications that our finding have for the interpretation of the paleo-dust archives retrieved from the NETAO.

2. Material and methods

Mineral dust was collected using a CAPYR-type reversed pyramid-shaped PVC collector installed about 8 m above ground on the rooftop terrace of the IRD-Mbour research building facing the Atlantic Ocean (14°24′38″N; 16°57′32″W; Skonieczny et al., 2011). The sampling site was located in a protected ecological center, which is a vegetated area where car traffic is minimal, reducing influence from locally-produced dust. Our collector has the advantage of being made of plastic only, minimizing potential contamination of the dust samples with metals of interest. However, due to its rather poor aerodynamic shape, the original CAPYR-type collector has lower efficiency (up to a mean factor of around three) than other sampling devices (Goossens and Rajot, 2008). For this reason, the 2500 cm^2 sampling area was covered with a 1-cm thick