Quaternary Science Reviews 78 (2013) 22–33

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

A 7500-year strontium isotope record from the northwestern Nile delta (Maryut lagoon, Egypt)

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ARTICLE INFO

Article history:
Received 3 December 2012
Received in revised form
19 June 2013
Accepted 22 June 2013
Available online

Keywords:
$^{87}Sr/^{86}Sr$
Ostracods
Nile
Delta
Mediterranean
Palaeohydrology
Holocene
African Humid Period
Alexandria

ABSTRACT

During the Holocene, delta evolution has been collectively mediated by relative sea-level changes, continental hydrology and human impacts. In this paper, we present a strontium isotope record from the Maryut lagoon (northwestern Nile delta) to quantify the interplay between relative sea-level variations and Nile flow changes during the past 7500 years. $^{87}Sr/^{86}Sr$ stratigraphy allows five hydrological stages to be defined. (1) The marine transgression of the area is dated to ~7.5 ka cal. BP, with a clear marine $^{87}Sr/^{86}Sr$ signature (0.70905–0.7091). (2) Between ~7 and ~5.5 ka, in the context of the so-called African Humid Period (AHP), freshwater inputs became progressively predominant in the Maryut's hydrology. Deceleration of sea-level rise coupled with high Nile discharge induced coastal progradation which led to the progressive closure of the Maryut lagoon. (3) Between ~5.5 and ~3.8 ka, the end of the AHP is translated by a progressive hydrological shift from a Nile-dominated to a marine-dominated lagoon ($^{87}Sr/^{86}Sr$ shifts from 0.70865 to 0.7088 to 0.70905–0.70915). (4) From ~2.8 to ~1.7 ka, $^{87}Sr/^{86}Sr$ ratios shift towards lower values (0.7084). Although this change is not precisely resolved because of a hiatus in the Maryut's sedimentary record, the $^{87}Sr/^{86}Sr$ transition from sea-like to Nile-dominated values is attributed to irrigation practices since the early Ptolemaic period (i.e. since ~2.3 ka), including the Alexandria canal which played a key role in isolating the Maryut from the Mediterranean sea. (5) The final phase of the record covers the period between ~1.7 and ~0.2 ka. $^{87}Sr/^{86}Sr$ ratios indicate high freshwater inputs (from 0.7080 to 0.7085), except between 1.2 and 1.1 to ~0.7 ka, when a Maryut lowstand and seawater intrusion are attested. In modern times, the Nile's coastal lagoons have been increasingly supplied by freshwater linked to the diversion of waters from the two Nile branches into the irrigation system. It is suggested that this process began in early Antiquity and has engendered a reduction in the number of Nile branches from seven in ancient times to just two at present.

1. Introduction

Today, hydrological changes in deltaic settings have important implications for coastal ecosystems, agriculture, fishery activities, freshwater resources and human geographies (Syvitski et al., 2009). With reference to the Nile delta, during the 20th century, river-channel modifications, artificial waterways and a series of dams have diverted around one third of Nile water (Stanley, 1996). Increasing freshwater discharge from the delta's canal system has led to desalinization of the lagoons (Bernasconi and Stanley, 1994), with implications for the management of fisheries. Paradoxically, rising relative sea level (Frihy et al., 2010), coastal erosion (Frihy and Lauwrence, 2004), deltaic subsidence (Becker and Sultan, 2009) and the recycling of sewage water have engendered soil salinization in the northern delta (Kotb et al., 1999). Long-term changes in the coastal hydrology of the Nile delta therefore reflect the complex interplay, at decadal to centennial timescales, between climate forcing, human management and local geomorphological responses.

Past fluctuations in the Holocene water budget provide insights into the drivers and amplitude of hydrological changes on the Nile delta coast. Previous research has described the early Holocene marine transgression of the late Pleistocene alluvial plain (see Stanley and Warne, 1993a; Butzer, 2002). The present Nile coast, characterized by widespread lagoons and marshes behind a nearly continuous coastal sand barrier, began to form at ca 7.5 ka cal. BP,

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http://dx.doi.org/10.1016/j.quascirev.2013.06.018

under the cumulative action of a deceleration in sea-level rise and the rapid influx of sediments (Stanley and Warne, 1993a). Since this time, (1) relative sea-level variations (Stanley and Warne, 1993b; Stanley and Toscano, 2009; Marriner et al., 2012a), (2) changes in Nile discharge and sediment load (Foucault and Stanley, 1989; Said, 1993; Revel et al., 2010, 2013; Williams et al., 2010; Bernhardt et al., 2012; Marriner et al., 2012b; Blanchet et al., 2013) and (3) early irrigation and drainage practices on the delta (Butzer, 1976; Said, 1993; Shaw, 2000), have induced significant water budget changes. To date, however, the coastal water budget has not been quantified for the Holocene period. Previous work has focused upon palaeontological proxies, which only yield qualitative insights into the evolution of the water budget on the Nile coast (Bernasconi and Stanley, 1994; Flaux et al., 2011).

Faunal assemblages in lagoon sediments must be used in conjunction with others indicators to quantify palaeohydrological changes. Reinhardt et al. (1998, 2001) demonstrated that faunal assemblages and the Sr isotopic composition of coastal shells is a reliable proxy to quantify the modern water budget on the Nile coast. In this paper, we adopt the same approach for the Maryut lagoon and look to generate a time series for the mid to late Holocene sequence. This time series helps to quantify the interplay between relative sea-level variations and Nile palaeohydrology in modulating lagoonal water budgets during the last 7500 years.

We selected the Maryut lagoon because: (1) its location at the margin of the delta makes it sensitive to hydrological changes, particularly phases of deltaic extension and retraction; and (2) the lagoon has been a key feature of Alexandria's hinterland economy since Antiquity (Empereur, 1998; Blue and Khalil, 2010; Blue et al., 2011). Its shores accommodated major production centres and the lagoon acted as a gateway to the Nile and the rest of Egypt. Sr isotopic ratios measured in the Maryut's Holocene archives have allowed us to evaluate the climatic, geomorphological and anthropogenic processes that have controlled hydrological modifications in the northwestern Nile delta and the Alexandria region during the last 7500 years.

2. Study site and methods

2.1. Hydrological context

The Maryut lagoon is partially isolated from the sea, behind consolidated late Pleistocene coastal ridges (Fig. 1; El-Asmar and Wood, 2000). An outlet into the sea existed through Abu Qir lagoon (completely drained today, Fig. 1; Flaux et al., 2011) before the completion of the Alexandria canal at least 2000 years ago (Hairy and Sennoune, 2006). Another outlet may have existed through the present-day El Mexx canal (Fig. 1). Nile inflow to the Maryut was supplied by at least two tributaries, linked to the former Canopic branch (Fig. 1; Trampier, 2009; Flaux, 2012). The latter was the westernmost branch of the Nile and has progressively silted up during the past 2000 years (Fig. 1; Toussoun, 1922; Bernand, 1970; Chen et al., 1992; Stanley et al., 2004a; Hairy and Sennoune, 2006). Local precipitation is negligible, given the semi-arid to arid climatic context of the area (Butzer, 2002). The Sr isotopic composition of Maryut ostracods therefore essentially results from a mixing between Nile water and seawater (Fig. 1).

Sr behaves conservatively in estuarine and brackish environments (Ingram and Sloan, 1992; Reinhardt et al., 1998). In contrast to oxygen isotopes, strontium isotopes show no measurable fractionation with temperature or other physical environmental changes (Faure and Powell, 1972; Gosz et al., 1983; Hart et al., 2004; Lance et al., 2011). Biogenic carbonates incorporate Sr in their crystal lattices without any vital effects (Durazzi, 1977; Graustein, 1989; Reinhardt et al., 1999; Holmes et al., 2007) and therefore record the $^{87}Sr/^{86}Sr$ of the water in which they grew. The Sr composition of Nile water ($^{87}Sr/^{86}Sr = 0.706$; $[Sr] = 0.235$ ppm; Brass, 1976; Gerstenberger et al., 1999) is well differentiated from

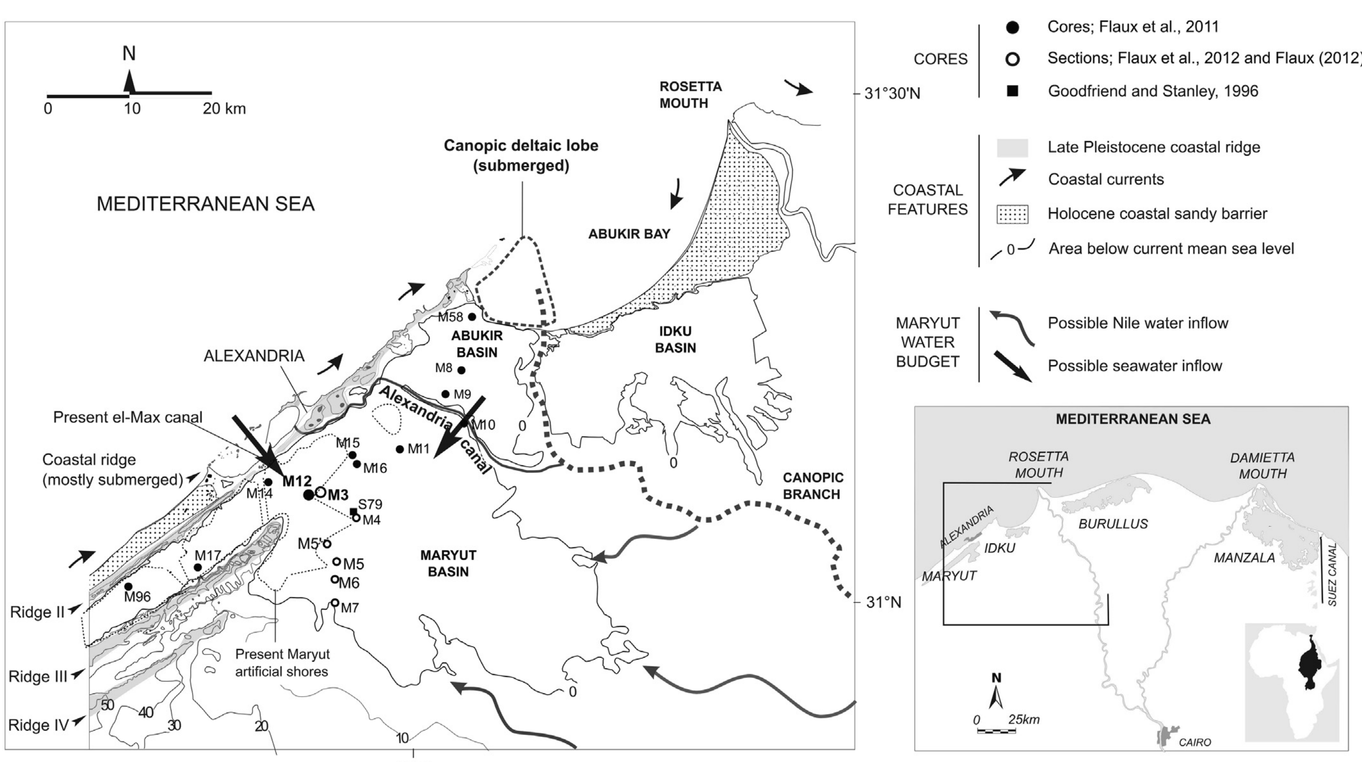

Fig. 1. Location map and main hydro-topographical features of the study area.