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Early-Holocene greening of the Afro-Asian dust belt changed sources of mineral dust in West Asia

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ABSTRACT

Production, transport and deposition of mineral dust have significant impacts on different components of the Earth systems through time and space. In modern times, dust plumes are associated with their source region(s) using satellite and land-based measurements and trajectory analysis of air masses through time. Reconstruction of past changes in the sources of mineral dust as related to changes in climate, however, must rely on the knowledge of the geochemical and mineralogical composition of modern and paleo-dust, and that of their potential source origins. In this contribution, we present a 13,000-yr record of variations in radiogenic Sr–Nd–Hf isotopes and Rare Earth Element (REE) anomalies as well as dust grain size from an ombrotrophic (rain fed) peat core in NW Iran as proxies of past changes in the sources of dust over the interior of West Asia. Our data shows that although the grain size of dust varies in a narrow range through the entire record, the geochemical fingerprint of dust particles deposited during the low-flux, early Holocene period (11,700–6,000 yr BP) is distinctly different from aerosols deposited during high dust flux periods of the Younger Dryas and the mid-late Holocene (6,000–present). Our findings indicate that the composition of mineral dust deposited at the study site changed as a function of prevailing atmospheric circulation regimes and land exposure throughout the last deglacial period and the Holocene. Simulations of atmospheric circulation over the region show the Northern Hemisphere Summer Westerly Jet was displaced poleward across the study area during the early Holocene when Northern Hemisphere insolation was higher due to the Earth's orbital configuration. This shift, coupled with lower dust emissions simulated based on greening of the Afro-Asian Dust Belt during the early Holocene likely led to potential sources in Central Asia dominating dust export to West Asia during this period. In contrast, the dominant western and southwest Asian and Eastern African sources have prevailed during the mid-Holocene to modern times.

1. Introduction

West Asia, also referred to as the Middle East, is a climatically sensitive region that extends across the eastern Mediterranean Sea, Syria, Iraq, Iran and the Arabian Peninsula. Major Eurasian synoptic systems dominate over this portion of Asia, including the Siberian anticyclone (SA), the Indian Ocean Summer Monsoon (IOSM) and the Northern Hemisphere Summer Westerly Jet (NHSWJ) (Fig. 1). The convergence of these systems over West Asia and their interaction with external forcing such as solar irradiance and insolation, internal climate oscillations and anthropogenic forcing mechanisms make this region highly susceptible to abrupt shifts in climate regimes (*e.g.*, Liu et al., 2015; McGee et al., 2014; Nagashima et al., 2011; Sharifi et al., 2015).

Mineral dust is an actively changing component of the biogeochemical (Moore et al., 2002) and hydrological cycles (Arimoto, 2001) and significantly influences the global radiation budget

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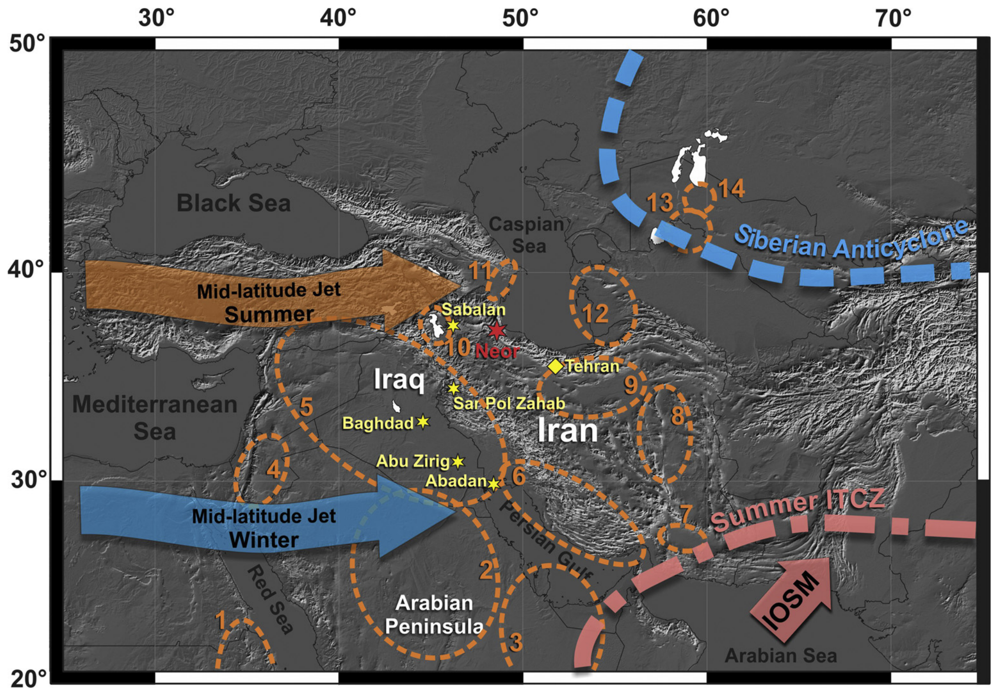

Fig. 1. Schematic position of major synoptic systems and dust sources over West Asia. Stars denote the location of Neor peat mire (red) and dust collection sites (yellow). Orange and blue arrows denote the location of Northern Hemisphere Summer Westerly Jet (NHSWJ) in summer and winter respectively (Schiemann et al., 2009). The approximate current location of the Intertropical Convergence Zone (ITCZ) is also shown (Aguado and Burt, 2012). IOSM refers to Indian Ocean Summer Monsoon. Dashed circles in orange denote the major dust sources in the region (Ginoux et al., 2012) and are numbered as follow: 1, northeast Sudan; 2, highlands of Saudi Arabia; 3, Empty Quarter (Rob Al Khali); 4, Jordan River Basin of Jordan; 5, Mesopotamia; 6, coastal desert of Iran; 7, Hamun-i-Mashkel; 8, Dasht-e Lut Desert of Iran; 9, Dasht-e Kavir Desert of Iran; 10, Lake Urmia of Iran; 11, Qobustan in Azerbaijan; 12, Atrek delta of Turkmenistan; 13, Turan plain of Uzbekistan, and 14, Aral Sea. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(Choobari et al., 2014; Miller and Tegen, 1998; Tegen and Lacis, 1996). The vast, arid and semi-arid areas across West Asia are part of the Afro-Asian "dust belt" and a major contributor to global atmospheric dust emissions (Prospero et al., 2002), with the Arabian Peninsula, Iraq and Syria contributing up to 20% (Hamidi et al., 2013) in modern times. Large amounts of dust are delivered from these regions to the Persian Gulf, the Red Sea and the northern Indian Ocean (Goudie and Middleton, 2006; Littmann, 1991; Middleton, 1986; Pourmand et al., 2004; Prospero et al., 2002; Sirocko et al., 2000).

Paleo-dust records in lacustrine/marine sediments and ice cores suggest a strong link between mineral dust and the climate state. These records also indicate systematic variations in dust emission and transport in the past, changes in the amount of dust, dust typology and shifts in the source areas (Shao et al., 2011). The controlling mechanisms on atmospheric circulation and dust emission during the Holocene and the effect of climate variability on introducing new dust source regions in West Asia are poorly investigated. Previously, we reported a high-resolution, 13,000 record of mineral dust deposition at Neor Lake in NW Iran (Sharifi et al., 2015) that indicated changes in the composition of dust may have occurred during the last deglacial and the Holocene. In this contribution, we investigate this possibility by taking a novel approach of combining the results from paleo-dust grain size analysis with geochemical fingerprinting of modern and paleo-mineral dust using radiogenic Sr–Nd–Hf isotopes and Rare Earth Element (REE) anomalies measured in samples from Neor Lake peat complex. We further use climate simulation experiments to examine how variations in Holocene insolation influenced the dominant atmospheric circulation regimes over the region. We show changes in dust composition and flux in the interior of West Asia were likely coincident with changes in soil coverage across the Afro-Asian dust belt.

2. Materials and methods

2.1. Study site

Neor Lake (37°57′37″ N, 48°33′19″ E) is a high-altitude (∼2,500 m.a.s.l.), seasonally-recharged lake in NW Iran (Fig. 1) and has hosted a peripheral peat complex since at least 13,000 yr ago (Sharifi et al., 2015). The mean annual precipitation (30-yr average) recorded at the nearest meteorological station, 50 km to the north east of the lake at 1,332 m.a.s.l., exceeds 300 mm. Mean annual temperature at the station is 15.4 °C and the mean maximum and minimum temperatures of the warmest and coldest months of the year are 25 °C (July) and −7.9 °C (January), respectively. It is expected that Neor Lake experiences higher annual precipitation and lower temperature relative to the weather station since its elevation is 1,200 m higher than the station.

2.2. Sampling

A total of 41 samples with masses of about 1 g were taken from high and low dust intervals based on the XRF elemental profiles of a 7.5 m core from Neor Lake's peripheral peat complex (Sharifi et al., 2015). The samples span the last 13,000 yr according to 19 calibrated radiocarbon dates (Sharifi et al., 2015). Modern dust samples were collected upwind of Neor site at Abadan and Sar Pol Zahab meteorological stations (Fig. 1) from December 2011 to May 2012 using a Low Volume (LVS) Microcomputer Controlled Air Sampler (Micro PNS) at a rate of 2.3 cubic meters per hour for 168 h (Ahmady-Birgani et al., 2015).

2.3. Radiogenic Sr–Nd–Hf isotope and the REE analyses

Dried samples were homogenized in an agate mortar and ashed at 750 °C for one hour. Approximately 0.015 to 0.035 g was fused