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Hydroclimate variability in the Nile River Basin during the past 28,000 years

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ABSTRACT

It has long been known that extreme changes in North African hydroclimate occurred during the late Pleistocene yet many discrepancies exist between sites regarding the timing, duration and abruptness of events such as Heinrich Stadial (HS) 1 and the African Humid Period (AHP). The hydroclimate history of the Nile River is of particular interest due to its lengthy human occupation history yet there are presently few continuous archives from the Nile River corridor, and pre-Holocene studies are rare. Here we present new organic and inorganic geochemical records of Nile Basin hydroclimate from an eastern Mediterranean (EM) Sea sediment core spanning the past 28 ka BP. Our multi-proxy records reflect the fluctuating inputs of Blue Nile versus White Nile material to the EM Sea in response to gradual changes in local insolation and also capture abrupt hydroclimate events driven by remote climate forcings, such as HS1. We find strong evidence for extreme aridity within the Nile Basin evolving in two distinct phases during HS1, from 17.5 to 16 ka BP and from 16 to 14.5 ka BP, whereas peak wet conditions during the AHP are observed from 9 to 7 ka BP. We find that zonal movements of the Congo Air Boundary (CAB), and associated shifts in the dominant moisture source (Atlantic versus Indian Ocean moisture) to the Nile Basin, likely contributed to abrupt hydroclimate variability in northern East Africa during HS1 and the AHP as well as to non-linear behavior of hydroclimate proxies. We note that different proxies show variable gradual and abrupt responses to individual hydroclimate events, and thus might have different inherent sensitivities, which may be a factor contributing to the controversy surrounding the abruptness of past events such as the AHP. During the Late Pleistocene the Nile Basin experienced extreme hydroclimate fluctuations, which presumably impacted Paleolithic cultures residing along the Nile corridor.

1. Introduction

The paleoclimate history of the Nile River valley in East Africa is of interest due to its rich history of human occupation (Vermeersch and Van Neer, 2015). Relationships between climate and the distribution of settlements on the Nile River corridor have long been recognized and it is hypothesized that extreme changes in African hydroclimate helped shape the growth and led to the decline of numerous complex societies (Kuper and Kröpelin, 2006). One of the most dramatic changes in North African hydroclimate, the so-called African Humid Period (AHP) (de Menocal et al., 2000), occurred during the early Holocene when increased rainfall allowed vegetation, lakes and human populations to occupy a "green Sahara", a region that today is a hyperarid desert (Kuper and Kröpelin, 2006). Variability in Nile River flow also played an important role in shaping Egypt's civilizations with the collapse of the Old Kingdom at 4160 yr before present, attributed to a 30 yr absence of annual Nile flooding (Stanley et al., 2003). Although lacking direct evidence, it is hypothesized that HS1, which is recognized as an extreme and widespread drought in North Africa, also had a major impact on Paleolithic cultures (Stager et al., 2011).

Previous investigations of North African hydroclimate since the Last Glacial Maximum (LGM) have documented abrupt and extreme hydrological fluctuations as well as considerable temporal and spatial heterogeneity. The timing and duration of the AHP varies with latitude (e.g. Kuper and Kröpelin, 2006) with sites in

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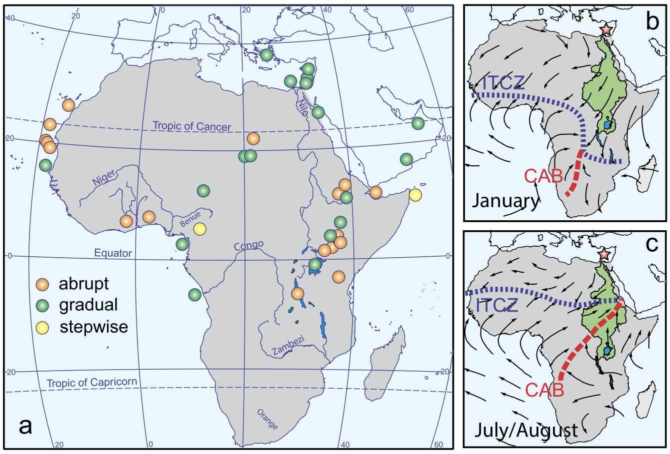

Fig. 1. a) The termination of the early Holocene Humid Period in North Africa. The colored circles indicate sites where the transition out of the African Humid Period is observed to be abrupt (orange), gradual (green) or stepwise (yellow). Note that the study locations depicted by the dots are approximate and in some cases have been shifted slightly where dots overlapped. See the Supplementary Material for the full list of sites and references. b and c) Mean surface winds over Africa in January and July/August. The locations of the Intertropical Convergence Zone (ITCZ) and Congo Air Boundary (CAB) are illustrated. In b and c, the Nile River catchment is indicated by the area outlined in green and the orange star indicates the location of sediment core GeoB7702-3.

the north experiencing a shorter humid phase and earlier termination than sites in the south (Shanahan et al., 2015), following changes in northern hemisphere summer insolation. However, whether the transitions leading into and out of the AHP were abrupt, gradual or stepwise (Fig. 1) remains a highly debated issue (e.g. Kuper and Kröpelin, 2006; Costa et al., 2014; de Menocal et al., 2000; Kuhlmann et al., 2004; Schefuß et al., 2005; Tierney and de Menocal, 2013; Tierney et al., 2008; McGee et al., 2013; Junginger et al., 2014; Weldeab et al., 2014; Marshall et al., 2011; Kutzbach and Street-Perrott, 1985; Claussen et al., 1999). In East Africa, the role of non-linear biogeophysical climate feedbacks is also debated with recent studies concluding that non-linear biogeophysical climate feedbacks between precipitation and vegetation are absent (Weldeab et al., 2014), that a non-linear convection feedback associated with Indian Ocean SST could be an important contributor to rainfall variability (Tierney and de Menocal, 2013), or that a non-linear change in vegetation and sediment erosion occurred in the Early Holocene without a significant decrease in precipitation (Blanchet et al., 2014).

Presently, a gap in our understanding of North African hydroclimate stems from a lack of continuous archives in the vast Nile River corridor (Bard, 2013), which spans 35 degrees of latitude (4°S to 31°N) over its ca. 6670 km course and has a catchment of nearly 3 million km^2. Here, we investigate the spatially integrated temperature and hydroclimate history of the Nile River Basin by examining the geochemistry of a sediment core collected from the Eastern Mediterranean (EM) Sea that receives sediment from the Nile River. We measured multiple organic and inorganic geochemical parameters on the same samples to provide a robust assessment of past hydroclimate variability and to examine shifts in the dominant sources of material transported by the Nile River to the EM Sea. We focus the discussion on two extreme and contrasting hydroclimate events: Heinrich Stadial (HS) 1, an arid interval driven by an abrupt external forcing, and the AHP, a wet period driven by gradual changes in insolation. We note that the term abrupt is used qualitatively in many paleoclimate studies; for the purpose of this study we consider an event as abrupt if its onset or termination occurs in 1000 yr or less.

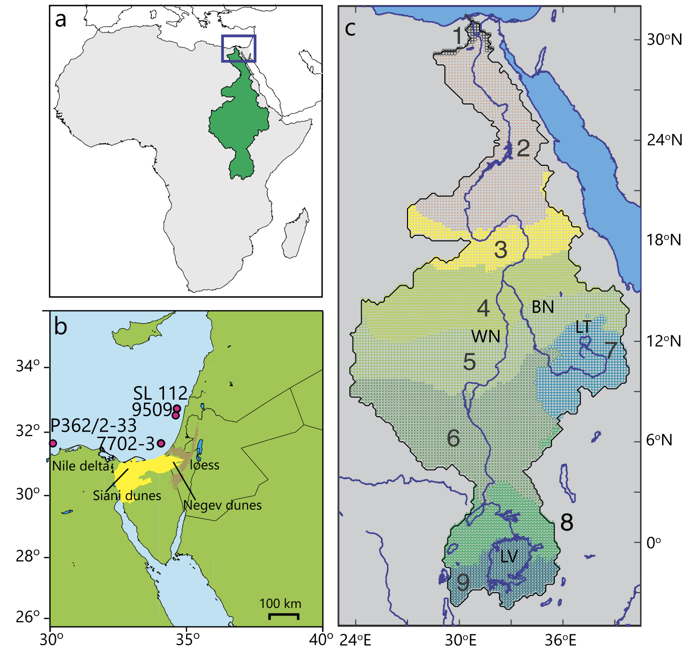

Fig. 2. a) Location of core GeoB7702-3 in the Eastern Mediterranean Sea. The blue box denotes the area expanded in b) and the green shaded area indicates the catchment of the Nile River. b) Close up of the location of core GeoB7702-3. The approximate locations of cores P362/2-33 (Blanchet et al., 2014), core 9509 (Box et al., 2011) and SL 112 (Weldeab et al., 2014) are also shown. The approximate locations of the Sinai/Negev dunes and loess are indicated by the yellow and brown shading, respectively. c) Precipitation regimes within the Nile River catchment are indicated by colors and numbers. The figure is modified from Camberlin (2009). The location of the Blue Nile (BN), the White Nile (WN), Lake Tana (LT), and Lake Victoria (LV) are indicated. From north to south, zone 1 in the northernmost part of Egypt receives winter rains from the Mediterranean; highest rainfall in January amounts to 11 mm per month. Hereafter, the precipitation numbers provided represent the maximum monthly precipitation for each particular zone and the data derives from Camberlin (2009). Zone 2 receives almost no precipitation throughout the year while zone 3 captures the northernmost part of the summer rainfall peak in August (27 mm). Zones 4 and 5 also experience maximum rainfall in August with zone 5 receiving more precipitation (169 mm) than zone 4 (92 mm). Continuing to the south, zone 6 in southern Sudan experiences a longer rainy season with maximum precipitation noted in August (183 mm). Zone 7 western Ethiopia is similar to zone 6 but sees maximum precipitation in July (301 mm) and August. Equatorial zones 8 and 9 experience two yearly passages of the ITCZ and hence two rainy seasons in April (206 mm for zone 9) and November. For information regarding total annual precipitation within the Nile catchment the reader is referred to Camberlin (2009).

2. Study location

Sediment core GeoB7702-3 was collected from the continental slope offshore Israel (31°39.1′N, 34°04.4′E, 562 m water depth) during R/V Meteor cruise M52/2 in 2002 (Fig. 2) (Pätzold et al., 2003). The chronology of this 592 cm long core, which spans the past 28,000 yr before present (hereafter 28 ka BP), is based on 15 AMS ^{14}C dates on foraminifera and was previously published along with alkenone and TEX$_{86}$ sea surface temperature (SST) estimates (Castañeda et al., 2010). The surface currents flow in an anticlockwise direction around the basin and sediment from the Nile River is transported eastward to the coring site (Weldeab et al., 2002).

Precipitation over the Nile Basin derives from both Atlantic and Indian Ocean sources (Gimeno et al., 2010). Total annual precipitation within the Nile Basin fluctuates widely (Fig. 2) related to the varying geographical influence of the Intertropical Convergence Zone (ITCZ), marking the convergence of the northeast and southwest trade winds, and the Congo Air Boundary (CAB), separating Atlantic and Indian Ocean sourced moisture (Camberlin, 2009) (Fig. 1). In boreal summer when the ITCZ is at its northernmost position, the CAB is at its most northerly and easterly extent,