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Sedimentation patterns off the Zambezi River over the last 20,000 years

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ABSTRACT

Marine sediments from continental margins provide high-resolution archives of marine and continental climate, in particular near large river mouths. The Zambezi is one of the largest rivers in East Africa, discharging large amounts of fine-grained sediments onto the western margin of the Mozambique Channel. Accurate reconstructions of past variations in river discharge can be retrieved from the depositional history of riverine sediments. In this study, sedimentation patterns along the Mozambique Margin are inferred from a series of sediment cores spanning the last 20 kyr. These cores were retrieved off the Zambezi Mouth from the shelf and from various depths at the continental slope to provide detailed information on the depositional history of this region. High-resolution X-ray fluorescence and magnetic susceptibility core scanning measurements as well as grain-size distributions of the lithogenic sediment fraction, and organic matter and carbonate content analyses resolve centennial–millennial timescale variations in sediment transport and deposition along the Mozambique Margin. Largest changes in lithogenic sediment deposition coincide with the flooding of the Mozambique Shelf. Due to deglacial sea-level rise and changes in oceanic currents, fine-grained, mainly Zambezi sediments were no longer primarily deposited south of the Zambezi Mouth, but increasingly deposited onto the Mozambique Shelf, and transported northwards over the shelf before spilling over to the slope. In addition, flooding of the shelf initiated remobilization and down-slope transport of coarse-grained, winnowed sediments. The Heinrich Event 1 and Younger Dryas are clearly indicated as events of increased fine-grained sediment deposition along the Mozambique Margin, possibly linked to increased riverine runoff from the Zambezi Catchment, which is in harmony with a southward shift of the Intertropical Convergence Zone (ITCZ) and associated African rainfall belts, causing wetter conditions. This study illustrates that interpreting marine and continental climate proxy records in the vicinity of river deltas in terms of climate change requires proper consideration of sea-level and oceanic circulation induced effects on the transport and deposition patterns of fine-grained sediments at continental slopes.

1. Introduction

Sediment archives close to large river delta systems along continental margins are of particular interest for high-resolution reconstructions of changes in climate and oceanography, as they can capture changes both from the river catchment area and in the adjacent ocean. In contrast, paleo-records from locations proximal to continental shelves are susceptible to changes in local sediment transport patterns and may therefore not exclusively record changes in climate. The understanding of spatiotemporal sediment distribution and deposition patterns is therefore a prerequisite for the interpretation of such paleo-records.

Over the last years, sedimentary records from the Mozambique Margin have become increasingly important for high-resolution reconstructions of past sea surface temperatures and continental rainfall (Schefuss et al., 2011; Wang et al., 2013a,b). The oceanic circulation in the Mozambique Channel is dominated by large and deep reaching eddies that generate a strong, net southward current along the Mozambique Margin. This southward flow forms an important link in the global oceanic circulation, carrying warm and saline Indian Ocean water into the Agulhas Current and triggering the Agulhas Leakage at the southern tip of Africa (Harlander et al., 2009) (Fig. 1). The Mozambique Margin receives large amounts of sediments from the Zambezi Catchment (ZC), which is the fourth largest river catchment in Africa (Walford et al., 2005). Maximum rainfall and Zambezi riverine runoff occur during austral summer (December–February) when the Intertropical Convergence Zone (ITCZ) and associated rainfall belts reach their southernmost position (Moore et al., 2008). Today, Zambezi sediments are distributed across the wide, shallow Mozambique Shelf before deposition at the continental slope. During the last (de)glacial sea-level low-stand and early rise, the Mozambique Shelf was sub-aerially exposed and the Zambezi ran through an incised paleo-valley discharging its sediments directly to the upper-slope (Beiersdorf et al., 1980).

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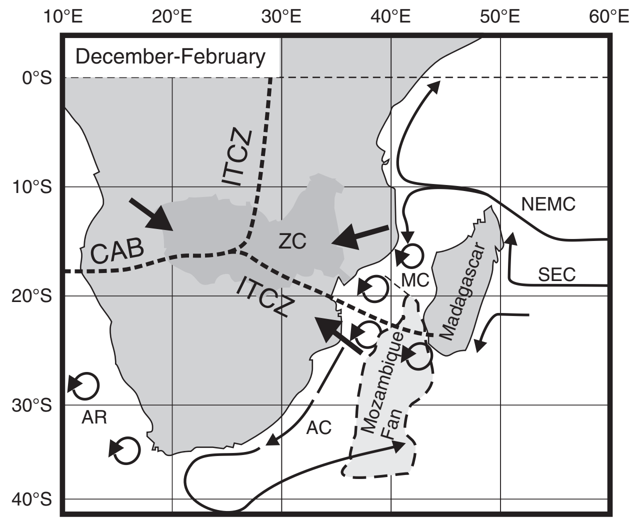

Fig. 1. Map of southern Africa indicating atmospheric boundaries over the continent and oceanic surface circulation. The Intertropical Convergence Zone (ITCZ) and Congo Air Boundary (CAB) receiving moisture from the Atlantic and Indian Ocean (thick arrows) are drawn at their southern position during austral summer (December–February). The main oceanic circulation features along southeastern Africa are indicated by thin arrows. The Northeast Madagascar Current (NEMC) partly continues as large anti-cyclonic eddies along the southeastern African Coast through the Mozambique Channel (MC). The large Zambezi Catchment (ZC) and Mozambique Deep-Sea Fan are highlighted in grey shading.

Climate proxy records from sediment cores obtained from the Mozambique Margin are therefore susceptible to past changes in sediment distribution and deposition by oceanic currents and flooding of the shelf. So far, the history of the sediment supply by the Zambezi and subsequent dispersal and deposition along the Mozambique Margin, as well as its relation to sea-level rise oceanographic and climatic changes are not well explored.

Therefore, to infer changes in sedimentation patterns over the last 20 kyr, a series of sediment cores collected from the Mozambique Margin was analysed for X-ray fluorescence (XRF), magnetic susceptibility (MS), and lithogenic grain-size distribution data in combination with measurements of calcium carbonate ($CaCO_3$) and organic matter contents. These records reveal spatiotemporal variations in deposition along the Mozambique Margin that were not solely affected by changes in runoff and sediment supply of the Zambezi, but also by variations in sediment dispersal by ocean currents, winnowing by bottom currents, and sea-level rise. The observed changes in sedimentation patterns along the Mozambique Margin are likely to be a widespread phenomenon along continental margins, potentially affecting climate and continental proxy records.

2. Background

2.1. Modern oceanic circulation along the Mozambique Margin

The strong, net southward flow along the Mozambique Margin is fed by the Northeast Madagascar Current (NEMC), which is the northern branch of the South Equatorial Current (SEC). The current flow along the Mozambique Margin is mainly due to the southward passage of large, anti-cyclonic eddies (Ridderinkhof et al., 2010). Annual mean velocities of the southward flow decrease progressively in the upper 1500 m of the water column along the Mozambique Margin from velocities exceeding 40 cm/s in the surface waters (Ullgren et al., 2012). Below 1500 m water depth, there is a weak northward undercurrent carrying Antarctic Intermediate Water (AAIW) and North Atlantic Deep Water (NADW) along the Mozambique Margin (de Ruijter et al., 2002). The propagating eddies through the Mozambique Channel transport salt and heat to the Agulhas Current (AC) and also trigger Agulhas Ring (AR) shedding, therefore the Mozambique Channel throughflow plays an important role in the Agulhas Leakage, which is in turn crucial for global thermohaline oceanic circulation (Swart et al., 2010).

2.2. Modern continental rainfall and Zambezi runoff

The Zambezi drains the fourth largest catchment in Africa and discharges sediments and freshwater to the Mozambique Shelf at ~18°S (Fig. 1). Rainfall in the western half of the ZC that extends far into the African Continent is under the control of the Congo Air Boundary (CAB), which moves in concert with the ITCZ. As a result, mean annual rainfall decreases from north (1200 mm) to south (600 mm) across the ZC. Austral summer rainfall in the ZC results in a large plume of freshwater and suspended sediment from the Zambezi Mouth. The Zambezi plume drifts mainly northwards along the Mozambique Coast due to the Coriolis Force and wind-induced northeastern current over the shelf (Siddorn et al., 2001; Nehama, 2008) (Fig. 1). Paleorainfall records obtained from the Mozambique Margin are therefore important in studying past changes in southern extension of the ITCZ and associated rainfall belts.

2.3. Modern sediment transport and deposition along the Mozambique Margin

With an estimated annual total sediment load of ~65 million tons, of which 10% is transported as bed-load (ESIA, 2011), the Zambezi is the dominant source of sediments to the Mozambique Shelf. The modern sediment load is reduced by extensive damming in the ZC. Fine-grained Zambezi sediments accumulate in a mud-belt parallel to the Mozambique Coast, extending from the Zambezi Mouth up to ~17.5°S (Fig. 2). The Mozambique Shelf is ~20 km wide at 17°S and broadens to ~80 km at 19°S, whereas the shelf-break ascends from ~90 m in the north to ~50 m water depth in front of the Zambezi Mouth (Beiersdorf et al., 1980) (Fig. 2). Beyond the mud-belt, the shelf is covered by dominantly fine sands that are distributed by tidal- and wave-induced currents (Beiersdorf et al., 1980). These sands extend further down-slope, to ~500 m water depth in front of the Zambezi Mouth and to ~200 m water depth north of 18°S (Fig. 2). Under the influence of the strong southward flow along the Mozambique Margin, large submarine dunes have been formed at the wider parts of the shelf zone where the shelf-break is relatively shallow. (Beiersdorf et al., 1980). Due to intense sediment winnowing near the shelf-break, foraminifera-rich sands have been accumulated between 50 m and 250 m water depth with $CaCO_3$ contents up to 30%, whereas the $CaCO_3$ content is generally low (<10%) in the inshore shelf sediments due to relatively high lithogenic input and low marine $CaCO_3$ production (Beiersdorf et al., 1980).

About 200 km north of the Zambezi Mouth, the mud-belt is situated relatively close to the shelf-break (Fig. 2). Here, fine-grained sediments spill over from the shelf to the adjacent continental slope by coastal lee-eddies that occur as semi-permanent features (Lutjeharms, 2010), and/or are pulled into the Mozambique Channel by large, southward propagating eddies (Tew-Kai and Marsac, 2009). Due to the net southward flow, sediment transport along the upper-slope is dominantly in a southern direction.

2.4. Last glacial–interglacial sediment transport and deposition along the Mozambique Margin

The Mozambique Shelf was sub-aerially exposed due to sea-level low-stand during the last glacial and most of the deglacial period. The Zambezi ran through a paleo-valley incised into the shelf, whereas the smaller rivers traversed over the shelf area (Beiersdorf et al., 1980). Most of the sands of the expanded shelf zone were probably deposited as proluvial cover sands during sea-level low-stands (Jaritz et al., 1977) when, the hinterland experienced intense droughts, as is documented in sediment cores from Lake Malawi during MIS 4 (Scholz