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North-African paleodrainage discharges to the central Mediterranean during the last 18,000 years: A multiproxy characterization

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ABSTRACT

Using elemental geochemistry, clay mineralogy, grain size end-member modeling, and planktonic foraminiferal $\delta^{18}O$, we characterize the provenance of central-Mediterranean sediments over the past 18 ka. The provenance is dust-dominated before and after the African Humid Period (AHP). By contrast, during the AHP (~11–5 ka), largely concurrent with organic-rich sapropel S1 formation, it is predominantly riverine from North-African sources. Such fluvial supply is suggested to come from paleodrainage networks that were reactivated by intensified monsoon precipitation during the AHP. The supply is characterized by high Mg/Al and smectite contents, and has been accompanied by considerable freshwater influx, as indicated by the enhanced grain size and lighter foraminiferal $\delta^{18}O$. The clay-mineral assemblages in our core and in nearby cores correspond with a provenance from the Libyan-Tunisian margin, mainly via the paleo-river Irharhar. The inferred fluvial discharge is strongest during the late-AHP (~8–5.5 ka), coinciding with reported enhanced fluvial dynamics and wettest conditions over western Libya and Tunisia/Algeria. This period is not only synchronous with the largest extension of open-water bodies in North Africa and lowest Saharan dust inputs, but also consistent with precipitation records of the West-African monsoon. Moreover, our records show a remarkable correspondence with that of a paleodrainage system towards the Atlantic West-African margin, inferring a common headwater region in the central Saharan mountains, and a similar climate mechanism. Taken together, we suggest a dominant control of North-African humid surfaces on the paleodrainage delivery, modulated by groundwater level, in response to the insolation-driven West-African monsoon precipitation.

1. Introduction

In North Africa, a humid episode occurred between ~11 and 5 ka cal. BP (hereafter referred to as "ka"), which led to the development of a savannah-type vegetation cover and extensive fluvial networks over the presently hyperarid Saharan desert (e.g. Hoelzmann et al., 1998; Jolly et al., 1998; Drake et al., 2011; Lézine et al., 2011; Armitage et al., 2015). This so-called African Humid Period (AHP; c.f. deMenocal et al., 2000) not only had a major influence on the settlement of Neolithic communities (e.g. Kuper and Kröpelin, 2006; Drake et al., 2011; Manning and Timpson, 2014; Timmermann and Friedrich, 2016), but also resulted in enhanced fluvial discharge to the surrounding ocean margins, such as the equatorial Atlantic (Schefuβ et al., 2005; Weldeab et al., 2007), western Sahara (Zühlsdorff et al., 2007; Tjallingii et al., 2008; Niedermeyer et al., 2010; Skonieczny et al., 2015), and north-eastern Africa (Almogi-Labin et al., 2009; Hennekam et al., 2014, 2015; Weldeab et al., 2014). Such enhanced freshwater influx to the eastern Mediterranean Sea (EMS) stimulated density stratification of the water column and was associated with higher productivity in the surface water. This ultimately caused deep-water stagnation and a basin-wide formation of the most-recent organic-rich unit, sapropel S1 (~10.8–6.1 ka) (Rohling, 1994; De Lange et al., 2008; Grimm et al., 2015; Filippidi et al., 2016). It is well understood that humid climatic conditions such as those during the AHP occurred repeatedly, in response to boreal precessional insolation

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maxima, associated with the strengthening of the African monsoon and the northward migration of the Intertropical Convergence Zone (ITCZ). This resulted in the rhythmic occurrence of sapropel units over the EMS (Rossignol-Strick et al., 1982; Tuenter et al., 2003; Zhao et al., 2012; Rohling et al., 2015).

Nevertheless, the exact mechanisms and sources for fluvial delivery and related changes are still insufficiently known. The monsoon-fed Nile discharge has been reported as the major freshwater source during sapropel formation (e.g. Rossignol-Strick et al., 1982; Freydier et al., 2001; Revel et al., 2010; Zhao et al., 2012; Hennekam et al., 2014). Increased precipitation and associated runoff from the Northern Borderlands of the Eastern Mediterranean (NBEM) may also constitute a considerable input (e.g. Kallel et al., 1997; Zanchetta et al., 2007; Magny et al., 2013). However, the potential fluvial contribution from the wider North-African margin is largely unknown.

At sapropel times, intensified monsoon precipitation could reactivate North-African fossil river/wadi systems (presently buried beneath sand dunes), transporting substantial amounts of detrital material and freshwater to the EMS. This scenario has been proposed for sapropel S5 (i.e. MIS 5e, ~125 ka) based on planktonic foraminiferal $\delta^{18}O$, indicating a northward shift of the ITCZ beyond the central Saharan watershed at ~21°N (Rohling et al., 2002, 2004). The inferred runoff from the Saharan mountains is also reflected in Nd isotopes of planktonic foraminifera at the same site, ODP971, off NE Libya (Osborne et al., 2008, 2010) (Fig. 1). Moreover, satellite mapping (Paillou et al., 2009, 2012) as well as paleohydrological and hydraulic modeling (Coulthard et al., 2013) have revealed the existence of paleodrainage networks. These routes into the EMS may have rivaled the Nile runoff in magnitude (Scrivner et al., 2004) and functioned for a majority of Quaternary sapropels (e.g. S1: Krom et al., 1999b; Freydier et al., 2001; S6: Emeis et al., 2003). This hypothesis is also supported by derived dust variations over the past 3 Ma (Larrasoaña et al., 2003, 2013). A similar case has been found off West Africa. The findings of a large submarine canyon (Krastel et al., 2004; Antobreh and Krastel, 2006), deposition of river-borne material (Zühlsdorff et al., 2007; Tjallingii et al., 2008), and the associated subaerial paleodrainage system Tamanrasett (Vörösmarty et al., 2000; Skonieczny et al., 2015) have revealed recurrent fluvial discharge to the Atlantic margin during late-Quaternary sapropel periods (core GeoB7920) (Fig. 1).

Based on Sr and Nd isotopes and supported by major elements, Wu et al. (2016) recently demonstrated that such a scenario occurred also for the Holocene sapropel S1. However, several critical issues about the North-African fluvial contribution remain elusive. Their geochemical and mineralogical composition has not been specified. The transport processes are also unknown: what/how the depositional environment was and whether the detrital supply was accompanied by considerable freshwater inputs. In particular, the origin of such paleodrainage discharge is not clear. With three major paleodrainage systems identified, Coulthard et al. (2013) suggested that the Irharhar flowing over the central Sahara represents the most likely route for human migration out of Africa. Although the Irharhar is mostly non-discharging under the present climate regime, it has been recognized as a large (paleo) river system in the world (Vörösmarty et al., 2000). Moreover, fluvial evidence has been widely inferred from lake and cave deposits as well as anthropogenic sequences over its headwater region (Cremaschi and Zerboni, 2009; Drake et al., 2011; Zerboni et al., 2015). By contrast, the presently buried fluvial networks over eastern Libya (i.e. Kufrah and Sahabi), as revealed by satellite imagery (Paillou et al., 2009, 2012), are reported to be the potential primary deliverers during sapropel S5 deposition (Rohling et al., 2002, 2004; Osborne et al., 2008, 2010) (Fig. 1).

To shed light on this gap in our knowledge, a multiproxy study – coupling major elements, clay minerals, grain-size distribution, and $\delta^{18}O$ of planktonic foraminifera – is employed to distinguish and characterize the terrigenous detrital supplies to the Libyan-Tunisian margin during the last 18 ka. Elemental geochemistry and clay mineralogy of marine sediments have been widely used to track changes in detrital supply over the circum-Mediterranean (Bout-Roumazeilles et al., 2007; Scheuvens et al., 2013; Martinez-Ruiz et al., 2015; and references therein). The end-member modeling technique of Weltje (1997) applied to grain-size distributions is a powerful tool for unmixing of different components in detrital sediments (e.g. Stuut et al., 2002; Hamann et al., 2008; Tjallingii et al., 2008; McGee et al., 2013). Planktonic foraminiferal $\delta^{18}O$ data can indicate freshwater input (e.g. Kallel et al., 1997; Rohling et al., 2002; Hennekam et al., 2014, 2015). In comparison with published results from other core-sites (Fig. 1), we not only constrain the variability of detrital supplies into the central Mediterranean Sea, but also give new insights in the fluvial discharge from the North-African margin, with implications for the mechanism controlling the paleodrainage delivery.

2. Material and methods

Cores CP10BC and CP11PC were collected at the same site (34°32.7′N, 16°34.0′E; 1501 m water-depth) in the SE Ionian Sea, central Mediterranean, during the RV *Pelagia* CORTADO cruise in 2011 (Fig. 1). This site is strategically located at the Libyan-Tunisian slope, underneath the eastward pathway of surface waters, thereby offering a sensitive monitor for the North-African fluvial discharge (Fig. 1a). The 35.5-cm long boxcore CP10BC was sampled every 0.25 cm for geochemical and grain-size analyses, and every 0.5 cm for clay mineral and foraminiferal studies. The description and sampling of core CP10BC was given in Wu et al. (2016). For obtaining the whole sapropel S1 related interval, piston core CP11PC (total length: 10.8 m) was sliced at 0.5 cm intervals for the upper 50 cm. The two cores were correlated using absolute radiocarbon dates and the well-established criteria of sapropel S1 boundaries (10.8–6.1 ± 0.5 ka) (De Lange et al., 2008; see Supplementary material). Hereafter, these combined cores from the same site are referred to as "core CP10/11".

The chronology for core CP10/11 was developed by means of 8 radiocarbon dates on mixed planktonic foraminifers, and 9 measurements of ^{210}Pb and ^{137}Cs on sediment samples. Around 15 mg of mixed planktonic foraminifera (*G. ruber* and *G. sacculifer*) in the 150–600 μm fractions was picked for ^{14}C analyses at the Poznan Radiocarbon Laboratory (Table 1). Inventories and activities of ^{210}Pb and ^{137}Cs on bulk sediments were determined via gamma spectrometry at ENEA, La Spezia (c.f. Barsanti et al., 2011), indicating that the age of CP10BC core-top can be assessed as the present-day (see Supplementary material). Taken together, linear interpolations between the tie-points result in a highly consistent depth-age curve with a basal age of ~18 ka for the sampled CP10/11 intervals (see Supplementary material).

Stable isotopes were analyzed on the sea-surface dwelling foraminifera *G. ruber* (white) (Hennekam et al., 2014). Clean and intact tests were picked from the 250–300 μm size range. Approximately 20–80 μg of foraminifera (i.e. 2–5 shells) was analyzed with a Kiel-III carbonate preparation device connected to a Finnigan MAT-253 mass spectrometer. The average standard deviation for $\delta^{18}O$ is 0.08‰, based on the regular measurements of duplicates and the NBS-19 standard. The *G. ruber* $\delta^{18}O$ ($\delta^{18}O_{ruber}$) values are reported in per mil (‰) relative to the Vienna PeeDee Belemnite (VPDB).

Following the protocol in Van Santvoort et al. (1996), freeze-dried, powdered bulk sediments were decarbonated by shaking in 1 M HCl for 4 + 12 h. Subsequently, the residues were rinsed