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Shifting sediment sources in the world's longest river: A strontium isotope record for the Holocene Nile

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ABSTRACT

We have reconstructed long-term shifts in catchment sediment sources by analysing, for the first time, the strontium (Sr) and neodymium (Nd) isotope composition of dated floodplain deposits in the Desert Nile. The sediment load of the Nile has been dominated by material from the Ethiopian Highlands for much of the Holocene, but tributary wadis and aeolian sediments in Sudan and Egypt have also made major contributions to valley floor sedimentation. The importance of these sources has shifted dramatically in response to global climate changes. During the African Humid Period, before c. 4.5 ka, when stronger boreal summer insolation produced much higher rainfall across North Africa, the Nile floodplain in northern Sudan shows a tributary wadi input of 40–50%. Thousands of tributary wadis were active at this time along the full length of the Saharan Nile in Egypt and Sudan. As the climate became drier after 4.5 ka, the valley floor shows an abrupt fall in wadi inputs and a stronger Blue Nile/Atbara contribution. In the arid New Kingdom and later periods, in palaeochannel fills on the margins of the valley floor, aeolian sediments replace wadi inputs as the most important secondary contributor to floodplain sedimentation. Our sediment source data do not show a measurable contribution from the White Nile to the floodplain deposits of northern Sudan over the last 8500 years. This can be explained by the distinctive hydrology and sediment delivery dynamics of the upper Nile basin. High strontium isotope ratios observed in delta and offshore records – that were previously ascribed to a stronger White Nile input during the African Humid Period – may have to be at least partly reassessed. Our floodplain Sr records also have major implications for bioarchaeologists who carry out Sr isotope-based investigations of ancient human remains in the Nile Valley because the isotopic signature of Nile floodplain deposits has shifted significantly over time.

1. Introduction

Over the last two decades strontium isotope ($^{87}Sr/^{86}Sr$) data have made an increasingly important contribution to research projects seeking to better understanding the Quaternary history of the Nile basin. As far as the fluvial record is concerned, it has often been stated that the Nile is well suited to such studies because the upper reaches of the major tributaries lie in markedly contrasting geological and hydrological settings (Gerstenberger et al., 1997; Krom et al., 2002). The headwaters of the White Nile are formed in ancient crystalline shield rocks (with high $^{87}Sr/^{86}Sr$ ratios) whilst the Blue Nile and Atbara rivers drain the much younger Cenozoic volcanic terrains of the Ethiopian uplands (with much lower $^{87}Sr/^{86}Sr$ ratios). Downstream of the Blue Nile/White confluence at Khartoum, therefore, the isotopic signature of river sediment in the Desert Nile and delta has commonly been viewed as a weighted average of the end-member isotopic signatures of rocks eroded in these upstream drainage basins (e.g. Krom et al., 2002; Padoan

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et al., 2011). Much less consideration, however, has been given to the supply of sediment from windblown dust and from the many thousands of wadis in Sudan and Egypt along the ~2700 km of the Saharan Nile between Khartoum and the delta. These sources of sediment also have distinctive properties but we know very little about their changing contributions to the suspended sediment load and valley floor deposits of the Saharan Nile during the climate changes of the Holocene.

Four broad areas of Nile basin Quaternary research have made use of strontium isotope data and they may be summarised as follows:

1) Studies seeking to gain a better understanding of the long-term evolution of the drainage network – especially the connections between the equatorial lakes and the White Nile headwaters. The abrupt overflow of Lake Victoria around 14.5 ka, for example, was a very significant event during the Late Pleistocene that has been constrained by Sr isotope data in conjunction with radiocarbon dating (Talbot et al., 2000; Williams et al., 2006).
2) A large corpus of work has used Sr isotope data as an indicator of change in Blue Nile/White Nile suspended sediment source contributions to infer long-term shifts in the hydrological regime of the entire Nile basin. This has mainly involved the study of Pleistocene and/or Holocene sedimentary records preserved in the delta (Krom et al., 2002; Stanley et al., 2003; Flaux et al., 2013) and offshore (Revel et al., 2010, 2015; Box et al., 2011; Blanchet et al., 2013).
3) A deeper understanding of the basin-wide pattern of erosion and sediment delivery in the *present-day* drainage system has recently been achieved. Padoan et al. (2011) and Garzanti et al. (2015) have compiled the most comprehensive sediment budget for the contemporary Nile river basin using strontium and neodymium isotopes alongside conventional petrological data for fluvial muds and sands.
4) Finally, a developing field of bioarchaeological research in the Desert Nile is using Sr isotope data in the analysis of human skeletal and dental remains from archaeological sites of various ages in Egypt and Sudan. This work aims to tackle a range of questions about human migration within and beyond the Nile Valley with a recent emphasis on the New Kingdom and later periods (e.g. Buzon et al., 2007; Buzon and Simonetti, 2013).

Despite the success of (1), (2) and (3), there remains a major geographical and temporal gap in our knowledge of the Nile basin because the strontium isotope signature of the Holocene floodplains in the Desert Nile itself, where the great riparian civilizations of Ancient Egypt and Sudan flourished, has not been documented. These data are needed – not only to advance our understanding of how the world's longest river system has responded to global climate change – but also to provide essential reach-specific geological context for (4) since strontium isotope-based investigations of human and animal skeletal remains have typically assumed the $^{87}Sr/^{86}Sr$ ratio of Holocene Nile alluvium to be fixed within a narrow range. This assumption has *not* been rigorously tested through direct investigation of the alluvial floodplains of Egypt and Sudan where these people lived, grew their crops, and watered their animals.

Against this background, this paper presents the first strontium (and neodymium) isotope data for the Holocene river sediment record in the Desert Nile. It has three principal aims:

1) To build upon the well-dated Holocene fluvial records in northern Sudan (Woodward et al., 2001; Williams et al., 2010; Spencer et al., 2012; Macklin et al., 2013) to examine the Sr and Nd isotopic signatures of the river sediment record with a particular focus on the period from 8.0 to 1.0 ka that includes profound cultural, climatic and hydrological change.
2) To examine the composition of the alluvial sedimentary record in a range of depositional contexts in northern Sudan to establish the dominant sediment source shifts during the Holocene – to better understand the behaviour of the world's longest river as the climate shifted from the African Humid Period to the hyper-arid conditions of the last 4500 years.
3) To demonstrate the importance of creating a reference database for the composition of Desert Nile river floodplain deposits for the entire Holocene to facilitate a more meaningful interpretation of the Sr isotopic data obtained from human remains from archaeological excavations in Sudan and Egypt.

2. Sediment sources in the Nile basin

The dominant feature of the hydrology of the present-day Nile is the marked spatial and temporal variability in the flux of water and sediment – expressed most vividly by the summer flood (Fig. 1). The suspended sediment load of the modern Desert Nile in Sudan and Egypt is dominated by sediments transported by the Blue Nile (*c*. 61 ± 5%) and Atbara (*c*. 35 ± 4%) (Padoan et al., 2011). In a typical year, the White Nile accounts for only a very small proportion (3 ± 2%) of the total sediment load despite draining by far the largest of the main tributary catchments (>1,730,000 km^2). The Blue Nile and Atbara drain catchments of *c*. 330,000 and 180,000 km^2 respectively (Table 1). It is clear, therefore, that the present-day Nile sediment system is dominated (typically ≥97%) by fine sediment originating from the Blue Nile and Atbara basins even though, together, they account for just 15% of the total Nile catchment. Much of this sediment load comes from the erodible volcanic highlands of Ethiopia and Eritrea (Fig. 1). During the summer monsoon, these deeply dissected landscapes deliver huge volumes of sediment–charged runoff to the main Nile. The Equatorial headwaters of the White Nile, in contrast, lie in much older and harder rocks, with lower relief, and without marked seasonal fluctuations in vegetation cover and runoff. In addition, a good deal of the sediment load in the White Nile basin is trapped in the lakes region and in the vast wetlands of the Sudd in South Sudan (Fig. 2) (Garzanti et al., 2015; Woodward et al., 2007; Williams et al., 2000). The modern Nile is the world's longest exotic river – today there are no significant tributary inputs downstream of the confluence with the Atbara in northern Sudan (Fig 2.).

A potentially important – but as yet unquantified – component of the fine-grained sediment load of the main Nile is the input from aeolian activity in the desert reaches of Sudan and Egypt along the c. 3000 km of river channel between Khartoum and the Mediterranean Sea. This contribution is much more difficult to quantify because it involves a range of processes that are diffuse in space and time. The input of windblown dust from the vast desert landscapes surrounding the Nile corridor has commonly been overlooked in considerations of the Holocene Nile sediment budget even though there is a good deal of geomorphological and stratigraphical evidence pointing to its importance. It is well known, for example, that windblown dust from the Sahara forms an important component (up to 90%) of the sediment on the floor of the Mediterranean Sea (Krom et al., 1999) and many hundreds of kilometres of river bank in Sudan and Egypt are lined with active aeolian dunes (Fig. 3) (Butzer and Hansen, 1968; Wendorf and Schild, 1976; Said, 1993; Spencer et al., 2012; Vermeersch and Van Neer, 2015). In the vicinity of El-Ugal, for example, in the southern part of the Northern Dongola Reach (Fig. 2), entire dune belts end up in the Nile (Welsby, 2001).