Earth and Planetary Science Letters 489 (2018) 166–178

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

The initiation and evolution of the River Nile

Laura Fielding [a], Yani Najman [a,*], Ian Millar [b], Peter Butterworth [c], Eduardo Garzanti [d], Giovanni Vezzoli [d], Dan Barfod [e], Ben Kneller [f]

[a] Lancaster Environment Centre, Lancaster University, Lancaster, UK
[b] British Geological Survey, Keyworth, UK
[c] BP Egypt, Cairo, Egypt
[d] University Milano-Biccoca, Milan, Italy
[e] SUERC, East Kilbride, UK
[f] University of Aberdeen, Aberdeen, UK

ARTICLE INFO

Article history:
Received 9 November 2017
Received in revised form 23 February 2018
Accepted 24 February 2018
Available online 9 March 2018
Editor: D. Vance

Keywords:
River Nile
Nile delta
detrital geochronology
isotopic provenance studies

ABSTRACT

The Nile is generally regarded as the longest river in the world. Knowledge of the timing of the Nile's initiation as a major river is important to a number of research questions. For example, the timing of the river's establishment as a catchment of continental proportions can be used to document surface uplift of its Ethiopian upland drainage, with implications for constraining rift tectonics. Furthermore, the time of major freshwater input to the Mediterranean is considered to be an important factor in the development of sapropels. Yet the river's initiation as a major drainage is currently constrained no more precisely than Eocene to Pleistocene.

Within the modern Nile catchment, voluminous Cenozoic Continental Flood Basalts (CFBs) are unique to the Ethiopian Highlands; thus first detection of their presence in the Nile delta record indicates establishment of the river's drainage at continental proportions at that time. We present the first detailed multiproxy provenance study of Oligocene–Recent Nile delta cone sediments. We demonstrate the presence of Ethiopian CFB detritus in the Nile delta from the start of our studied record (c. 31 Ma) by (1) documenting the presence of zircons with U–Pb ages unique, within the Nile catchment, to the Ethiopian CFBs and (2) using Sr–Nd data to construct a mixing model which indicates a contribution from the CFBs. We thereby show that the Nile river was established as a river of continental proportions by Oligocene times. We use petrography and heavy mineral data to show that previous petrographic provenance studies which proposed a Pleistocene age for first arrival of Ethiopian CFBs in the Nile delta did not take into account the strong diagenetic influence on the samples.

We use a range of techniques to show that sediments were derived from Phanerozoic sedimentary rocks that blanket North Africa, Arabian–Nubian Shield basement terranes, and Ethiopian CFB's. We see no significant input from Archaean cratons supplied directly via the White Nile in any of our samples. Whilst there are subtle differences between our Nile delta samples from the Oligocene and Pliocene compared to those from the Miocene and Pleistocene, the overall stability of our signal throughout the delta record, and its similarity to the modern Nile signature, indicates no major change in the Nile's drainage from Oligocene to present day.

1. Introduction

The Nile is generally regarded as the longest river in the world, stretching >6800 km across the length of north-eastern Africa. Its evolution has been used to date the timing of the region's surface uplift and hence constrain continental break-up tectonics (e.g. Paul et al., 2014). In addition, its runoff is proposed to have had a major influence on sapropel development in the Mediterranean (e.g. Krom et al., 2002; Meijer and Tuenter, 2007) and its delta plays host to a major hydrocarbon producing region. However, despite its clear importance, little is known of the river's evolution through time.

The present-day Nile has three main tributaries: the White Nile, the Blue Nile and the Atbara (Fig. 1). Sediment supplied to the Nile trunk in Egypt is dominated by contributions from the Blue Nile (50–61%) and Atbara (30–42%) (Padoan et al., 2011). The vast majority of White Nile sediment load is trapped in

* Corresponding author.
E-mail address: y.najman@lancs.ac.uk (Y. Najman).

https://doi.org/10.1016/j.epsl.2018.02.031

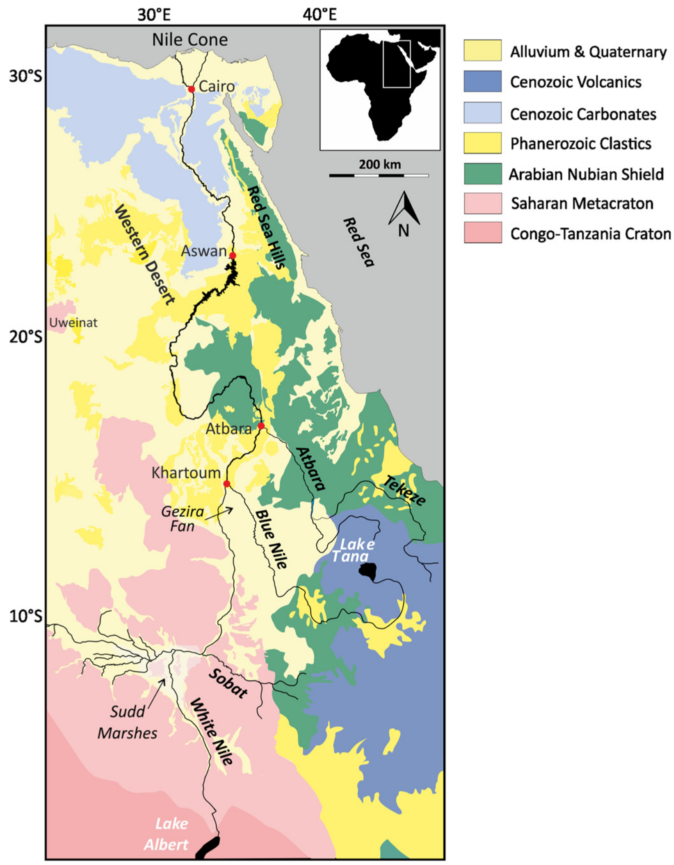

Fig. 1. Geological map of the Nile drainage (modified from Fielding et al., 2017). (For interpretation of the colours in the figure(s), the reader is referred to the web version of this article.)

extensive swamps in South Sudan (the Sudd marshes, Fig. 1), and does not reach the main Nile trunk, thus accounting for <3% of the total sediment reaching the modern delta. Today, detritus supplied to the Nile trunk is derived from the volcanic Ethiopian Highlands, Precambrian basement rocks of the Arabian–Nubian Shield and Saharan Metacraton, and Phanerozoic sedimentary cover that blankets much of the region (Fig. 1), together with a contribution from aeolian sources (e.g. Fielding et al., 2017; Padoan et al., 2011). However, little is known about the past evolution of the Nile River, and the changing influences of tectonics and climate through time (Hamann et al., 2008; Paul et al., 2014; Pik et al., 2003; Woodward et al., 2015). There is no consensus as to when the river first initiated; ages of Oligocene (Gani et al., 2007; Pik et al., 2003) to Pleistocene (Macgregor, 2012; Shukri, 1949/1950) have been proposed for the time the Nile trunk river first drained as far south as the Ethiopian Highlands.

In this paper, we provide a range of analyses from a unique archive of offshore Nile delta sediments aged from 31–0 Ma. We use the data to: i) determine when the Nile river evolved from one of local catchment to a major river of continental proportions; ii) document the evolution of the river through time; iii) discuss the influence of the river runoff on sapropel development; and, iv) provide new evidence constraining the timing of Ethiopian plateau uplift, thus contributing to our understanding of Cenozoic African tectonics.

2. Approach and geological background

In this study, we use sediments from the Nile delta cone as a record of Nile evolution through time. Biostratigraphically dated samples were provided by BP Egypt. We studied samples from the Oligocene between 31 and 27.5 Ma; from the Miocene between 17–15.2 Ma; from the Pliocene between 3.25 to 2.65 Ma; and from the Pleistocene at 1.3 Ma. We carried out isotopic, geochemical, petrographic and heavy-mineral analyses on the Nile delta cone samples in order to identify provenance changes through time. Comparisons are made with published data from potential Nile catchment source regions in the past, and with data from the modern Nile River.

2.1. *The Nile delta cone*

The earliest records of the delta are preserved onshore in Egypt near Fayoum, and have been dated as Eocene (38–35 Ma) (Salem, 1976; Underwood et al., 2013). The delta began to prograde north as the Tethys Ocean receded, depositing in its current offshore location from the Oligocene. Changes in sediment accumulation, composition, facies and architecture (Craig et al., 2011; Gardosh et al., 2009) are interpreted as initiation of major Nile drainage at 30 Ma, but this was not thought to extend as far south as the Ethiopian Highlands (Macgregor, 2012). Sediment accumulation continued in the Mediterranean until the end-Miocene Messinian Salinity Crisis (Dolson et al., 2001), after which the Zanclean flood rapidly filled the Mediterranean basin. An increase in sedimentation rate in the Nile delta cone during the Late Pliocene–Early Pleistocene is proposed by Macgregor (2012) to result from uplift of the Ethiopian Rift shoulders, with associated increased rainfall and erosion.

This study represents the first access to the deep sedimentary archive of the Nile delta for multi-proxy provenance analysis. Previous provenance studies have largely concentrated on the younger Plio-Pleistocene record. Previous mineralogical work (summarised in Macgregor (2012)) recorded a down-core decrease in detritus derived from the Ethiopian Continental Flood Basalts (CFBs), and interpreted this as a provenance signal indicating only a recent connection between the Blue Nile and the main trunk Nile. However, the influence of diagenesis on this record was not considered. Sr–Nd bulk-sample data, complemented by geochemical and/or clay mineralogy analyses, have also been used to assess Nile provenance over the recent geological past (e.g. Freydier et al., 2001; Krom et al., 2002; Revel et al., 2014). These studies inferred mixing between Blue Nile Ethiopian input and White Nile cratonic/Saharan aerosols. Such variations have been ascribed to alternating wetter and drier periods, potentially relating to shifting of the Inter Tropical Convergence Zone, and to climatic episodes such as the Last Glacial Maximum and African Humid Period.

In this study, we present the first detrital zircon U–Pb and Hf-isotope data for samples from the Nile delta cone. We also extend petrographic, heavy-mineral and Sr–Nd data as far back as the Oligocene, thus providing the first long-range provenance study of the delta. In addition to data from the Nile delta cone, we present the first detrital zircon U–Pb and hafnium isotope data for Saharan dune sands, in order to constrain the composition of aeolian input into Nile delta sediments.

2.2. *Geology of the Nile River catchment and hinterland*

The geology of the modern Nile catchment has largely been shaped by the events of the Pan-African Orogeny (Kröner and Stern, 2004), when east and west Gondwana collided to form 'Greater Gondwana' at the end of the Neoproterozoic. In North Africa, this orogeny involved the collision of ancient cratons such as the Congo–Tanzania craton and the Saharan Metacraton with juvenile oceanic island arcs of the Arabian Nubian Shield. Subsequent to that orogeny, erosion of the Trans-Gondwanan mountain belt and recycling of the eroded detritus during later inversion tectonics resulted in the deposition of a thick cover of flu-