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Geochimica et Cosmochimica Acta 75 (2011) 3627–3644

Geochimica et Cosmochimica Acta

www.elsevier.com/locate/gca

Tracing Nile sediment sources by Sr and Nd isotope signatures (Uganda, Ethiopia, Sudan)

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Received 30 November 2010; accepted in revised form 28 March 2011; available online 3 April 2011

Abstract

Strontium and neodymium isotopes, measured on diverse mud and sand fractions of sediment in transit along all major Nile branches, identify detritus sourced from Precambrian basements, Mesozoic strata, and Tertiary volcanic rocks exposed along the shoulders of the East African rift and in Ethiopian highlands. Sr and Nd isotopic ratios reflect the weighted average of detrital components generated in different catchments, allowing us to discriminate provenance, calculate sediment budgets, and investigate grain-size and hydraulic-sorting effects.

$^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ range, respectively, from as high as 0.722 and as low as 0.5108 for sediment derived from Archean gneisses in northern Uganda, to 0.705 and 0.5127 for sediment derived from Neoproterozoic Ethiopian and Eritrean basements. $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$, ranging 0.705–0.709 and 0.5124–0.5130 for Blue Nile tributaries, are 0.704–0.705 and 0.5127–0.5128 for largely volcaniclastic sediments of River Tekeze–Atbara, and 0.705–0.706 and 0.5126–0.5127 for main Nile sediments upstream Lake Nasser.

Model mantle derivation ages (t_{DM}), oldest in Uganda where sediment is principally derived from the Congo Craton (3.4–3.0 Ga for Victoria and Albert Nile), progressively decrease northward across the Saharan Metacraton, from 2.6 Ga (Bahr el Jebel in South Sudan), to 2.4–2.2 Ga (Bahr ez Zeraf across the Sudd), and finally 1.6–1.3 Ga (White Nile upstream Khartoum). Instead, t_{DM} ages of Sobat mud increase from 0.9 to 1.5 Ga across the Machar marshes. T_{DM} ages are younger for sediments shed by Ethiopian (1.2–0.7 Ga) and Eritrean basements (1.5–1.2 Ga), and youngest for sediments shed from Ethiopian flood basalts (0.3–0.2 Ga).

Integrated geochemical, mineralogical, and settling-equivalence analyses suggest influence on the Nd isotopic signal by volcanic lithic grains and titanite rather than by LREE-rich monazite or allanite. Because contributions by ultradense minerals is subordinate, intrasample variability of Sr and Nd ratios is minor. In Blue Nile, Atbara and main Nile sediments of mixed provenance, however, the Nd ratio tends to be higher and t_{DM} ages lower in largely volcaniclastic mud than in mixed volcaniclastic/metamorphiclastic sand.

The complete geochemical database presented here, coupled with high-resolution bulk-petrography and heavy-mineral data, provides a key to reconstructing erosion patterns and detrital fluxes across the whole Nile basin, and to investigate and understand how sources of sediment have changed in the historical and pre-historical past in relation to shifting climatic zones across arid northern Africa.

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0016-7037/$ - see front matter © 2011 Published by Elsevier Ltd.
doi:10.1016/j.gca.2011.03.042

In these deserts the river was life itself. Had it failed to flow, even for one season, then all Egypt perished. Not to know where the stream came from, not to have any sort of guarantee that it would continue – this was to live in a state of insecurity where only fatalism or superstition could reassure the mind.
The White Nile, Alan Moorehead, Prologue

1. INTRODUCTION

The Nile is the most important river flowing into the Eastern Mediterranean. Its water and sediment fluxes influenced marine circulation throughout the Quaternary, and are widely considered as one of the factors concurring to formation of sapropels (Krom et al., 1999, 2002; Freydier et al., 2001; Weldeab et al., 2002; Scrivner et al., 2004; Tachikawa et al., 2004; Box et al., 2011). In historical times, variations in annual floods and sediment yields of the Nile, controlled by climate change, had major impact on the rise and demise of Egyptian dynasties (Stanley et al., 2003). Reconstructing and discriminating present erosion patterns and detrital fluxes through the Nile drainage basin is a prerequisite to investigate and understand how sources of sediment have changed in the past, as related to shifting of climatic zones across arid northern Africa.

The Nile, carrying little sediment across Egypt since construction of the Aswan High Dam in 1964 (Stanley and Wingerath, 1996; Abdel-Fattah et al., 2004), is still an active sediment conveyor-belt in Ethiopia and Sudan (Billi and El Badri Ali, 2010), where we focused our attention. In order to define sediment sources for the three main branches of the Nile system (White Nile, Blue Nile, Atbara), we analyzed strontium and neodymium isotopes in sediments of their major tributaries. River Nile is well suited to isotopic studies, because its catchment includes crystalline basements of various ages yielding high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ ratios, whereas Ethiopian highlands are capped by Tertiary flood basalts with low $^{87}Sr/^{86}Sr$ and high $^{143}Nd/^{144}Nd$ ratios. By studying the variations in the isotopic makeup of sediments carried by different Nile branches and tributaries, we can discover much about the geological and geochemical features of the whole basin. Isotopic data provide important complementary information to that obtained from mineralogical and petrographic analyses (Shukri, 1950; Garzanti et al., 2006), helping us to constrain the different types and ages of basement sources and to constrain by an independent method sediment budgets calculated for various catchments.

2. THE NILE BASIN

The Nile, flowing northward for ~6700 km from 4°S to 32°N, is the longest river system on Earth. Climatic conditions across this wide latitudinal belt, straddling both the Equator and the Tropic of Cancer, range from warm–humid in the south to hot-hyperarid in the north (Fig. 1; Woodward et al., 2007). Its major tributaries, sourced in areas with markedly different climate and geology, display contrasting hydrological and sedimentological regimes.

The White Nile, sourced from equatorial uplands of Uganda, Rwanda and Burundi, where 1–2 m of annual rainfall is distributed in two rainy seasons in autumn and spring, receives the outflow of Lake Victoria and Lake Albert. Named Victoria Nile and Albert Nile in northern Uganda, and Bahr el Jebel in South Sudan, the river loses half of its waters in the flat treeless swamps of the Sudd, one of the world's largest inland wetlands. Here the river divides into two main branches, the eastern one being named Bahr ez Zeraf. Annual water discharge is restored to $\sim$30 km^3 by River Sobat, and the White Nile eventually flows sluggishly in its low-gradient broad channel towards Khartoum (Williams et al., 2003, 2006).

Rivers Blue Nile and Atbara drain the Ethiopian highlands, where elevations range mainly between 1500 and 3000 m a.s.l., with several peaks above 4000 m. Climate is governed by the seasonal migration of the intertropical convergence zone from south to north and back, so that total precipitation as well as the duration of the summer rain and runoff season progressively decrease northward. Fluvial regimes consequently vary from perennial in the subequatorial south (e.g., River Baro, the main branch of the Sobat), to seasonal for the Blue Nile, to markedly seasonal for the Dinder, Rahad and Tekeze–Atbara, which virtually dry out from December to May (Sutcliffe and Parks, 1999).

The main Nile receives no significant tributary water north of Atbara town, and hardly any rainfall across the Sahara (<50 mm/a). Its regime thus reflects evenly distributed runoff from equatorial Africa, with the superposed pulse of summer monsoonal floods from Ethiopian highlands. About 85% of Blue Nile water flow is concentrated from July to October, whereas high levels in the White Nile persist from late September to January. The latter provides the main Nile with 83% of its low-season water flow, but only 10% of its peak flow (Williams et al., 2000).

2.1. Geological setting

The course of the Nile is directly controlled along its entire length by the East Africa–Red Sea rift system (Fig. 1; Adamson and Williams, 1980). The White Nile largely drains Archean to Paleoproterozoic amphibolite-facies to granulite-facies gneisses of the Congo Craton and Saharan Metacraton (Abdelsalam et al., 2002; Link et al., 2010). The Congo Craton represents the backbone of northern Uganda (Gneissic–Granulitic Complex) and includes gneisses as old as 3.5 Ga, greenstone belts emplaced at 3.2–2.6 Ga, and two main generations of granitoids emplaced at 2.9–2.7 Ga (Schlüter, 1997, 2008). A much younger belt of kyanite schists is traced along the northeastern shores of Lake Albert to Murchison Falls (Van Straaten, 1976; U–Th–total Pb ages on monazite 621 ± 26 and 633 ± 27 Ma: Appel et al., 2005). The Saharan Metacraton to the north, mostly formed between 2.8 and 1.2 Ga but largely overprinted by Neoproterozoic tectonic events, is dominated by medium to high-grade gneisses and migmatites, but also includes low-grade volcano-sedimentary units intruded by granitoids ranging in age between 750 and 550 Ma (Stern et al., 1994, 2006; Abdelsalam and Stern, 1996).