Quaternary Science Reviews 57 (2012) 58–70

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

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

Reconstructing precipitation changes in northeastern Africa during the Quaternary by clay mineralogical and geochemical investigations of Nile deep-sea fan sediments

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A R T I C L E I N F O

Article history:
Received 19 July 2012
Received in revised form
5 October 2012
Accepted 8 October 2012
Available online 31 October 2012

Keywords:
Clay minerals
Eastern Mediterranean Sea
Nile deep-sea fan
North Africa
Precipitation
African monsoon
Saharan dust

A B S T R A C T

Clay mineralogy combined with high-resolution element geochemistry of core MD90-9064, located in the distal part of the Nile deep-sea fan (Levantine Basin), have been investigated to reconstruct rainfall changes in northeastern Africa during the Quaternary and to determine possible climatic controls. Clay minerals of core MD90-964 are derived mainly from three sedimentary sources (the Sahara, Nile River and Egyptian wadis) and are characterized by contrasted mineralogical composition. Variations in illite content and logarithm ratios of *Si/Al* and *K/Al* permit the tracking of eolian input from Sahara to the Mediterranean Sea. It is suggested that precipitation changes in the Sahara are mainly dominated by glacial–interglacial cycles. Such variations are owing to a shift of climatic conditions in the North Atlantic from a NAO-positive-like condition in glacial times to a NAO-negative-like condition in interglacial times. Fe content in the Levantine sediments is mostly derived from Fe-bearing heavy minerals brought by the Nile River. Therefore, variations of *Fe/Al* ratios can be used to establish precipitation changes in the Nile River basin. Long-term variation in precipitation in the Nile River basin is governed by precessional and eccentricity signals, implying that the African monsoon is the most significant controlling factor for precipitation changes in this region. Precipitation changes in the northeastern coasts of Africa are reconstructed using kaolinite contents provided by the Egyptian wadis. It is reported that precipitation in coastal northeastern Africa is mainly of the Mediterranean-climate type. Long-term variations in rainfall in this region are also affected by the NAO-like climatic variability and thus dominated by the glacial –interglacial cycles.

1. Introduction

Annually, huge amounts of sediments are transported from the North African continent to the eastern Mediterranean Sea by permanent rivers and dust-bearing winds. Those sediments have well documented climate variability in North Africa, particularly due to changes of precipitation in the catchment of the Nile River and changes in aridity in the Sahara Desert (e.g. Foucault and Stanley, 1989; Wehausen and Brumsack, 1999, 2000; Foucault and Mélières, 2000; Calvert and Fontugne, 2001; Revel et al., 2010). Therefore, a great number of studies have been performed on terrigenous sediments from deep-sea cores (Cita et al., 1977; Maldonado and Stanley, 1981; Aksu et al., 1995; Brumsack and Wehausen, 1999; Wehausen and Brumsack, 1999, 2000; Foucault and Mélières, 2000; Calvert and Fontugne, 2001; Roussakis et al., 2004; Anastasakis, 2007; Ehrmann et al., 2007; Hamann et al., 2009), surface and core-top sediments (Venkatarathnam and Ryan, 1971; Maldonado and Stanley, 1981; Stanley et al., 1998; Sandler and Herut, 2000; Bayhan et al., 2001), borderland riverine or delta sediments (Weir et al., 1975; Stanley and Liyanage, 1986; Foucault and Stanley, 1989; Abu-Zeid and Stanley, 1990; Abdel Wahab and Stanley, 1991; Stanley and Wingerath, 1996; Stanley et al., 1997; Revel et al., 2010), and eolian dust samples (Chester et al., 1977; Tomadin et al., 1984; Wilke et al., 1984; Caquineau et al., 1998, 2002) in the eastern Mediterranean region in order to investigate the potential links between terrigenous sediments and climate changes in North Africa. These studies have greatly enriched our knowledge on (1) provenance and mineralogical compositions of terrigenous sediment in the eastern Mediterranean basin, (2)

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0277-3791/$ – see front matter
http://dx.doi.org/10.1016/j.quascirev.2012.10.009

changes in the contribution of different sediment sources, and (3) climate variability in adjacent continents, especially changes in the intensities of the subtropical African monsoon. It is suggested that climate variability in North Africa is strongly affected by variability of the subtropical African monsoonal system (Almogi-Labin et al., 2009; Rohling et al., 2009), with elevated precipitation in the Nile catchment (Revel et al., 2010) and decreased dust production in the Sahara (Larrasoaña et al., 2003) observed during monsoonal maxima. However, it is reported that climate changes in North Africa can also be greatly affected by glacial–interglacial oscillations of the Pleistocene (Rohling et al., 2009), which are closely related to climatic processes in the northern hemisphere high-latitudes. Nevertheless, up to now few continuous terrigenous sediment records in the eastern Mediterranean basin could cover a long-enough time interval of the Pleistocene that permit us to decipher the influences of both the African monsoonal system and the major Pleistocene glacial–interglacial oscillations on climate variability in North Africa. The existing records are either dedicated to relatively short intervals of the late Quaternary (Cita et al., 1977; Aksu et al., 1995; Calvert and Fontugne, 2001; Roussakis et al., 2004; Anastasakis, 2007; Ehrmann et al., 2007; Hamann et al., 2008, 2009; Revel et al., 2010) or specific intervals in the Pliocene (Brumsack and Wehausen, 1999; Wehausen and Brumsack, 1999, 2000; Foucault and Mélières, 2000). In this study, we report for the first time a continuous terrigenous record of the last 1.75 Myr from the southeastern Mediterranean Sea (Levantine Basin) with the aim of reconstructing precipitation changes in northeastern Africa. The potential links of precipitation changes in northeastern Africa with variations of the African monsoon and other climatic processes, such as the glacial–interglacial cycles and mid-Pleistocene climatic transition (MPT) are discussed.

2. Environmental settings

2.1. Climatic conditions

Climate in North Africa exhibits a broadly latitudinal distribution pattern with varying precipitation. Climate in the northern Africa coastal area is generally of the Mediterranean type, receiving most of its precipitation during winter from westerly cyclonic disturbances. In summer, this region is dominated by the subtropical high, making rainfall unlikely except for occasional thunderstorms. Further inland to the south where the subtropical high dominates throughout the year, the climate is very arid. In spring and early summer, local low pressure centres (usually called *Sharav* cyclones) can form in the western part of the Sahara as a result of the strong thermal contrast between cold Atlantic water and warm continental surfaces (Alpert et al., 1990). The *Sharav* cyclones usually move eastward along the North African coast and finally cross the eastern Mediterranean basin between Libya and Egypt (Alpert and Ziv, 1989). Further south, climate is controlled by the seasonal migration of the InterTropical Convergence Zone (ITCZ) in response to the changes in the location of maximum solar heating (Fig. 1a; Gadgil and Sajani, 1998; Camberlin et al., 2001). Rainfall pattern in the region is usually "monsoonal" – characterized by summer floods and winter drought. As long-term changes of the boreal summer insolation (JJA) is modulated by the precessional cycles, the intensities and location of monsoonal precipitation trough times in North Africa are characterized by strong precessional cycles (Tuenter et al., 2003). The African monsoon generally responds to the maxima of boreal summer insolation with a 3000-year lag (Lourens et al., 1996; Ziegler et al., 2010). During the maxima of boreal summer insolation (with a 3000-year lag), both amplitudes and extents of African monsoon precipitation are greatly enhanced, leading to the intermittent deposition of the dark, often laminated, organic-rich layers, called sapropels, between normal deep-sea marls in the Mediterranean Sea (Rossignol-Strick, 1985) and the expansion of vegetation cover in the Sahara (Brovkin et al., 1998; Claussen et al., 1998).

2.2. Sediment supply to the Levantine Basin

Terrigenous input to the eastern Mediterranean basin is generally a comparatively simple two "end-member" mixing system between fluvial sediments from the Nile River and eolian dust from the Sahara (Venkatarathnam and Ryan, 1971; Krom et al., 1999; Weldeab et al., 2002). As for the Levantine Basin, the easternmost sector of the eastern Mediterranean basin, terrigenous input is dominated by fluvial sediments from the Nile (Venkatarathnam and Ryan, 1971; Krom et al., 1999; Wehausen and Brumsack, 1999, 2000; Calvert and Fontugne, 2001; Weldeab et al., 2002; Hamann et al., 2009; Revel et al., 2010; Padoan et al., 2011). Prior to the completion of the High Dam at Aswan in 1964, the Nile River discharged 57×10^6 tons/year of sediment into the eastern Mediterranean basin, most of which accumulated in the Levantine Basin (Hurst, 1952; Williams et al., 2006). It is estimated that up to 90% ($\sim 55 \times 10^6$ tons/year) of the Nile sediment is provided by the Blue Nile and the Atbara River, both originating in the Ethiopian Highlands (Williams et al., 2006). The White Nile, which originates in the African Great Lakes Region (Fig. 1a), provides only about 10% ($\sim 2 \times 10^6$ tons/year) of total suspended sediments (Williams et al., 2006). Despite the huge sediment load, both the Blue Nile and the Atbara River are highly seasonal rivers, with the overwhelming majority of sediment discharge transported by the annual summer floods (Hurst, 1952). Because the occurrence of summer floods in the Ethiopian Highlands is highly dependent on the intensities of African monsoon precipitation (Said, 1981; Williams et al., 2000), variations of the Nile sediment discharge are closely related to the intensities of African monsoon precipitation. The Nile is also fed by a series of ephemeral rivers in northern Egypt during winter. These rivers, usually called wadis, provide the Nile with additional runoff and sediments only during rainy seasons. Compared to sediments brought from its main tributaries, sediments from these wadis are of minor importance to sediment discharge of the Nile (Stanley and Wingerath, 1996; Stanley et al., 1997; Sandler and Herut, 2000).

Eolian dust from the Sahara is also an important source for terrigenous sediments in the eastern Mediterranean basin. Annually, about 20×10^6 tons of dust is deposited in the Levantine Basin sector (Ganor and Mamane, 1982), although the total dust influx to the whole eastern Mediterranean basin can reach $\sim 100 \times 10^6$ tons/year (Ganor and Foner, 1996). The most frequent source for Saharan dust reaching the Levantine Basin is central-southern Algeria (Ganor et al., 1991). It is observed that eastward delivery of Saharan dust to the Levantine Basin usually accompanies the eastward passage of the *Sharav* cyclones and occurs predominantly during spring (Dayan et al., 1991; Moulin et al., 1998). Passage of the *Sharav* cyclones can also transport some dust from the Libyan and Egyptian deserts into the eastern Mediterranean Sea. The Levantine Basin is, to some extent, also affected by dust brought from the Middle East in autumn. Analyses of heavy dust storms in Israel during a 22 year period (1967–1988), however, suggest that dust storms originating in the Middle East are much less frequent than those originating in the Sahara (Ganor et al., 1991).

3. Material, methods and age model

Core MD90-964 (33°02.75′N, 32°38.57′E; water depth 1375 m; 32.12 m in length) was collected on the distal part of the Nile deep-sea fan in the eastern Levantine Basin (Fig. 1b) during the PROMETE III research campaign of the R/V Marion Dufresne in September 1990. The core was retrieved from a deep-sea basin that is well